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TOYOTA

Optimum Human Machine Interface for the IT Generation

YTPD Garage

all great design firms started in someone's garage

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1 Front Matter

1.1 Executive Summary

Driving the vehicle has been the primary task of the driver since the automobile was invented over 100 years ago. Yet as technology increasingly invades the car, the driver is required to divert attention to managing secondary (non-driving) tasks created by these technologies. The goal of the Toyota project is to investigate the types of secondary tasks that might be available to the IT Generation in future vehicles, and to design an interface that will allow the driver to accomplish these secondary tasks safely.

The design team, a collaboration between Stanford University and the Tokyo Metropolitan Institute of Technology (TMIT), has explored many ideas for future vehicle functions and determined that most involve the idea of "connectedness." The teams are focusing on improving this in-car "connectedness" by designing an interface system that allows drivers to create text while driving safely.

Fig. 1: The Optimum Human Machine Interface for text entry while driving.

The system consists of four components: a text input device, a logic core (software), an output device, and a test vehicle for collecting user data. The input system that has been designed and tested is illustrated in Fig. 1 above.

Even though voice recognition is one obvious design approach for an input system, Toyota has specifically requested the design team to explore alternate approaches.

The design requirements are listed in detail in section 3. Most importantly, the ergonomic interface must enable the driver to steer safely while entering data. A design featuring a single thumb keypad has been developed and integrated into a test vehicle as described in section 4. The keypad is asymmetrically mounted in the hub of the steering wheel. The keypad consists of 12 multi-directional switches, and follows the conventional alphanumeric layout of a cellular phone. The keys are arranged along an arc, following the natural sweeping motion of the thumb. The spacing and location of the keypad accommodates users with a wide range of hand sizes.

The keypad operates in two text entry modes: beginner and advanced. The beginner mode emulates the multi-tap method of text entry where the user cycles through 3-5 characters per numeric key. Multi-tap is the standard entry protocol for cellular phones and heavily depends on visual feedback from the display. Users typically have to glance at the display with each attempt to enter a character to confirm they stopped at the correct position in the cycle.

The advanced mode, multi-direction, enables single keystroke per character entry, where the compass points (left/right/up/down) of each switch correspond to a single letter, and select (in) corresponds to a number or function. Multi-direction enables drivers to touch type without the need for continuous visual confirmation, diverting less attention from the main task of driving.

The wheel spoke is designed to align the operator's hand to the input device, decreasing the effort needed to acquire and reacquire the keys. The keypad's position in the hub of the wheel functions as a built-in safety mechanism. During active steering situations, the rapid wheel movements make it impossible to track the keys to enter error free text, naturally limiting text entry, and thus driver distraction during intense driving situations.

A major goal of the project was to test the system with a wide range of users to establish the operation safety boundaries of the system; the conditions where it might be safe as well as unsafe to enter text. Liability questions prevented extensive road testing, however, a small set of data was collected from the designers and additional users in a static vehicle test system. The change in response time measured with LED clusters mounted throughout the car provided a basis for the impact of the text input device on potential driving performance.

The text input system allows for text input speeds of 5 words per minute (WPM) without training, increasing to 10 WPM after 3 hours of training. Operating the text input device increases the response time of the driver as compared to driving without texting. The overall increase in total response time was 0.6 to 3.1 seconds for beginner and advanced mode, respectively. Testing has shown that the multi-direction method results in a larger increase in response time, mostly due to the uniqueness of the interface. These response times can be compared to an increase of 0.6 seconds when the driver changes radio stations while driving.

All interactions are distractions in the car environment; the text entry interface does not change that axiom. However, the testing completed to date, although limited, has shown that the text entry device is comparable to existing in-vehicle interfaces such as the radio, using increase in response time as the metric for safety.

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1.5 Glossary

Adaptive –Taking available information into account.

Attention –The process of selecting things to concentrate on, at one point in time, from the range of possibilities available.

Basic Stamp - an easy-to-use microcontroller made by Parallax <http://www.parallaxinc.com>. The Stamp contains a microcontroller, memory, a clock, and a voltage regulator in a package that resembles an integrated circuit. All you need is a PC to program it and a 9V battery or other power supply. The only external circuitry you need is whatever you want the Stamp to do (LEDs, buzzers, relays, motors, etc.).[1]

Black Box – a device or system in which only its externally visible behavior is considered and not its implementation or "inner workings".[2]

Carpal Tunnel Syndrome – A repetitive stress injury linked to extensive keyboard use. In this context, physical pain or fatigue caused by typing while driving.

CFP – Critical Function Prototype. An early prototype that demonstrates the key functionality of a given design. Can be crudely constructed, but must not be a mockup.

Chorded Keyboard – text input device that uses simultaneous keystrokes from multiple buttons to generate a character.

Cognitive Budget –The concept that people have a finite resource for cognitive ability.

CyKey – chorded keyboard marketed for PDA and mobile computing use. http://www.megasharp.com/pda/

Distraction –[n] an obstacle to attention.[3]

FFP – First Functional Prototype. A second-generation prototype that focuses on a system implementation. Typically constructed of duct tape and bailing wire, it builds upon the CFP demonstrating the functionality of the system rather than just the critical features.

FP – Final Prototype. The last of a series of prototype design iterations, this edition is the deliverable product to the sponsor. Fully constructed of engineering materials, there is not even a trace of duct tape to be found in the design. Optimally, this design meets or exceeds all of the design requirements. Hopefully it looks nice, too.

FrogPad – mobile, chorded keypad. Contains 20 full-size keys with the layout optimized around the most frequently used characters. Patented keystroke algorithms enable it to be used in either a right or left-handed mode and with any international language set. http://www.frogpad.com/

GPS – Global Positioning System. A system for determining postion on the Earth's surface by comparing radio signals from several satellites. Depending on one's geographic location, the GPS receiver samples data from up to six satellites, it then calculates the time taken for each satellite signal to reach the GPS receiver, and from the difference in time of reception, determines the location.[4]

HUD – Head Up Display. An optical system that superimposes a synthetic display providing navigational or weapon-aiming information on a pilot's or driver's field of view. The system includes a cathode-ray tube, collimating optics and a combiner that projects the image in front of the window.[5]

Human Machine Interface (HMI) – where people and technology meet. This people-technology intercept can be as simple as the grip on a hand tool or as complex as the flight deck of a jumbo jet.[6]

Interaction – Mutual or reciprocal action or influence.[7]

IT Generation - also know as: Net Generation, Net-geners, Thumb Generation, Thumb Tribe. Person's born after the personal computer was introduced in 1985.

Keiboard – alternative text input device that mimics the keypad of a cell phone. Primarily available in Japan and Asia. USB keyboard manufactured by mevael that enables typing as if you use "keitai", which mean handy phones in Japanese.[8] http://www.mevael.co.jp/item.html

KeyWiz – a hardware PS/2 keyboard emulation device. Allows standard single pole switches to be used for character input to the computer through the standard PS/2 port. Directly accessible inputs (interrupt driven) eliminate the need for the keypad matrix found in typical QWERTY keyboards. Developed by IDVT, Inc. www.groovygamegear.com

LED – Light Emitting Diode. Diode such that light emitted at a p-n junction is proportional to the bias current; color depends on the material used.

Look Away Time – Duration of time the driver's eyes are not focused on the road while performing a task or action.

Microwriting - the leading system of chord keying and is based on a set of mnemonics. It was developed by Cy Endfield and Chris Rainey in the 1970s. The system was originally used in the Microwriter and the Microwriter Agenda personal organizer, and has been adapted for use with the CyKey one-handed chorded keyboard.[9]

Multi-direction Input Typing– proprietary input method designed by YTPD Garage as part of the design of the input device. Each switch contains 5 unique positions (North, South, East, West, Select), with each position corresponding to a unique character. Allows direct character input with the standard 12 key cell phone layout.

Multi-switch Input Typing– see Multi-direction Input Typing.

Multi-tap Input Typing – The most common, and generally least efficient system of text input. Commonly referred to as "multitap". Using multitap, a key is pressed multiple times to access the list of letters on that key. For instance, pressing the "2" key once gives "a", twice gives "b", thrice gives "c". To enter two successive letters that are on the same key, the user must either pause or hit a "next" button. Since the letters are ordered alphabetically, rather than with any consideration of letter frequency, the efficiency of a multitap system is very low. [10]

Net Generation - see Internet Generation

Net-geners - see Internet Generation

PDA – Personal Data Assistant. A small hand-held computer typically providing calendar, contacts, and note-taking applications but may include other applications, for example a web browser and media player. Small keyboards and pen-based input systems are most commonly used for user input. A common example is the PalmPilot.[11]

Seamless Integration – Seamless is somewhat similar to the term transparent. Both mean that the user of something is unburdened by having to see what went into making it. Integration is the process of putting two or more things together. Seamless integration is putting two or more pieces together without the user being able to see where one piece ends, and the next begins.

Segmentation - a difficulty with multi-tap in entering consecutive letters that appear on the same key.

SFP – Second Functional Prototype. Also referred to as "2FP." A third-generation prototype following the CFP and FFP. It includes all of the major components of the system either in working form, or nearly working form. It may contain trace amounts of duct tape, but the majority of the components are attached using engineering grade Velcro.

T9 – predictive text input system for mobile phones. Primarily used with numbered keypads for text entry. Allows users to enter one number per character instead of multi-tap to cycle through letters. Predicts letter combinations from database of word frequency. T9 is a registered trademark of Tegic Communications.

Texting – [v] The act of entering text while driving using a steering wheel mounted keypad.

Thumb Generation - also referred to as Thumb Tribe. Members of the Internet Generation with grossly muscled and dexterous opposing thumbs as a result of hours of cell phone text messaging and video game playing.

Tokyo Metropolitan Institute of Technology (TMIT) – a young institution founded in 1986, whose mission is to take leadership in science and technology, both in education and research. The home of one of the global learning partners with ME310.

Ubiquitous Computing – Computers everywhere. Making many computers available throughout the physical environment, while making them effectively invisible to the user. Ubiquitous computing is held by some to be the Third Wave of computing. The First Wave was many people per computer, the Second Wave was one person per computer. The Third Wave will be many computers per person. Three key technical issues are: power consumption, user interface, and wireless connectivity. The idea of ubiquitous computing as invisible computation was first articulated by Mark Weiser in 1988 at the Computer Science Lab at Xerox PARC.[12]

U.S. National Highway Traffic Safety Administration (NHTSA) – United States government agency responsible for reducing deaths, injuries and economic losses resulting from motor vehicle crashes.

Velcro – Magic Tape. Hook and loop fastening system typically found in CFP, FFP, and SFP prototypes. Velcro is a trademarked name of Velcro Industries B.V.

WPM – words per minute. Metric of text input speed. In this context, one word is defined as 6 characters (5 letters and 1 space).

2 Context

2.1 Need Statement

Driving the vehicle has been the primary task of the driver since the automobile was invented over 100 years ago. Yet as technology increasingly invades the car interior, the driver is required to divert attention to managing the secondary (non-driving) tasks created by these technologies. In addition to driving, a few of the technologies already existing in today's vehicle cockpit include GPS navigation systems, passenger specific environmental controls, blue-tooth and voice activated phone calls.

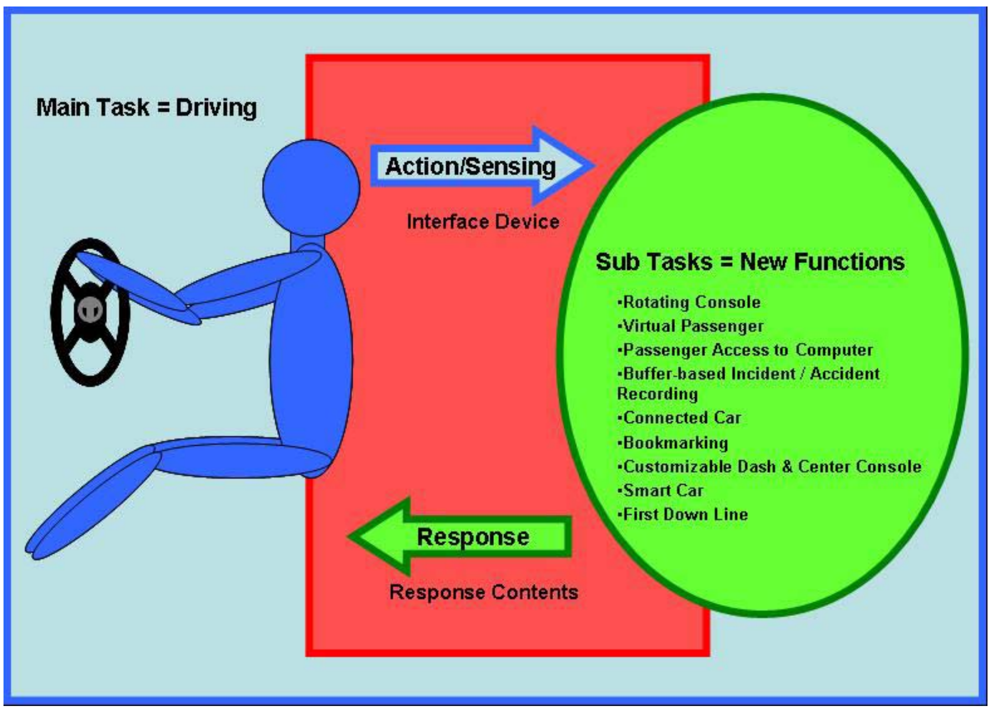

Fig. 2: Diagram illustrating the interface and interaction between the main task of driving an automobile and the sphere of possible sub tasks the driver can perform.

The U.S. National Highway Traffic Safety Administration (NHTSA) has conducted several inquiries into the nature of driver distraction. The NHTSA has defined four dimensions of distraction based on the nature of the interference experienced by an individual: cognitive, visual, auditory, and biomechanical. However, there is no common basis for determining when an activity represents a distraction. Driver distraction is a factor in 20% - 50% of collisions. The perception of driver distraction, however, is also important. While drivers often engage in potentially distracting behaviors, these behaviors are perceived as more dangerous when other drivers are engaged in the activity.[13], [14] The rise of distracting technologies in the vehicle cockpit has somewhat been balanced by the increase in pre-emptive safety technology measures in the vehicle. In recent years, adaptive cruise control, dynamic vehicle control, adaptive head restraints, and electronic braking and parking assistants systems have been integrated into most luxury and a few standard car lines to increase the safety of the driving experience. In the next 10 years, most of these technologies will become standards in all car models. A large proportion of these vehicles will be driven by a new generation of car owners, the Internet Generation.

The Internet Generation is one of the many monikers given to the over eighty-eight million young people born after 1985, in the midst of the digital age. The Internet has grown up immersed in digital technologies and media, from personal computers to the Internet, to mobile telephones and DVDs. In his book Growing Up Digital, researcher Dan Tapscott documented several traits that make the Internet Generation unique from their parents, the Baby Boomer Generation[15]. A sense of strong independence and autonomy, a need for innovation, immediate interaction responses, free expression, as well as loathing to what they deem as "corporate agendas" are just a few examples of qualities that typify the Internet Generation. After interviewing hundreds of Net-geners, Tapscott found that this generation "loves their music, movies, magazines, some TV shows, video games, computers, software, and the Net," and also wants to be "connected with their family, close friends, in school, in neighborhoods, interest groups, and online virtual communities." This desire to remain "connected" has given rise an explosion in the use of digital communication media such as email and text messaging. Text messaging has almost become a standard mode of communication in Europe and Asia, and it has recently erupted in the United States. In December 2003, an estimated 2.1 billion cellular text messages were sent in the United States. According to a survey by Forrester Research Inc., 26% of the respondents under age 35 reported that they send text messages[16]. An estimated 30 million Americans 12 or older are text messaging with cell phones.

The upsurge in the use of cell phones has produced another nametag for the Internet Generation, the "Thumb Generation" or "Thumb Tribe." Dr. Sadie Plant, a member of the Warwick University Cybernetic Culture Research Unit researched cell phone users in some of the world's largest cities for six years[17]. Dr. Plant observed a pattern of activity among young adults and children. While their older counterparts hunt and pecked on cell phone keypads with several fingers, teenagers and children "ambidextrously" used their thumbs to quickly navigate around the minute cell phone key pads. The Thumb Tribe has extended the use of their thumbs from their cell phones to other activities commonly reserved for their other fingers, such as ringing the doorbell.

2.2 Problem Statement

Toyota Motor Corporation is investigating car driver interfaces to be implemented five to ten years from now. The goal of the Toyota project is to investigate the types of secondary tasks that might be available to the IT Generation in future vehicles, and then design an interface that will allow the driver to accomplish one of these secondary tasks safely. In specifically addressing the needs and wants of the IT generation, Toyota is interested in developing new driver functions and potential human machine interfaces to them. A common interface between the car and home environment allows users to focus on using the interface, rather than users focusing on understanding how to use an interface they are completely unfamiliar with.

The optimum design will integrate all of the current and future functions into one seamless interface. Many functions such as navigation, entertainment, and communication are already available in current production cars. Preeminent interface designs can still distract the driver. This is a large design space and team YTPD Garage has decided to focus on issues concerning safe and effective means of communication between the driver and the world outside of the vehicle. As communication mediums have become more ubiquitous in our daily lives, especially as the IT Generation ages and become automobile consumers, there will be demand to eliminate the "information blackout" that occurs when stepping into the current car.

YTPD Garage focused on improving the driver's in-car "connectedness" by designing a text input system that allow drivers to safely input text for short emails or text messages while driving. The primary design focus is on the text input device; however additional elements of the system are required in order to realistically test the concept under normal driving conditions. These elements include an output device for feedback to the user, a system to process the input, and a test system to quantify the magnitude of distraction created by texting. The team decided to focus on handed text entry devices rather than other modes such as voice recognition, as Toyota has already developed and implemented voice recognition systems in several of its product lines. There is also extensive industry-wide voice recognition development still in progress, while the exploration area of handed input in-vehicle systems has been fairly limited to graphically based input systems controlled by touch screens, touch pads, and jog wheels (AUDI MMI type devices). In light of these facts, Toyota has specifically requested the design team to explore alternate approaches to voice recognition and graphically based input systems.

2.3 Design Team

The international design team consisted of a Stanford team from ME310 and a team of graduate students from the Tokyo Metropolitan Institute of Technology (TMIT). The student design team was supported the teaching staffs and coaches from Stanford and TMIT, as well as corporate liaisons from Toyota Motor Corporation, Japan and the Toyota InfoTechnology Center, U.S.A.

2.3.1 Student Design Team Members

The communication among the student design teams consisted of email contacts and weekly videoconferences. The teams exchanged project ideas and collaborated on research and early prototyping activities. The Stanford students took the lead on developing an input device and test system; while the TMIT students lead the development of the output device and software design.

Team Toyota Student Design Team members from bottom row, left to right : *Kazumasa Hayashi (TMIT), Tori Bailey (Stanford), Kohei Hiwaki (TMIT);* top row, left to right: Dave Fries (Stanford) and *Philipp Skogstad (Stanford)*

Team Toyota Design Team members from left to right: *Shigeo Onogi (Toyota Liaison), Terry Ito (Coach), Dave Cannon (Coach), Dave Fries (YTPD Garage), Tori Bailey (YTPD Garage), Philipp Skogstad (YTPD Garage), and Kentaro Oguchi (Toyota Liaison)*

Stanford University • Team YTPD Garage

Tori is a first year PhD student in the Design Division. She's resurfaced in the PhD program after finishing her Master's here a few years back as a 218er. Tori is famous for masterminding the 2.5 minute packing job in order to catch the Shinkansen, and not mastering the intricacies of setting an alarm clock to actually 'alarm.' Tori's favorite saying is "What time is it again?" Interested in Tori's alarm clock, check out it's spec sheet:

Tori Bailey
tlbailey@stanford.edu
650.218.4882

Design Requirements	Product Specifications
A working alarm function	Works 2/5 days (4/5 days when set)
Annoying alarm sound	So annoying, you'll sleep right through it
Displays correct time	Set 15 minutes ahead
Easy to use	As long as you plug it in

Dave is in his third quarter of the Honors Co-op Program and works for Endwave Corporation. He hails from the great state of Maryland and is a Fighting Terrapin all the way, but has a called California his home for the past few years. Dave's favorite saying is "It tastes just like chicken…I promise." He's still looking for that 3 child-seat convertible, with the addition of Lillian Catherine Fries on April 26, 2004. Here is her spec sheet:

Dave Fries
dave.fries@endwave.com
408.522.3153

Design Requirements	Product Specifications
A healthy baby	7 lbs & 20 inches long (3.175 kg & 51 cm)
A happy baby	She sleeps…sometimes
On-time completion	Born 1 ½ weeks early
Low pain delivery	Mom is o.k. (Dad is too)

Philipp has journeyed from both the Midwest and across the Atlantic Ocean to a first year Master's student in the Design Division. He was born and raised in Germany and did his undergraduate work at Parks College of St. Louis University. Philipp is famous for masterminding the prototype of the steering method that shall not be named. Philipp's favorite saying is "….you know what I mean?" If you are in need of a station wagon, check out these specs, and give him a call:

Philipp Skogstad
skogstad@stanford.edu
650.926.9960

Design Requirements	Product Specifications
No engine problems	V6 Engine
Clean interior	Cleaned at least 16,598 times since 1999.
Low Speeding Violations	Red car = no speed limit.

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Kohei made his first and hopefully not his last journey across the Pacific to visit his teammates at Stanford this past January, and then played host when Dave, Tori, and Philipp visited Japan in the Spring. He is famous for teaching inquisitive youngsters the ins-and-outs of ubiquitous computing in fast food restaurants, as well as directing lost teammates through the subways and rail systems of Japan using maps downloaded to his cell phone.

Kazumasa “Kaz” Hayashi
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Kaz also made his first and hopefully not his last journey across the Pacific to visit Stanford this past January, and also played host when Dave, Tori and Philipp visited Japan in the Spring. He is famous for being the only team member to master the Need for Speed PC game racing series, for finishing an entire Armadillo Willy’s rib and chicken platter in one sitting, and for coding faster than a speeding bullet (or the Shinkansen).

2.3.2 Coaches

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2.4 Team Circumstances

YTPD Garage was originally formed by the ME310 teaching team during the Paper Bike design project at the beginning of the Autumn quarter. The team was not formed based on personality preferences, as the team did not complete any personality evaluations until the end of the paper bike project. A group comprised of members with complementary personality preferences is a vital step in creating a successful design team. After the conclusion of the paper bike project, the team successfully lobbied to remain a together for the corporate projects. The team lost one of its original members, Yoko Kobayashi, after the Autumn quarter to the ME 317: Design for Manufacturability sequence and the dreaded 10 unit course limit. Yoko stayed on as an English-Japanese translation consultant for the Winter quarter.

3 Design Requirements

3.1 Introduction

The Toyota Optimum Human Machine Interface development project is one small component of Toyota Motor Corporation's (TMC) larger, global vision for adaptable vehicles. Until now, all car companies have provided a limited selection of car options, requiring drivers to adapt to the car. TMC is reversing that design process by focusing, at all levels of the company, on creating new designs that will allow the car to adapt to the driver.

The text input system of the Optimum Human Machine Interface will allow the car to adapt the needs of future drivers, such as the IT Generation. The concept of ubiquitous connectivity, along with the tremendous usage of SMS, instant messaging, and email by the IT Generation will fuel the demand for providing these features in future vehicles. The goal is to specifically address the needs and expectations of the IT generation.

One key component of the connected lifestyle is the ability to input text and discrete characters. While there are many different types of input devices, along with mobile cell phone technology, little effort has been spent on creating a system that allows drivers to enter text while safely driving. This text entry interface is the focus of the design effort of YTPD Garage. The design requirements for this text entry interface are provided below.

The requirements are divided into functional and physical requirements. Functional requirements identify actions the product should do. Physical requirements identify what the product should be. Each of these two sections is further broken down to include constraints and opportunities. Constraints identify boundaries placed on the design. The origins of these boundaries are also discussed. Opportunities identify areas where the design can extend the intended problem statement.

3.2 Functional Requirements

The overall functional requirement is to develop an interface that allows the driver to enter text while driving safely. The functional requirements are divided into categories to specifically address Toyota's design priorities for the text input interface. The top three priorities are:

1. Safety
2. Accuracy
3. Speed of Text Input

Functional Requirements		
Objective	**Requirement #**	**Requirement**
Safety	3.2.1	The Interface must be safe to use in a car.
	3.2.1.1	The Interface must minimize "look away time".
	3.2.1.1.1	Average glance duration should be less than 1.2 seconds.
	3.2.1.1.2	No glances should be longer than two seconds.
	3.2.1.1.3	Total task time should be less than fifteen seconds.
	3.2.1.1.4	The display should be mounted near the driver's line of sight to minimize look away time
	3.2.1.2	The Interface must not significantly affect lateral and longitudinal control of the vehicle, driver workload, and situation awareness.
	3.2.1.2.1	Must not interfere with standard driving functions.
	3.2.1.2.2	Must not block driver's vision.
	3.2.1.2.3	Must not preclude motion required during emergency event.
	3.2.1.3	The Interface must be ergonomically appropriate.
	3.2.1.3.1	Must be comfortably positioned.
	3.2.2	The Interface must cause minimal distraction.
	3.2.2.1	The Interface must follow aviation concept of "dark and silent cockpit."
	3.2.2.1.1	Must provide the minimum amount of information.
	3.2.2.1.2	Must adjust the magnitude of the information to be proportional to criticality of response.
	3.2.2.1.3	Displays should only attract drivers' attention when necessary.
	3.2.2.1.4	Movement and/or flashing of graphical elements should be avoided unless these are absolutely necessary.
	3.2.2.2	The Interface must manage the information load by monitoring the driver and driving situation.
	3.2.2.2.1	Must restrict information when necessary.
	3.2.2.2.2	New features only available when driver has cognitive resources available.
	3.2.2.2.3	Information must be prioritized.
	3.2.2.3	Visual clutter should be minimized, maximum contrast should be used between display elements, colors should be used sparingly and consideration for color blindness should be given.
	3.2.2.4	Keep backgrounds simple and muted.
Accuracy	3.2.3	The Interface must be easy to use.
	3.2.3.1	Must not require memorizing complicated key sequences.
	3.2.3.2	Must be customizable to suit different preferences, abilities, and
	3.2.3.3	Group information logically. Consider the frequency and sequence
	3.2.3.4	Must satisfy the users behavior and needs.
	3.2.3.5	Must let the user set the pace and initiate interaction.
	3.2.3.6	Must accommodate for users with varying degrees of experience.
	3.2.3.7	Must be able to be learned in <5 hours.
	3.2.3.8	The user should not be required to remember anything to use the system.
	3.2.4	The Interface must be accurate to use.
	3.2.4.1	Data entry accuracies of 90% should be achieved after training.
	3.2.4.2	Data entry speed should exceed 5 corrected WPM.
Speed	3.2.5	The Interface should not require significant movement to operate.
	3.2.5.1	All controls should be within the reach of one hand.
	3.2.6	The Interface should communicate with other systems.
	3.2.6.1	Must connect to other car systems to reduce driver input.
	3.2.6.2	Must connect to external electronic devices such as PDA's, cell phones, etc to have access to their data.

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Table 1. Functional requirements categorized according to Toyota's design priorities.

3.2.1 Functional Requirement Verification Methodology

Many of the functional requirements identified in Section 3.2 cannot be verified by direct measurement or analysis. They must be inferred from observations of the driver, or user feedback from interacting with the system. A major component of the project will be the development of a test methodology to verify the design achieves the required performance. The verification method for each high-level requirement is identified in Table 2 below.

Functional Requirement Verification			
Objective	**Requirement #**	**Requirement**	**Verification Method**
Safety	3.2.1	The Interface must be safe to use in a car.	User testing in vehicle
	3.2.1.1	The Interface must minimize "look away time".	Lane departures
	3.2.1.2	The Interface must not significantly affect lateral and longitudinal control of the vehicle, driver workload, and situation awareness.	Lane departures Speed variations
	3.2.1.3	The Interface must be ergonomically appropriate.	User feedback
	3.2.2	The Interface must cause minimal distraction.	Reaction/awareness time
Accuracy	3.2.3	The Interface must be easy to use.	Training time
	3.2.4	The Interface must be accurate to use.	Word accuracy
Speed	3.2.5	The Interface should not require significant movement to operate.	User feedback
	3.2.6	The Interface should communicate with other systems.	Design

Table 2. Functional requirements verification methodology.

Each test method is summarized in Table 3 below. Additional details regarding the test setup and equipment are described in section 4.5

Verification Method	Test Description
User testing in vehicle	Users will test the interface in a real car under driving conditions.
Lane departures	Cameras will be used to identify if the vehicle touches the lane markers on either side of the vehicle.
Speed variations	A GPS unit will be used to generate near-instantaneous speed measurements. The speed will be analyzed to look for changes in operator performance.
User feedback	A survey will be used to capture user feedback on specific questions related to using the interface.
Reaction/awareness time	A timer, switch, and LED cluster will be used to measure the drivers reaction time. A distributed set of LEDs will be used to confirm whether the driver is aware of his surroundings.
Training time	The total training time for a given interface will be established.
Word accuracy	The input to a device will be captured to analyze word accuraccy (spell check).
Design	Requirement can be verified by inspection of the design.

Table 3. Verification method test description.

3.2.2 Constraints

The design must assume driving is the primary function of the driver. Autopilot or self-driven cars are outside the scope of the current project. Toyota's current belief[19] is that even if automatic driving technology is perfected within the next 15 years, the cost to implement a full system in each car would be prohibitively expensive. This cost would require at least some portion of the system to be external to the car. These external systems would be built into the transportation infrastructure system, such as roads, bridges, lane markers, etc.. The enormous cost of implementing these infrastructure improvements will prevent automatic driving systems from being fully operational in the time frame of interest.

Voice recognition is not an option from the client's perspective since Toyota has already implemented this technology and would like this interface to explore and build on new ideas.

3.2.3 Opportunities

Driver interfaces that are simple and easy to use can be extendable to the passengers in the car. Additionally, passenger interfaces can reduce driver distractions by allowing the passenger to assume tasks that the driver would otherwise be responsible for.

Preventing distractions from primary tasks is a common theme in many interface designs. The interface features that minimize distractions could have opportunities in other areas such as manufacturing or military operations.

3.3 Physical Requirements

The physical requirements for the Interface will ensure that the driver can enter text while driving safely. The driver will also be able to enter the text accurately and quickly.

Physical Requirements	
Requirement #	**Requirement**
3.3.1	The Interface must function in car interior environment.
3.3.1.1	Temperature range Operating: 0 to +35C
3.3.1.2	Humidity: 10 to 100% non-condensing
3.3.1.3	Shock
3.3.1.4	Vibration
3.3.1.5	10 year design life
3.3.1.6	No accidental contact due to water, vibration, or other environmental conditions.
3.3.2	The Interface buttons must be large and easily activated.
3.3.2.1	Buttons must be >= 0.5 inches square.
3.3.2.2	Buttons must not be closer than 0.5 inches center to center.
3.3.2.3	Force to press key < 1.47N, per ANSI/HFS 1988-100.
3.3.2.4	Key travel -- 2.5 to 7.5mm for standard keyboards
3.3.2.5	Must be adjustable to be within arms reach. Nominally 14 inches from typical elbow position, with +/- 3 inches of adjustment.
3.3.3	The Interface must provide feedback and confirmation of keystrokes.
3.3.3.1	Feedback from controls should be effectively instantaneous.
3.3.3.2	Must have a sampling rate >= 60Hz.
3.3.3.3	Must provide tactile feedback so user knows button activated.
3.3.4	The Interface must have a defined home position.
3.3.4.1	Must be able to find keys in 2 seconds without looking -- by feel only.
3.3.5	The Interface must be implementable in car environment.
3.3.5.1	Must use standard communication protocols.
3.3.5.2	Must not interfere electromagnetically with other systems.
3.3.5.3	Must accommodate left and right hand drive cars.

Table 4. Physical Requirements.

3.3.1 Physical Constraints

The driver will continue to be actively engaged in driving the vehicle, even while using the Interface. Therefore the position and orientation of the driver is constrained to the front seat, looking forward.

The physical envelope of the dashboard must also provide sufficient crumple room clearance to protect the driver in a collision. Therefore the Interface must not appreciably change the outline of the existing dashboard.

3.3.2 Opportunities

The design space allows for a rearrangement of an automobile's components. All cars have very similar layouts, which simplifies switching among different vehicles. The layout essentially has not changed since the automobile was invented more than a century ago. This design project gives the opportunity to reexamine these perceived constraints and to come up with a revolutionary solution for the entire vehicle.

There are many vehicles outside of IT Generation appropriate passenger models that could benefit for improved connectivity. Business users, traveling sales personnel, delivery drivers, and long-haul freight drivers could all benefit from better utilizing their time behind the wheel of the vehicle. The amount of time available for productive work will increase as assistive technologies come on-line that reduce the driver's workload.

3.4 Assumptions

For the purpose of this project, it can be assumed that the layout of the entire vehicle will remain essentially the same unless the team uses the opportunity in the section above to revolutionize it.

The designers may also assume, based on past record, that the size and layout of humans will generally remain the same over the anticipated product's life cycle.

The legal landscape and product legislation will not preclude the interface from being used while the car is in motion.

The IT Generation will continue to make ever expanding use of character-based communications. It is assumed that a disruptive technology will not be developed that renders text based data entry obsolete.

4 Design Development

4.1 Overview

The design teams YTPD Garage at Stanford University and at the Tokyo Metropolitan Institute of Technology (TMIT) approached the design task by first benchmarking interface technologies, brainstorming on future in-vehicle tasks and researching specifics about the IT-Generation. Utilizing the lessons learned, the design teams decided to build an interface that allows a driver to enter text for short-messages, email or web browsing in a safe manner.

The design task was divided between the two globally distributed teams based on the strengths of each team; YTPD Garage was responsible for the input device, hardware construction and testing of the final system while TMIT developed the system's software and ideas for an output and feedback system as illustrated in the diagram in Fig. 3.

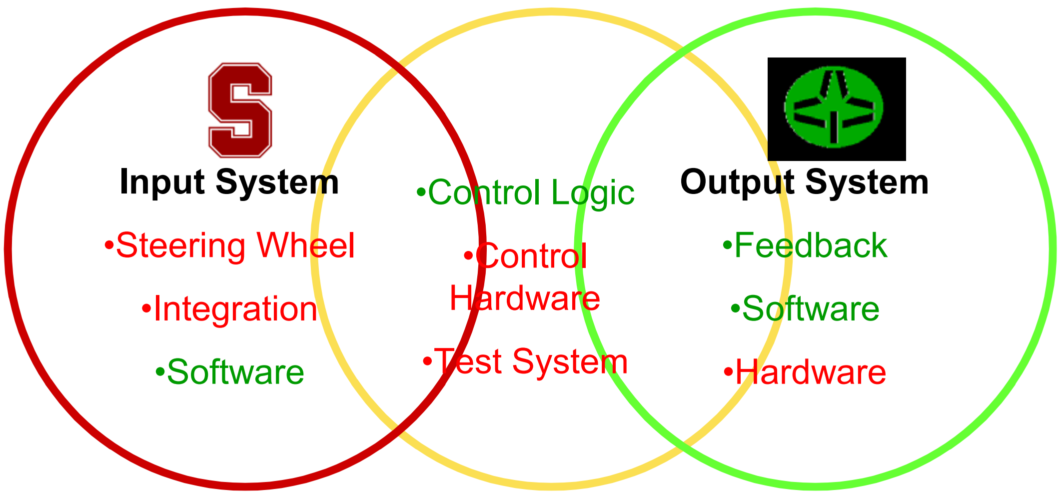


Fig. 3: Diagram illustrating the division of responsibilities between Stanford University (red) and TMIT (green).

The final design of the input interface is shown in Fig. 4 below and consists of a curved matrix of twelve buttons on the center section of a steering wheel. Each of the buttons can be activated in five different directions. This allows for fast and accurate text entry without the need for visual attention since each character is uniquely mapped.

Fig. 4: Final design of a steering wheel with twelve buttons that can be activated in five directions to allow unique character mapping.

The development process leading to this final design and the considerations made at each step are described in the following section.

4.2 Input Interface

Team YTPD Garage started the design process by benchmarking automotive and non-automotive human-machine interfaces. The team concluded from this research that one could design the optimum interface by combining the advantages of the various current systems described in 9.2.1 of the appendix. In order to satisfy the requirement of addressing the needs specific to the IT-Generation, the design team found that the following two characteristics must be considered in the design. The IT-Generation is accustomed to ubiquitous computing and communication anytime and anywhere. All current interfaces do not allow for this in a satisfactory manner and therefore the vehicle is experienced as a communication blackout area. In addition, members of the IT-Generation have a much better dexterity of their thumb than other generations due to their experience with video games and messaging on cell phones.

The objective of the project was therefore stated as follows: To develop an interface system that allows the driver to accurately and efficiently enter text data while driving safely.

4.2.1 Current Input Interfaces

In order to develop a good text input interface, the design team tested current interfaces and possible implementations inside a vehicle. These interfaces were the QWERTY keyboard, the Frogpad, CyKey and Keiboard, which is representative of a cell phone keypad, as shown in Fig. 5.

Fig. 5: Text input interfaces considered: QWERTY keyboard, Frogpad, CyKey and Keiboard.

The various setups and tests are described in detail in section 9.3 of the appendix and summarized here. The great advantages of the QWERTY keyboard are that all characters are uniquely mapped, which greatly reduces the need for visual feedback, and that all users have previous experience, which eliminates a learning period. In order to type, however, one must use both hands, which greatly affects the ability to drive. Simulator tests with implementations ranging from a QWERTY keyboard mounted to a steering wheel to steering by foot in order to free the hands for typing demonstrated that it is not feasible to install a QWERTY keyboard in a vehicle but that it would be desirable to have a design that provides unique mapping and takes advantage of prior user training.

The Frogpad and CyKey were tested while mounted to the center console. Tests revealed that even though the CyKey is easier to use than the Frogpad due to its more natural hand position, they both require a considerable amount of training time. Since

Toyota asked for an interface that can be used immediately, neither of these devices constituted a desirable solution. The possibility to operate these devices with one hand, however, made them a possible option.

Next, the Keiboard was tested in two configurations: mounted to the center console and handheld as shown in Fig. 6. The disadvantage of the Keiboard is the requirement for multi-tab, which means that one must press a button up to four times in order to scroll to the desired letter. This slows down the data input rate in addition to requiring visual feedback. The advantage of the Keiboard, on the other hand, is that it does not require any training time since the user already has prior experience from the use of cell phones. It was concluded that leveraging off this experience would be the best way to satisfy the goal of immediate usability.

Fig. 6: Keiboard mounted to the center console and handheld.

In addition, combining the various testing experiences the team concluded: “One hand steering full time is better than two hands steering part time”.

4.2.2 Optimum Input Interface

The testing described before showed that the various existing input interfaces all had some advantages but none of them was suitable for integration into a vehicle. Therefore, YTPD Garage needed to design a new interface that would meet the following goals:

- One-handed operation.

- Immediately usable with the possibility for an expert mode.
- Unique character mapping.
- No visual feedback necessary.

In order to leverage off prior training and for one-handed operation the design had to be based on the standard twelve-button matrix found on cell phone displays. The requirement for unique mapping, however, called for at least 26+10 buttons (all letters and numbers). In addition, punctuation and editing symbols should be integrated. This meant that twelve buttons needed to be turned into at least 36. The joystick interface used for navigation on the Nokia 6800 cell phone, as shown in Fig. 7, inspired the solution: A standard cell phone matrix of twelve buttons with each button being capable of providing four or five distinct signals.

Fig. 7: Nokia 6800 cell phone with joystick inspiring solution.

A diagram of the initial character layout of the buttons using twelve four-way navigation switches is shown in Fig. 8.

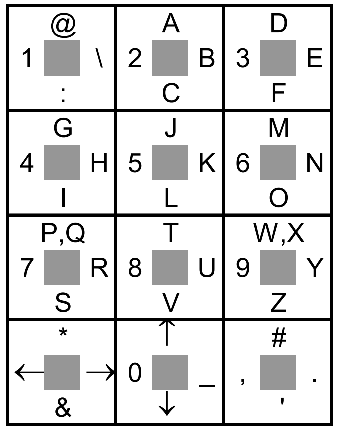


Fig. 8: Initial character layout using twelve four-way navigation switches.

4.2.3 Location in Vehicle

Another primary design task was to find the optimum location of the input device. Consideration was given primarily to safety but also to efficiency, ergonomic issues, and styling. Team YTPD Garage considered the following locations feasible: steering wheel, center console or handheld. Initial simulator and road tests using the setup in Fig. 9 showed:

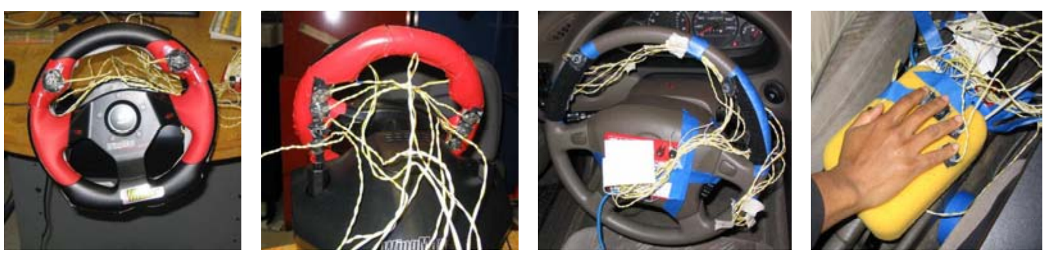


Fig. 9: Initial test setups with buttons on the front and back of steering wheel and the center console.

- It is difficult to operate switches with both hands while steering with both hands simultaneously.
- Buttons on the backside of the steering wheel are undesirable because the combination of the muscles under tension leads to the carpal tunnel syndrome.

- The design must incorporate an intuitive home position to ensure that the driver does not hesitate to remove the hand from the buttons to avoid the trouble of finding the buttons again.

For the reasons above, it was concluded that the input device should be located on the center console if it requires the use of multiple fingers. An interface operated with the thumb only, however, could be placed ergonomically on the steering wheel. In order for an easy to find home position regardless of the driver's size and to satisfy Toyota's paradigm of "hands on the wheel and eyes on the road," the design team preferred the steering wheel mounted solution.

The optimum input interface described in section 4.2.2 was designed for operation with the thumb only and thus the team decided to move forward with a steering wheel mounted solution once the input design was conceived. The design of the steering wheel and the buttons for activation is described in the following two sections.

4.2.4 Buttons and Steering Wheel

4.2.4.1 Layout of Buttons

The goal of this part of the design process was an intuitive and ergonomic layout that allows users with all hand sizes to operate all buttons comfortably by moving their thumbs only. In order to accomplish this, the design team traced the natural thumb movement of people with various hand sizes and created multiple foam mockups of possible layouts as shown in Fig. 10.

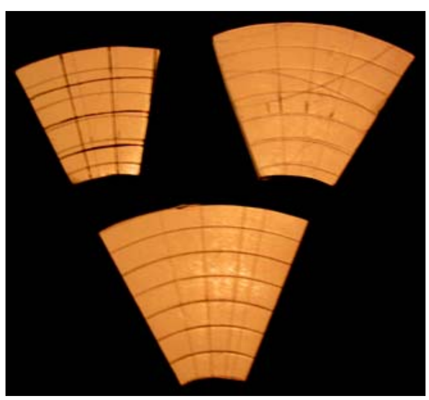


Fig. 10: Foam mockups of possible button layouts.

All of these mock-ups are based on an arc for the columns since it is much easier to move the thumb in an arc around the carpometacarpal basal joint rather than in a straight line up and down. Similarly, the rows are on lines through the arc's center rather than horizontal. Each of these mockups was tested using the two extreme hand sizes as depicted in Fig. 11.

Fig. 11: Comparison of small and large hands used for testing during design evolution.

It was found that the arced layout shown in Fig. 12 allowed users with small and large hands to operate all buttons comfortably. A prototype of this design was built using acrylic and a PC board as shown in Fig. 13.

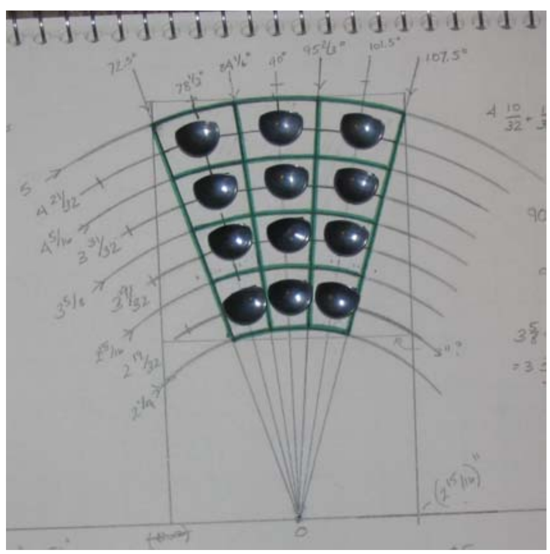


Fig. 12: Initial layout of buttons.

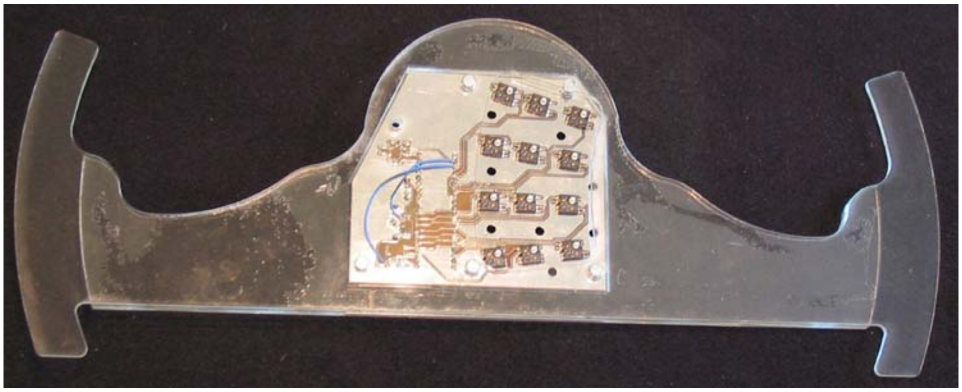


Fig. 13: Mock-up of steering wheel and button layout from acrylic and PC board.

User testing of this prototype revealed that the buttons had to be spaced further apart in the radial direction and closer together in the tangential direction. In addition, it was found that it is much easier to reach the upper buttons rather than the lower buttons. Since the average thumb could reach even higher up than the top buttons, the entire matrix was rotated more upwards. The resulting buttons centers are shown in Fig. 14.

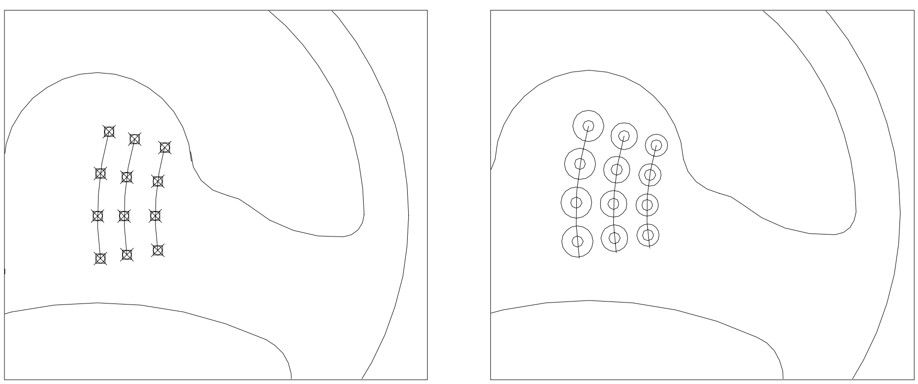


Fig. 14: Drawing of initial (left) and final (right) button layout.

4.2.4.2 Location on and shape of steering wheel

In the beginning of the design process, YTPD Garage considered placing buttons on the front and/or backside, the center, spokes, or rim of the steering wheel. Since the optimum interface was designed for thumb operation only, the possibilities were reduced to the front side. In addition, the layout described in section 4.2.4.1 above requires a large flat area. In order to satisfy these constraints in an ergonomic fashion, many different shapes of steering wheels and ways to hold the wheel were considered. The full range of ideas that were mocked up is shown in section 9.4 of the appendix and the most prominent designs are given here in Fig. 15.

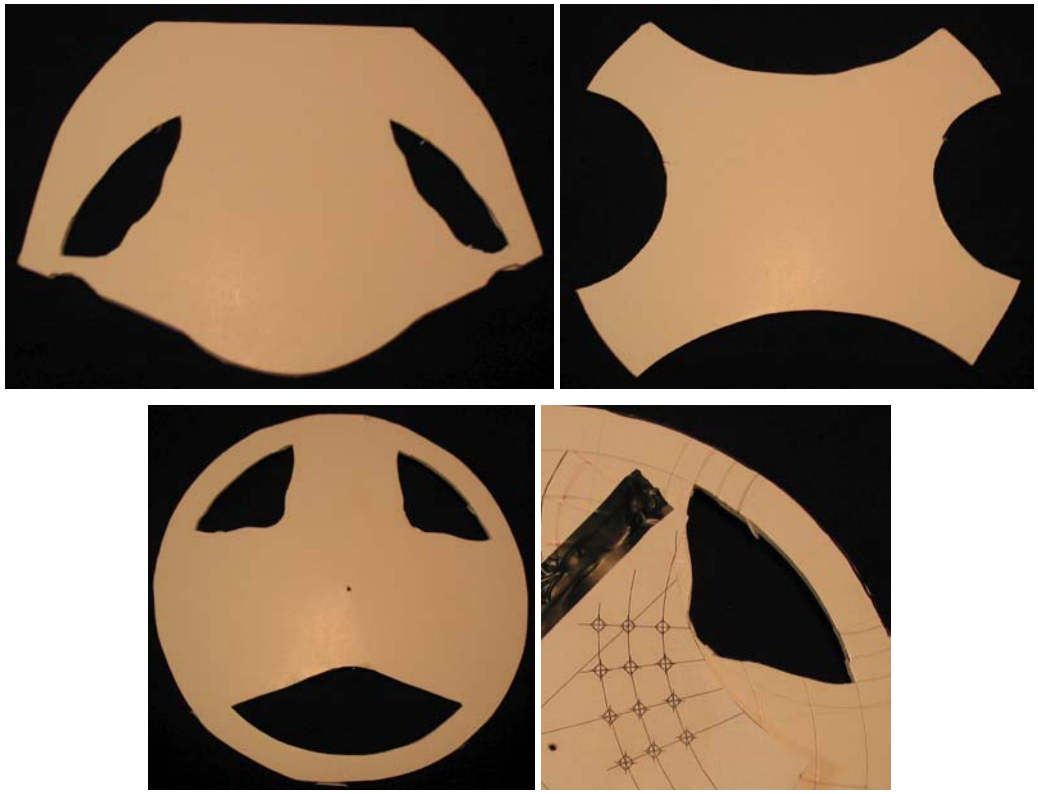


Fig. 15: Foam mock-ups of steering wheel shapes and button locations.

The final selection is shown in Fig. 16. The design choice was primarily based on safety since the hand position away from the rim of the wheel would provide an intuitive and natural lockout of the text input mode during intense driving maneuvers. In order to make a sharp turn, the driver would have to remove the hand from the spoke and thus would no longer be able to type. At the same time, the hand would be in sufficient proximity to the wheel as that the driver could easily and quickly grab the wheel in the 10 and 2 positions if needed. The other variations of the steering wheel such as the yoke were dismissed for safety reasons; they either had sharp edges and corners or the lack of a fully round rim would make it difficult to grab the wheel correctly when moving hand positions quickly during a steering maneuver.

Fig. 16: Illustration of final position of buttons on wheel.

The design team deliberated at length about the feasibility of encouraging drivers to hold the steering wheel spoke due to safety concerns. It was concluded, however, that the overall safety improvement due to the natural typing lockout of this design more than offsets the safety concern of holding the wheel at the spoke. Additionally, as steer by wire systems are about to replace steering columns in vehicles, this would not be a problem anymore in vehicles equipped with this technology since no dangerous forces can be transmitted to the wheel in case of an accident.

4.2.4.3 Shape of Spokes

The "shape" of a steering wheel is mainly created by the shape of the spokes and thus great consideration must be given to aesthetics during their design. The outside rim diameter and total wheel diameter in addition to the button layout on the center of the wheel provided an envelope within which the spokes were to be designed. In order to give the steering wheel a sporty appearance and to counteract the "heavy" center of the wheel, the design team decided to use a two spoke design. It was also decided for aesthetics that the steering wheel apart from the buttons should be symmetrical around the vertical center axis. This greatly reduced the aesthetic design freedom to a small portion of the wheel as indicated in Fig. 17.

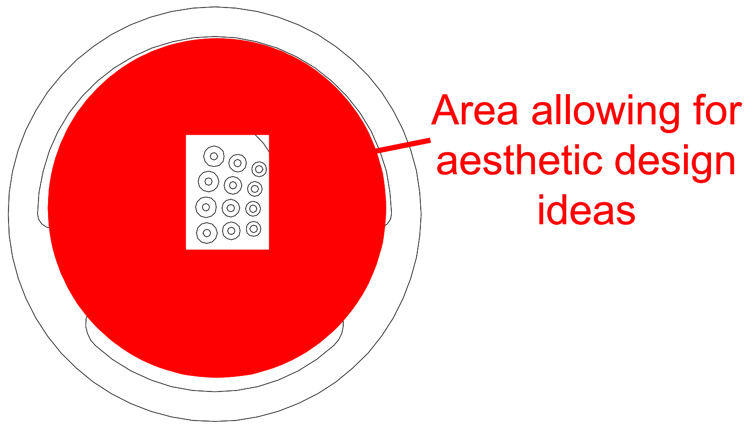


Fig. 17: Steering wheel area available for aesthetic design considerations.

Apart from the aesthetics and structural support, the shape of the spokes greatly affects the ergonomics and functionality of the interface in this design. Therefore the spokes had to be designed to provide a rest for the hand with an integrated home position, which one would find intuitively. The shape of the palm when placed around an edge lead to the rounded design with two depressions of different radii. The two steep slopes on each end of the spoke were designed to help guide the hand into the right location. The final design of these spokes was achieved through continuous iterations between foam cutouts and user testing. A sample of this iterative process and the final design is shown in Fig. 18.

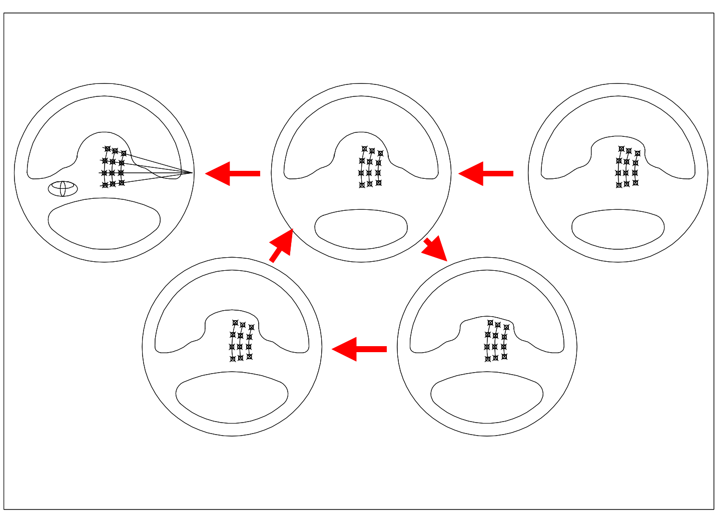


Fig. 18: Iteration and final shape of steering wheel spoke.

4.2.4.4 Shape of Buttons

The shape of the buttons should be ergonomic and intuitively imply how to operate them. In order to achieve this goal, variations of rectangular buttons were considered and tested as shown in Fig. 19.

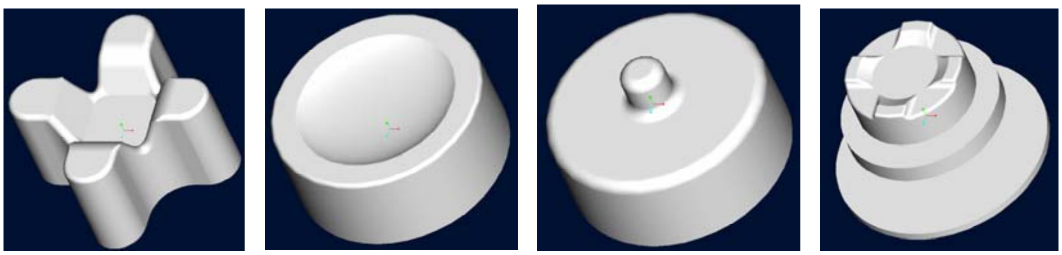


Fig. 19: Sketches and pictures of variations for initial button designs.

User testing, however, showed that with any of these buttons the user easily activated two buttons simultaneously through the diagonal or inadvertently activated a button while sweeping across to reach the desired button. Most users suggested that simple joysticks might be easier to use after they used the switches without button caps. Therefore, round joystick button caps were manufactured in addition to inserts that encompass these joysticks. Since this design proved to be much less error-prone and easier to operate, the final design utilizes this variation as shown in Fig. 20.

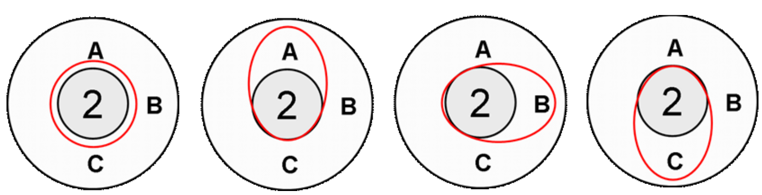
Fig. 20: Final button design with joysticks encompassed by inserts.

4.2.5 Final Design

The final design of the steering wheel with the twelve five-way switches allowing text entry while driving is shown in Fig. 21.

Fig. 21: Final design of optimum human-machine input interface steering wheel.

The layout takes advantage of the user's prior training on cell phone keypads while taking this to the next level: It allows for unique character mapping eliminating the need for multi-tab or predictive text entry and thus greatly reduces distractions while increasing efficiency as illustrated in Fig. 22. The system adjusts for user experience by allowing for a beginner and advanced mode in addition to personalization.



	Select	Up	Down	Right	Left
Button	2	2	2	2	2
Result	2	A	B	C	

Fig. 22: Illustration of five-way switching.

The system also provides a natural lockout during serious driving maneuvers due to the interface's placement on the hub of the wheel requiring the driver to remove the hands when turning the wheel past 45 degrees. Therefore there are two distinct regions, a driving and a typing region to the steering wheel as shown in Fig. 23.

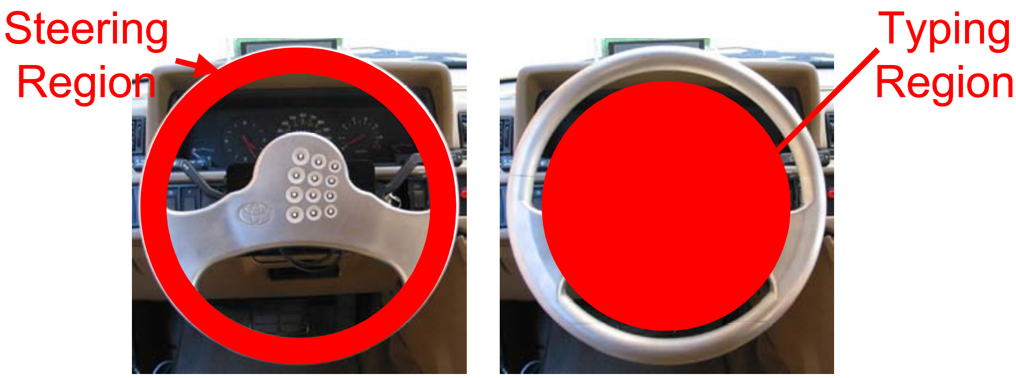


Fig. 23: Steering and typing regions of steering wheel.

4.2.6 Final Assembly

The system needed to be designed to allow for manufacturing, assembly and testing in the team's test vehicle. In order to do so, the design was broken up into the parts described below.

4.2.6.1 Adaptor

An adaptor allowing the designed wheel to be mounted into the test vehicle was made by taking the center portion of the original steering wheel and machining it into a slotted ring as shown in Fig. 24 and Fig. 25.

Fig. 24: Picture of original steering wheel center section.

The adaptor was press-fitted into the steering wheel and retained on the inside with a retention plate as shown in the picture below:

Fig. 25: Adaptor retained in steering wheel.

4.2.6.2 Wheel

The actual steering wheel was broken up into two sections: The wheel and the bezel. The wheel attaches to the steering column through the adaptor, houses the electronics and provides the structure to transmit forces between the driver and the steering system. The wheel is shown in Fig. 26.

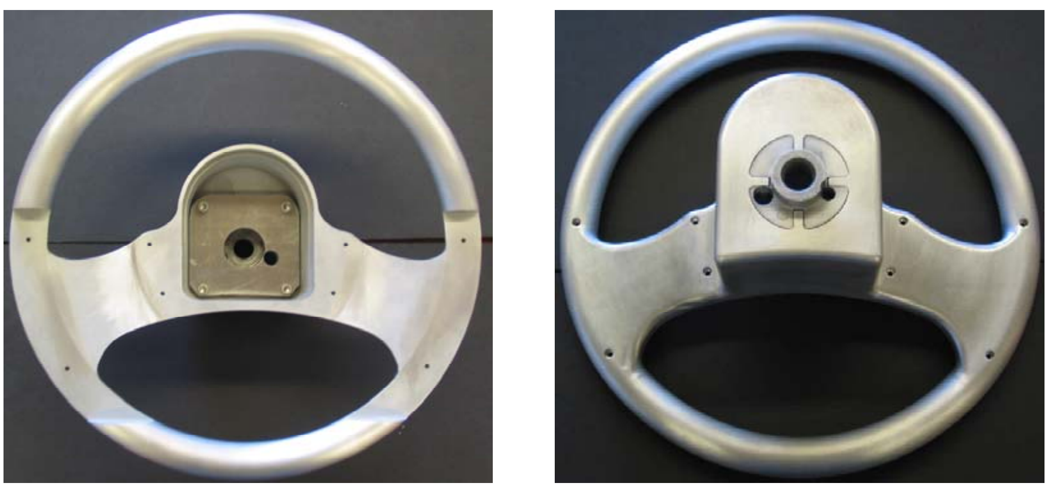


Fig. 26: Wheel part of final system.

4.2.6.3 Bezel

The bezel is the front portion of the steering wheel as shown in Fig. 29. It is the cover and mounting plate for all electronics and bolted to the wheel from behind.

Fig. 27: Bezel part of final design.

4.2.6.4 PC Board

The PC board mounts behind the bezel, providing a mounting surface for all of the switches. The PCB also provides all of the electrical interconnects between the switches and the keyboard encoder. The keyboard encoder translates the switch activations into a standard PS/2 interface.

YTPD selected a KeyWiz ECO keyboard encoder for the design. The KeyWiz uses a ground interrupt scheme where the common arms of all switches are tied to ground. When the switch is closed, the input port of the Keywiz is connected to ground, providing the input signal. The 5 position switches selected for the design have a common shared between several of the switch positions, prohibiting the use of a matrixed switch encoder. The KeyWiz has 32 unique inputs, however 24 of those inputs can be multiplexed with the use of switching diodes. The switching diode multiplexing scheme is shown in Fig. 28 below as the “Advanced Method.”

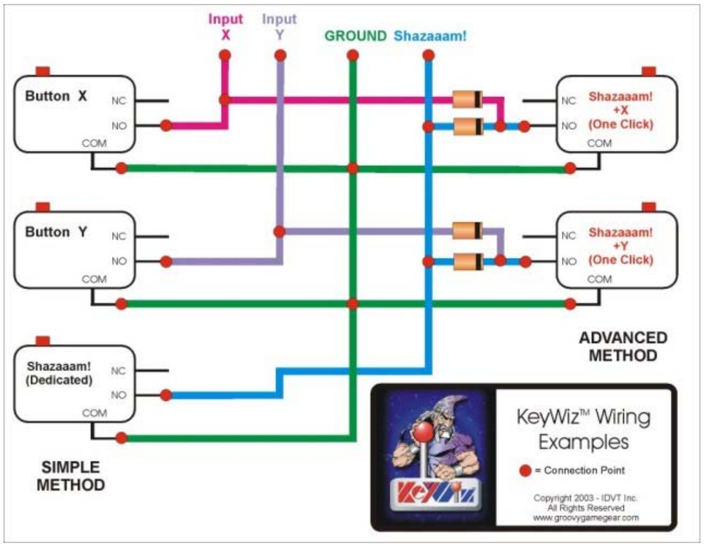


Fig. 28: KeyWiz Keyboard Encoder Wiring Diagram.

YTPD Garage purchased unassembled KeyWiz ECOs from IDVT, Inc. After the signal interconnects were reverse engineered, the KeyWiz circuitry was incorporated into the PCB design. The KeyWiz components were mounted in DIP sockets so that the parts could be moved from one board to the next as revisions to the PCB were made.

The full schematic and details of the PCB are included in section 9.8.1 of the appendix while a front and rear view photograph are shown in Fig. 29.

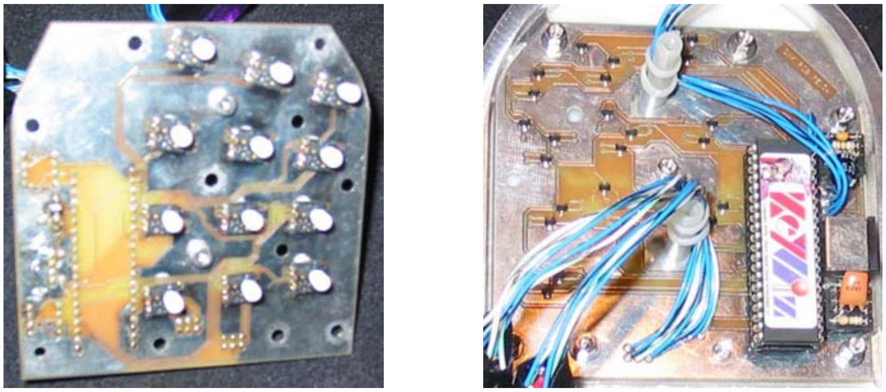


Fig. 29: Front and back view of PC Board with navigation tact switches.

4.2.6.5 Buttons

The button caps are joysticks surrounded by circular inserts as shown in Fig. 30. For the prototype of this project, they were both manufactured out of ABS plastic using fusion deposition. An actual production version would most likely have the inserts shaped in with the steering wheel cover and the joystick caps integrated as part of the keypad.

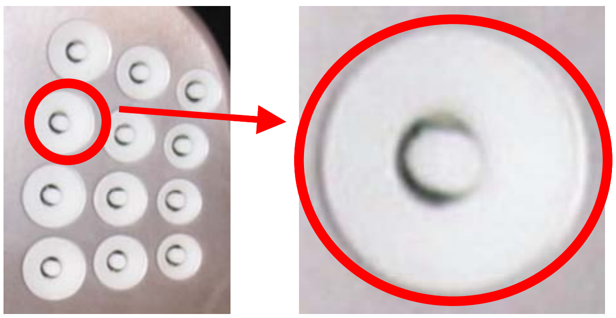


Fig. 30: Joystick button caps and circular inserts surrounding them.

In order to make the button caps for the prototype, several iterations with varying hole sizes were made to ensure tight fit with the navigation tact switches. This was necessary because the tolerances and tool paths used by the fusion deposition machine are rather unpredictable for such small and intricate parts.

4.3 Feedback and Output Interface

The design team at TMIT was responsible for the development of the feedback and output portion of the interface. The TMIT team recommended the use of a heads-up-display immediately below the line of vision of the driver to display characters

The hardware used for testing simulated such a heads-up-display using an LCD display mounted to the dashboard at the bottom of the windshield as shown in Fig. 31.

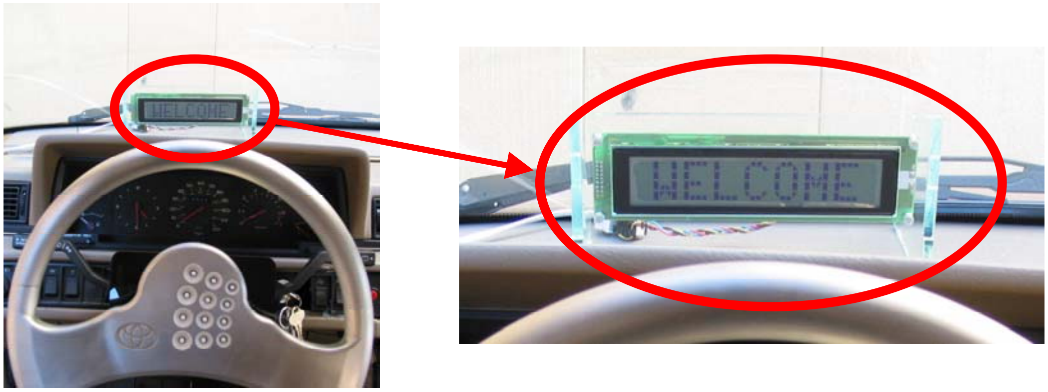


Fig. 31: LCD Display used for simulation of a heads-up-display.

4.4 Software

Team TMIT developed and wrote all software for the interface. The full source code is given in section 9.18 of the appendix, while Fig. 32 below illustrates the information flow through the program.

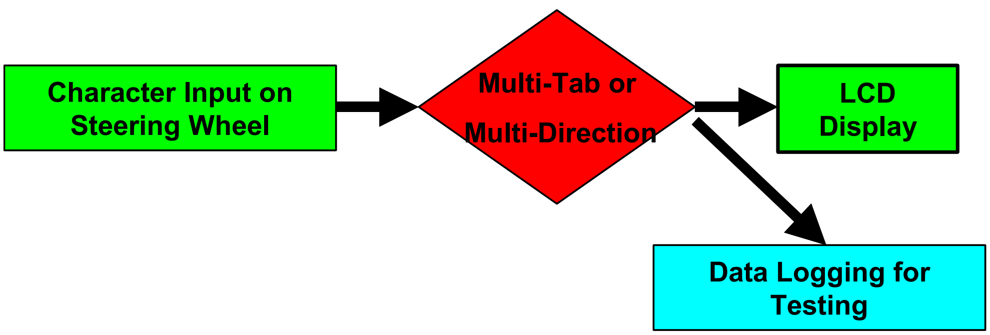


Fig. 32: Flow chart of interface software.

The system reads the input from the interface mounted to the steering wheel and then displays it on the LCD display in addition to writing a log file for test purposes only. The core of the system consists of a subroutine that allows multi-tab as an input mode in addition to the multi-directional mode described in section 4.2.2.

4.5 Test System

Team YTPD Garage quickly realized that all interactions are distractions, which reduce the driver's ability to safely drive the car. Since the goal of the project was to design an interface that would inherently be a distraction, it was important to find a way to measure this distraction in order to fully evaluate the design. The system and metrics used to evaluate the design are described in this section.

4.5.1 Test Parameters and Metrics

The goal of this interface design is to allow the driver to complete secondary tasks while driving safely. Since driving is an extremely complex task with infinite variables, the design team researched prior driver attention metrics and devised a list of parameters to be measured. The parameters and metrics to measure safe driving were defined as shown in Table 5 below:

Parameter	Metric	Explanation
Reaction time	Time to respond to a stimulus directly ahead in the line of vision in seconds.	The time to respond to an emergency situation (e.g. the vehicle ahead stopping suddenly) is critical for safe driving and often increases when the driver is distracted or even looks away.
Surrounding awareness	Time interval between checking of mirrors in seconds.	The awareness of surrounding traffic is critical to defensive and safe driving and is greatly affected by how frequently the driver checks the mirrors.
Speed variation	Standard variation in driving speed in mph.	Distracted drivers often do not keep a constant speed but rather slow down without realizing and then speed up again when they realize the low speed.
Speed offset	Offset between	Distracted drivers often drive much faster

	intended (speed limit) and actual driving speed in mph.	or slower than the intended driving speed, which may be assumed to equal the posted speed limit.
Lane departures	Number of departures on right and left side.	Distracted drivers often have difficulty staying within the boundaries of their lane.

Table 5: Parameters and metrics to test driver distraction.

Almost every driver has observed themselves or others showing any or all of the above signs when they are distracted. The design team believes that if the use of an interface does not have an effect on any of the metrics above or remains within the boundaries stated in section 3, then using the interface while driving can be considered safe.

In addition to ensuring driving safety, the objective of the interface design is to allow for efficient and accurate text entry. This can be measured by the number of words that can be typed per minute and the number of errors in the final text.

In order to test all of the above parameters realistically, it was decided to equip a vehicle with technology that would allow the measurement of the parameters described above quantitatively and qualitatively.

4.5.2 Test Vehicle

Vic Scheinman, a consulting professor for the course, donated a 1986 Volvo 740 GLE Station Wagon as shown in Fig. 33 to the design team since he believes that no realistic data can be obtained from a driving simulator but only from real world traffic.

Fig. 33: 1986 Volvo 740 GLE Wagon donated by Vic Scheinman for use as a test vehicle

Team YTPD Garage equipped the vehicle with measurement systems as described in the following sections. Fig. 34 shows an overview diagram of where components of this system are located and how they are connected.

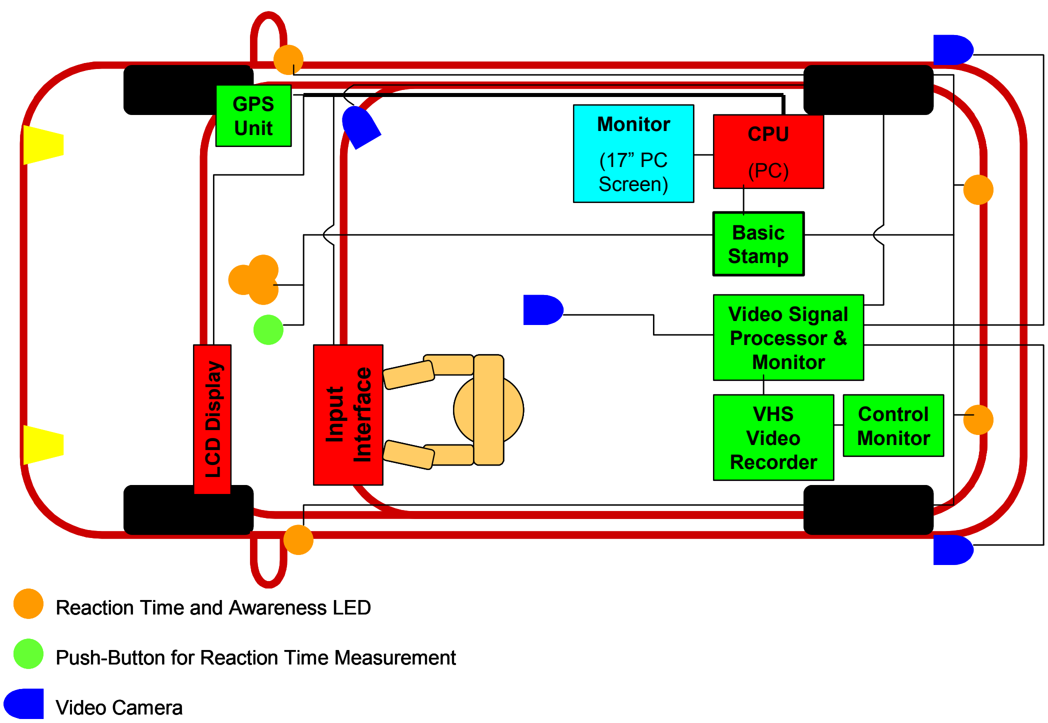


Fig. 34: Overview of test vehicle.

4.5.2.1 Reaction Time

Reaction time is the paramount parameter when emergency situations arise. These situations are usually triggered by something in front of the vehicle such as the vehicle ahead stopping suddenly or a child running into the street. Since the reaction time often determines a life or death situation, it is critical to ensure that the use of the interface has no perceivable effect on the reaction time of the driver.

In order to test the reaction time without endangering the driver or those around, the team developed a system consisting of bright LEDs in the center of the dashboard and a button near the steering wheel. These are connected to a Basic Stamp for interfacing with a computer. During the test drive, the computer will at random turn on the LEDs to simulate an emergency stop situation. The driver then has to press the button to turn off the LEDs and the computer records the time between the activation of the LEDs and when the driver pressed the OFF button. The time will be logged and allows for comparison between various driving and interaction situations.

Fig. 35: LEDs and button used to measure reaction time.

4.5.2.2 Awareness of Surroundings

Awareness of the surrounding is measured just like reaction time as explained in section 4.5.2.1 above. In this case, however, the LEDs are smaller and placed in more subtle locations close to the mirrors as shown in Fig. 36

Fig. 36: LEDs placed by mirrors to measure awareness of surroundings.

The LEDs are activated individually, turned off and recorded in the same way as reaction time. Since these LEDs are much smaller and not as close to the line of vision, they will not catch the driver's attention unless he or she actually checks the rearview mirrors.

4.5.2.3 Speed Variation and Offset

A GPS unit in the test vehicle measures the actual driving speed and logs this on a PC computer. The log file is then imported into the data analysis spreadsheet. The average speed and variations in speed are computed and overlaid with the other data on a single graph for comparison with other tests. The receiver is shown in Fig. 37 and an example of the Excel spreadsheet is given in the appendix in section 9.6:

Fig. 37: GPS receiver used for speed measurement.

4.5.2.4 Lane Departures

The setup used to track lane departures is shown in Fig. 38. It consists of a camera on each rear fender of the vehicle and a video recording system. The cameras are pointed so that the position of all tires with respect to the lane markers can be monitored at all times.

Fig. 38: Cameras on rear fenders and video recording system used to monitor lane departures.

The number of lane departures on each side is counted manually after completion of the test drive using the recorded videotape.

4.5.2.5 Driver Observation

In order to be able to recreate and further analyze the test drive, the design team also captures the ongoing scenario. This is accomplished with two cameras. One is mounted by the A-Pillar on the passenger side and records the face of the driver and thus where he or she is looking at all times. The other camera is placed in the middle between the driver and passenger below the headliner. This camera captures the road in front of the car and where the driver's hands are. Illustrations of both cameras are shown below.

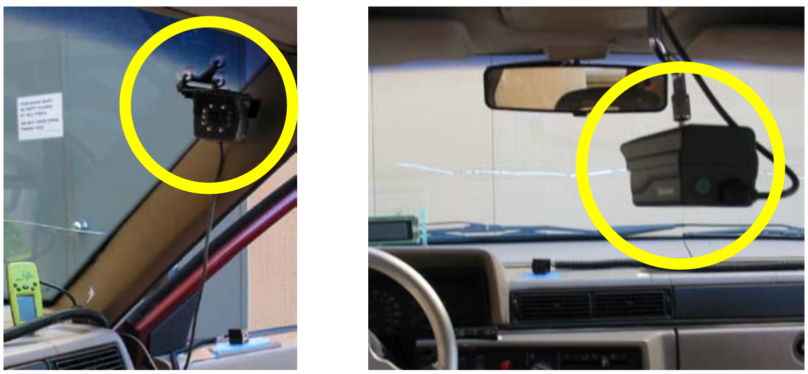


Fig. 39: Driver and road observation cameras

4.5.3 Interface Efficiency and Accuracy

The two requirements for the text input portion of the interface are high accuracy and efficiency. These can be expressed as the number of errors per 100 words and in words typed per minute.

In order to record these two parameters for evaluation, the TMIT team integrated a data logging function into the software described in section 4.4. This subroutine records the time and character entered in a text file every time a button is activated. The data log is then imported into the spreadsheet template used for character input and driving speed analysis as shown in the appendix. The written text is checked manually for errors and the number of errors is counted.

4.5.4 Test Drive Loop

The map in Fig. 40 shows the test drive path, which the team intended to use for testing of the interface. It had been chosen because it contains all regular driving situations: slow city driving (Stanford campus), stop signs and lights, rural highways, interstates and a great number of turns.

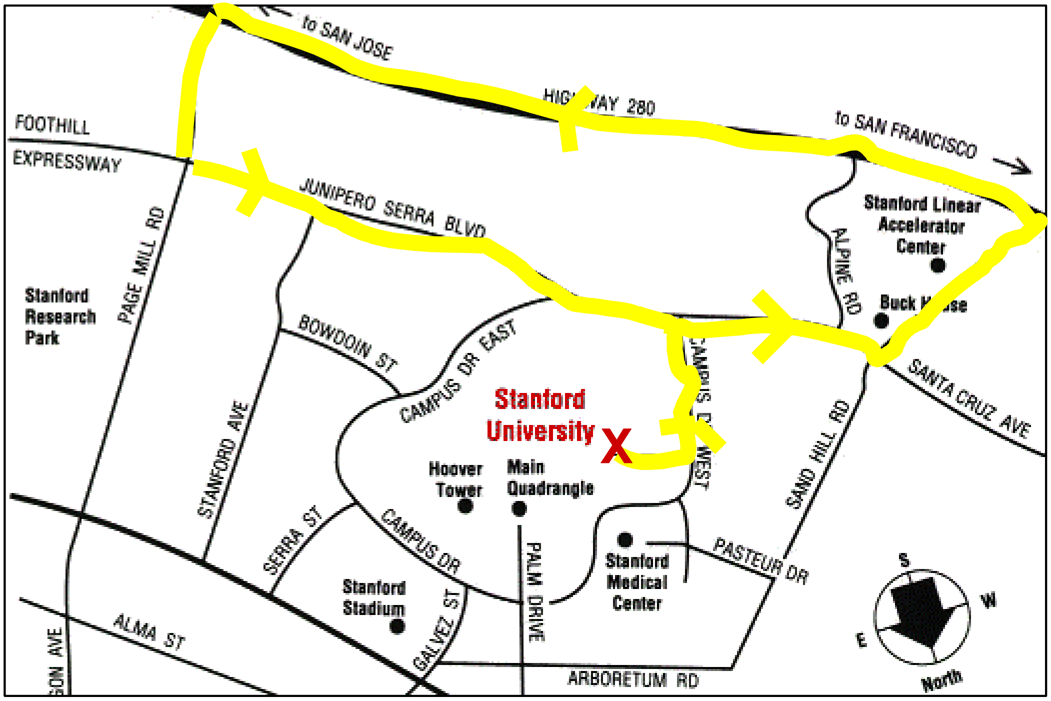


Fig. 40: Map of test drive loop

All test drives were supposed to be completed on this path. Due to the inherent danger of driving, however, Toyota Motor Corporation and Stanford University in the end, did not allow YTPD Garage to do road testing with users who were not part of the design team for liability reasons.

In order to still test the system carefully, the design team reverted to testing with the vehicle parked, driven in a parking lot at low speeds or on the test drive loop without using the input device. The actual test scenario for each test is provided on the data sheets, which are shown in the appendix in section 9.6.

5 Design Specifications

The product design discussed in section 4 has been compared to the Requirements presented in section 3. The goal is to establish that the design satisfies the requirements.

The text input system as tested produces text input speeds of 5WPM without user training, increasing to 10 WPM after 3 hours of training. Using the text input device increases the response time of the driver as compared to driving without texting. The overall increase in total response time ranges from 0.6 to 3.1 seconds. The increase in emergency reaction time ranges from 0.7 to 2.5 seconds. Testing has shown that the multi-switch method results in a larger increase in response time, mostly due to the uniqueness of the interface. These response times can be compared to an increase of 0.6 seconds from the driver changing radio stations while driving.

For the purposes of comparison, the system is defined to include the LCD display and software interface described in section 4.3. While the primary design development was focused on the input device, TMIT contributed the software interface and output features so the individual components could be tested as a complete system.

The input device is considered separately in the tables below. Some of the requirement items are still identified as TBD, as additional road testing is required to quantify the representative values. Road testing had been originally planned, but was removed late in the development cycle due to liability concerns.

Many of the requirements are more qualitative than quantitative. The specification comparison is therefore presented in a compliance matrix format. Each item is rated on a scale of OK, Poor, and No with the following definitions:

- OK – design satisfies the intent of the requirement.
- Poor – design satisfies the intent of the requirement, but additional development is required to produce an acceptable design.
- No – design does not meet the intent of the requirement.
- Future Function – design requirement that will need to be incorporated into a higher level of design.
- TBD – specification that will need to be validated through additional realistic testing.

- N/A – requirement that is not applicable to the current design.

5.1 Functional Specifications

Functional Requirements			Functional Specifications
Objective	Requirement #	Requirement	Steering Wheel Keyboard
Safety	3.2.1	The Interface must be safe to use in a car.	TBD
	3.2.1.1	The Interface must minimize "look away time".	OK
	3.2.1.1.1	Average glance duration should be less than 1.2 seconds.	OK
	3.2.1.1.2	No glances should be longer than two seconds.	OK
	3.2.1.1.3	Total task time should be less than fifteen seconds.	N/A
	3.2.1.1.4	The display should be mounted near the driver's line of sight to minimize look away time	OK
	3.2.1.2	The Interface must not significantly affect lateral and longitudinal control of the vehicle, driver workload, and situation awareness.	TBD
	3.2.1.2.1	Must not interfere with standard driving functions.	TBD
	3.2.1.2.2	Must not block driver's vision.	OK
	3.2.1.2.3	Must not preclude motion required during emergency event.	OK
	3.2.1.3	The Interface must be ergonomically appropriate.	OK
	3.2.1.3.1	Must be comfortably positioned.	OK
	3.2.2	The Interface must cause minimal distraction.	OK
	3.2.2.1	The Interface must follow aviation concept of "dark and silent cockpit."	OK
	3.2.2.1.1	Must provide the minimum amount of information.	OK
	3.2.2.1.2	Must adjust the magnitude of the information to be proportional to criticality of response.	OK
	3.2.2.1.3	Displays should only attract drivers' attention when necessary.	OK
	3.2.2.1.4	Movement and/or flashing of graphical elements should be avoided unless these are absolutely necessary.	OK
	3.2.2.2	The Interface must manage the information load by monitoring the driver and driving situation.	Future Function
	3.2.2.2.1	Must restrict information when necessary.	Future Function
	3.2.2.2.2	New features only available when driver has cognitive resources available.	Future Function
	3.2.2.2.3	Information must be prioritized.	Future Function
	3.2.2.3	Visual clutter should be minimized, maximum contrast should be used between display elements, colors should be used sparingly and consideration for color blindness should be given.	OK
	3.2.2.4	Keep backgrounds simple and muted.	OK
Accuracy	3.2.3	The Interface must be easy to use.	OK
	3.2.3.1	Must not require memorizing complicated key sequences.	OK
	3.2.3.2	Must be customizable to suit different preferences, abilities, and needs of different users.	OK
	3.2.3.3	Group information logically. Consider the frequency and sequence that functions will be used and design user interactions to support	OK
	3.2.3.4	Must satisfy the users behavior and needs.	OK
	3.2.3.5	Must let the user set the pace and initiate interaction.	OK
	3.2.3.6	Must accommodate for users with varying degrees of experience.	OK
	3.2.3.7	Must be able to be learned in <5 hours.	OK
	3.2.3.8	The user should not be required to remember anything to use the system.	No
	3.2.4	The Interface must be accurate to use.	OK
	3.2.4.1	Data entry accuracies of 90% should be achieved after training.	OK
	3.2.4.2	Data entry speed should exceed 5 corrected WPM.	OK
Speed	3.2.5	The Interface should not require significant movement to operate.	OK
	3.2.5.1	All controls should be within the reach of one hand.	OK
	3.2.6	The Interface should communicate with other systems.	OK
	3.2.6.1	Must connect to other car systems to reduce driver input.	Future Function
	3.2.6.2	Must connect to external electronic devices such as PDA's, cell phones, etc to have access to their data.	Future Function

Table 6. Functional specification comparison to requirements.

5.1.1 Discussion of Safety Requirements

Many of the functional requirements related to safety can only be determined after several users have tested the system. Data has been collected for a small number of users operating the system while driving. The majority of the test data is from non-moving simulations of reaction time while typing. Additional future testing under driving conditions will help to further refine the results.

The LCD display portion of the system has been specifically designed to provide a minimum amount of data – eight characters at a time. It has also been located just below the driver's line of vision to not block vision, but also minimize look-away time. TMIT has added additional features to improve non-driving review of data entry, however the primary moving interface continues to have the eight character limit.

The majority of the metrics selected to verify safety involve a moving vehicle. These metrics include lane departures, speed variations, and reaction times. With the de-scope of user testing in the moving vehicle, the primary safety metric used is reaction time.

All of the testing involved establishing a response time baseline for the operator, which was then compared with the response time while entering text. The response time was divided into reaction time, which simulates an emergency stop, and awareness time, which is a measure of how often the driver is examining the side and rear mirrors. The text entry speed was also captured for each test.

A small subset of data was collected under real driving conditions, however the number of test cases was limited to the design team. Driving speed, text entry speed, and response time data were collected for the driving tests.

5.1.1.1 Discussion of Response Time Testing

Response time data was collected for four test subjects using the text input device. Initially, the baseline reaction data was collected in a stationary vehicle. The "driver's" only task was to observe and react to the response time LEDs placed throughout the vehicle. As a result, the response times were optimistically low (less than 1 second) and did not reflect representative response times of a driver focused on operating a vehicle.

In an attempt to make the baseline response time value more realistic, the baseline response time testing was repeated in a moving vehicle while the driver was focused on driving. The multi-tap and multi-switch response times are for a stationary vehicle with the driver texting only. A summary of the response time and entry speed for the two input methods is shown below in Table 7.

					Change from Baseline		
	Avg. Response Time	Avg. Reaction Time	Avg. Awareness Time	Avg. WPM	Response	Reaction	Awareness
Multi-Tap	2.0 sec	1.6 sec	2.2 sec	4.4	0.6 sec	0.7 sec	-0.9 sec
Multi-Switch	4.5 sec	3.4 sec	4.8 sec	5.7	3.1 sec	2.5 sec	1.7 sec
Baseline	1.4 sec	0.9 sec	3.1 sec				

Table 7. Summary of Response Time and Text Entry Speed Data for Stationary Testing.

The multi-tap and multi-switch input methods had 0.6 and 3.1 second increases in overall response time, respectively, from the driving only baseline. The larger increase in the multi-switch response time is predominantly attributable to one specific test subject. Table 8 below summarizes the response and text entry data with the outlying test subject results removed. The multi-tap and multi-switch input methods reduce 0.6 and 1.8 second increase in overall response time, respectively, from the driving only baseline.

					Change from Baseline		
	Avg. Response Time	Avg. Reaction Time	Avg. Awareness Time	Avg. WPM	Response	Reaction	Awareness
Multi-Tap	2.0 sec	1.6 sec	2.2 sec	4.4	0.6 sec	0.7 sec	-0.9 sec
Multi-Switch	3.1 sec	1.0 sec	3.5 sec	5.2	1.8 sec	0.2 sec	1.6 sec
Baseline	1.4 sec	0.9 sec	3.1 sec				

Table 8. Subset of Response Time and Text Entry Speed Data for Stationary Testing.

An additional moving test was performed to compare the response times of driving to a current typical driving task. The baseline driving response time was compared to the driving response time of a driver changing radio stations.

Input Method	Avg. Response Time	Avg. Reaction Time	Avg. Awareness Time	Change from Baseline: Response	Reaction	Awareness
Using Radio	2.5 sec	1.6 sec	2.9 sec	0.6 sec	0.7 sec	-1.1 sec
Baseline	1.9 sec	0.9 sec	4.0 sec			

Table 9. Summary of Driving Response Time to Changing Radio Stations Response Time.

In addition to the driving baseline/static text entry testing discussed above, a limited set of data was collected while driving the vehicle and texting. The testing was limited to two members of the design team. A summary of the data is provided in Table 10 below. While there was a considerable increase in the total response time, the increase is predominantly attributable to the awareness component of the response metric. Multi-tap was shown to have essentially the same reaction time as driving alone, while the reaction time for the multi-switch input method increased only 0.4 seconds.

	Avg. Response Time	Avg. Reaction Time	Avg. Awareness Time	Avg. WPM	Change from Baseline: Response	Reaction	Awareness
Multi-Tap	10.5 sec	1.5 sec	12.0 sec	2.3	7.3 sec	-0.2 sec	10.8 sec
Multi-Switch	7.1 sec	1.6 sec	8.6 sec	5.8	4.9 sec	0.4 sec	7.4 sec
Baseline	2.5 sec	1.4 sec	1.2 sec				

Table 10. Summary of Response Time and Text Entry Speed Data for Driving Testing.

5.1.2 Discussion of Accuracy Requirements

The input device satisfies a major Toyota requirement that the device be immediately usable to anyone entering the car. The basic assumption is that the IT Generation is cell phone aware, so the input device leverages the existing cell phone keypad. All of the “training” is performed outside of the car in normal daily text message usage.

The multi-switch configuration of the device also fulfills a design requirement of accommodating users with varying skills. As users become more proficient, the single key per letter input method eliminates many of the multi-tap inherent problems of cycling past the letter of interest.

The text entry accuracy requirements are addressed by allowing the users to correct their text entries as they type. All of the WPM values are reported as corrected values.

The testing revealed one interesting observation regarding the effect of text correction on response time. While in the multi-tap input mode, one user experienced difficulty in entering the correct text. As the user diverted more attention to text correction, both, their reaction and awareness response times increased. Simultaneously, they had lower text input speeds as they entered and then backspace deleted incorrect entries. The effect of the correction effort on response time and input speed is shown in Fig. 41 below.

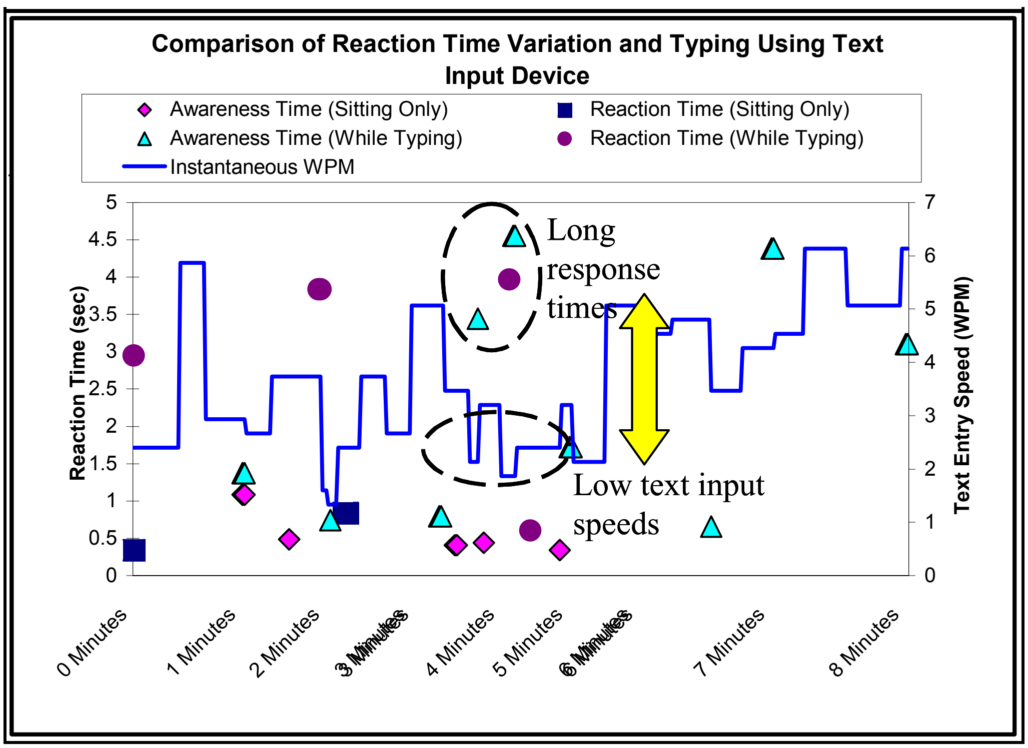


Fig. 41:Text Entry Correction Effect on Response Time and Text Input Speed.

5.1.3 Discussion of Speed Requirements

Speed is an important metric in comparing different input devices. All other things being equal, an input device that is faster to use will be more desirable. The 5 WPM requirement is slow compared to 2 handed touch typists, however it is comparable to cell phone text entry rates.

The average input speed for the device was 5.7 WPM for the multi-switch input method, which satisfies the design requirement. A summary of the text input speeds is shown in Table 11 below.

Input Method	Stationary	Driving	With 3 Hours Practice
Multi-Tap	4.4 WPM	2.3 WPM	
Multi-Switch	5.7 WPM	5.8 WPM	9.7 WPM

Table 11. Summary of Text Input Speeds.

The stationary and driving values represent users with approximately 10 minutes training on the multi-switch input method. To determine the long term potential of the multi-switch method, one user was allowed to practice in a stationary car for approximately 3 hours. The result was a nearly 100% input speed improvement to 9.7 WPM.

The driver will naturally modulate their text entry speeds based on the specific driving situation. The input speed variation is due to the asynchronous nature of text entry. The driver is not obligated to interact with the system as he or she is with synchronous communication methods, such as cell phone conversations. In Fig. 42 and Fig. 43 below, the circled area illustrates the effect of the driver focusing on a demanding driving situation. Both instances are Highway 280 on and off-ramps. These high-speed ramps have sharp corners and require hard braking. While the driver is busy driving, the text entry rate drops to zero until they feel it is safe to resume typing. The driver modulated input is identical regardless of the text input method.

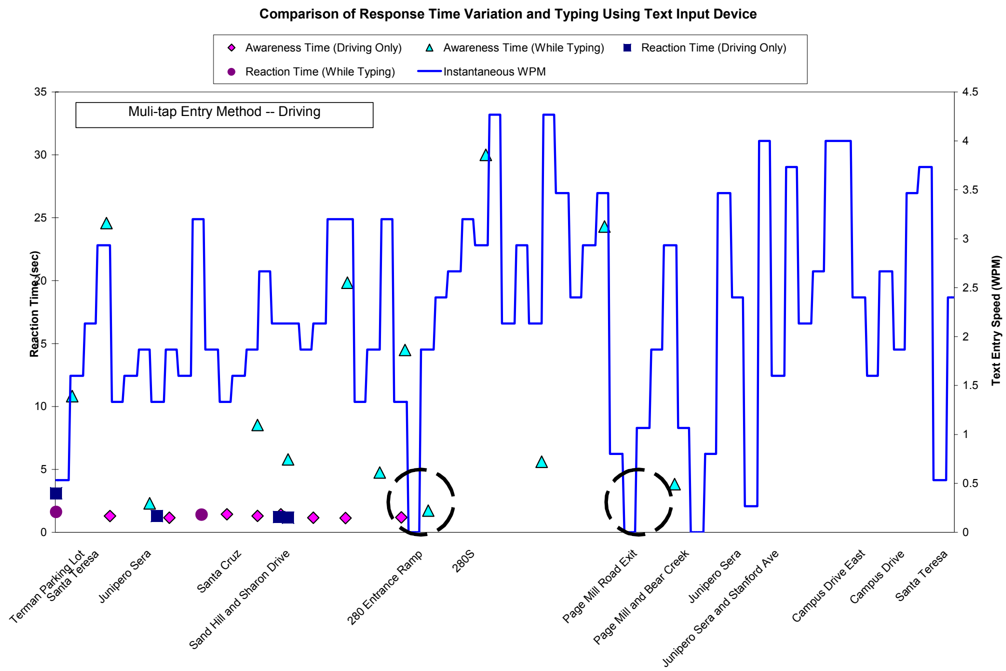


Fig. 42: Multi-tap Text Entry Speed While Driving.

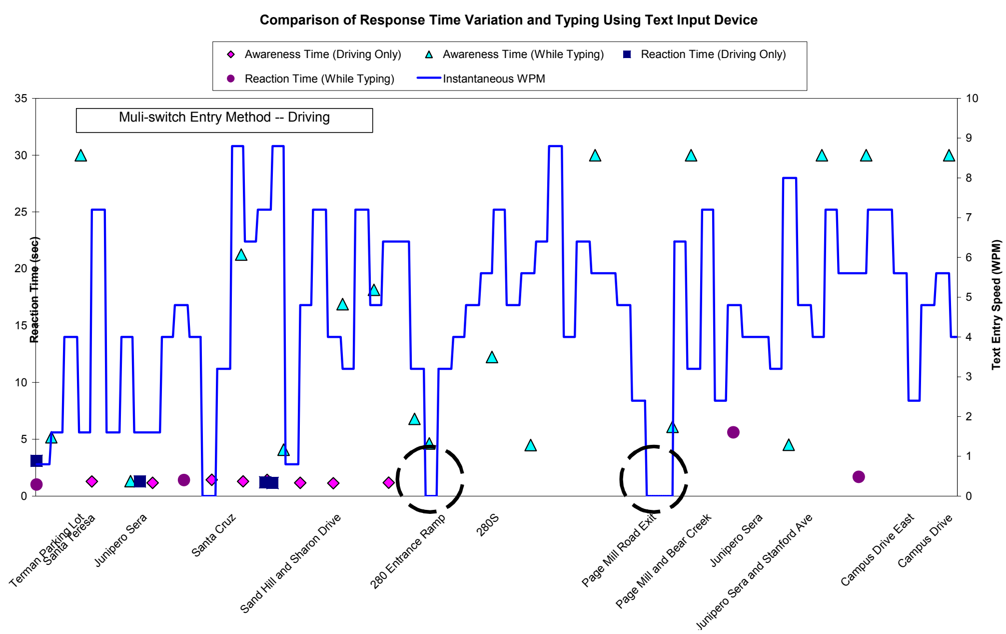


Fig. 43. Multi-switch Text Entry Speed While Driving.

5.2 Physical Specification

Physical Requirements		Physical Specifications
Requirement #	**Requirement**	**Steering Wheel Keyboard**
3.3.1	The Interface must function in car interior environment.	OK
3.3.1.1	Temperature range Operating: 0 to +35C	OK
3.3.1.2	Humidity: 10 to 100% non-condensing	OK
3.3.1.3	Shock	OK
3.3.1.4	Vibration	OK
3.3.1.5	10 year design life	OK
3.3.1.6	No accidental contact due to water, vibration, or other environmental conditions.	OK
3.3.2	The Interface buttons must be large and easily activated.	OK
3.3.2.1	Buttons must be >= 0.5 inches square.	OK
3.3.2.2	Buttons must not be closer than 0.5 inches center to center.	OK
3.3.2.3	Force to press key < 1.47N, per ANSI/HFS 1988-100.	OK
3.3.2.4	Key travel -- 2.5 to 7.5mm for standard keyboards	OK
3.3.2.5	Must be adjustable to be within arms reach. Nominally 14 inches from typical elbow position, with +/- 3 inches of adjustment.	OK
3.3.3	The Interface must provide feedback and confirmation of keystrokes.	OK
3.3.3.1	Feedback from controls should be effectively instantaneous.	OK
3.3.3.2	Must have a sampling rate >= 60Hz.	OK
3.3.3.3	Must provide tactile feedback so user knows button activated.	OK
3.3.4	The Interface must have a defined home position.	OK
3.3.4.1	Must be able to find keys in 2 seconds without looking -- by feel only.	OK
3.3.5	The Interface must be implementable in car environment.	OK
3.3.5.1	Must use standard communication protocols.	OK
3.3.5.2	Must not interfere electromagnetically with other systems.	OK
3.3.5.3	Must accommodate left and right hand drive cars.	OK

Table 12. Physical specification comparison to requirements.

The 5 position switch used in the input device is designed for the car environment, so it inherently meets all of the environmental requirements presented above.

The input device meets all of the physical requirements presented. The device has button sizes and spacings that match well with the requirements. While the joystick style buttons are smaller than the 0.5 inches square requirement, the guiding cone portion of the bezel is within this size requirement.

The 5 position switch used provides a tactile “snap” and “click” when a key is activated, providing a confirmation of keystroke to the user. This confirmation is primarily felt through the thumb, as opposed to an audible confirmation.

The device satisfies the home position requirement with the guiding position of the hand rest on the wheel spoke. While every user will have a slightly different grip on the wheel and keys, the design features take into consideration a wide variety of users. The radial alignment of the keys allow the thumb to comfortably sweep across the keys with a minimum of hand motion. All users attributed to the ergonomic features of the design, stating the device was comfortable to grip and use.

6 Recommendations

6.1 Vision

At the conclusion of the Autumn quarter, Team YTPD Garage proposed the "smart car" design space as a solution for the need of an optimum human machine interface for future in-vehicle subtasks. The original design space was divided into "smart functions" and detection of driver cognitive load and attention. The "smart car" design space is extremely broad and the team decided to investigate "smart functions" which will continue the trend of safely integrating disparate subsystems such as navigation, entertainment and communication.

In the Winter quarter, the team further explored the communication subsection of the "smart car" design space since communication mediums have become more ubiquitous in our daily lives. This need is probably greatest exemplified by members of the IT Generation. As this generation ages and become automobile consumers, there will be a greater demand to eliminate the "information blackout" that occurs when operating current vehicles. Thus, YTPD Garage focused on improving the driver's in-car "connectedness" by designing a text input system that allow drivers to safely input text for short emails or text messages while driving.

During the Spring quarter the team primarily focused on designing and developing an input device to integrate into a vehicle. The team had previously decided to focus on one-handed device, so the product development focused on selecting the location for the device, selecting the text input methods, the design and fabrication of the device, and conducting user testing. The team decided to utilize an LCD display as a stand-in for the output system ideas being investigated by the partners at TMIT. In addition to brainstorming ideas for the output system, TMIT developed the logic core for the stand-in output device. Finally, the team developed a test procedure utilizing an instrumented test vehicle and conducted user testing to evaluate the affect of the text input system on the operator's driving performance.

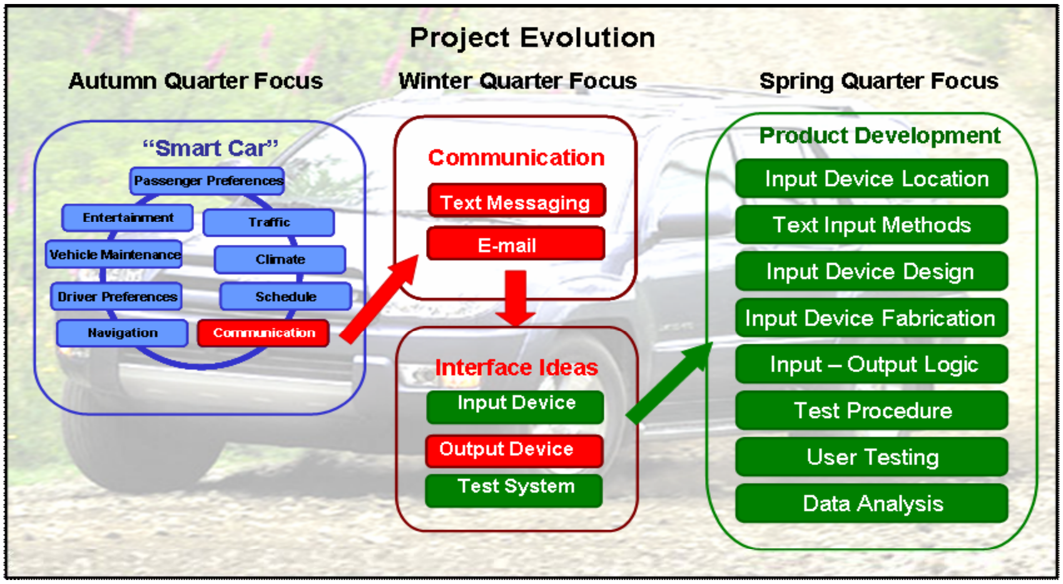


Fig. 44: Schematic of the evolution of the Team YTPD Garage's focus on the project from "smart functions" design space of the "smart car," to focusing on the communication "smart function." The project cycle concludes with the development of an integrated input interface for enabling safe text messaging and e-mail communications between the driver and the world outside of the vehicle, as well as a test system to evaluate the safety and function of the device.

6.2 Enhancements of the Text Input Device System

Handed in-vehicle text entry device is an extremely broad design space. As documented in the previous sections, Team YTPD successfully developed the *Textura 310* steering wheel text input device and accompanying system elements. The development of the *Textura* is a major innovation in the area of handed in-vehicle texting. The interface has unlocked a wealth of exciting research areas to explore related to texting as a future in-vehicle function. These areas include minor refinements to the *Textura* system to make it a more marketable device as well as areas for further in-vehicle texting research.

6.2.1 Refinements of the Textura 310 Steering Wheel for Enhanced Marketability

6.2.1.1 Steering Wheel Manufacturing

The final prototype of the *Textura 310* consists of 2 aluminum machined parts, the steering wheel rim and bezel. Although many users commented on the attractiveness of the aluminum steering wheel, more conventional steering wheel assembly manufacturing methods and materials should be used in the production of additional devices. Using standard processing methods and materials would increase user safety in the case of an accident, and would also reduce the cost of producing the unit.

6.2.1.2 Button Assembly Manufacturing

As with the steering wheel assembly, the button top assembly should be refined further using more standard manufacturing techniques and materials. This would increase the fidelity and finish texture of the button tops. The current design of the button assembly integrates a metallic PC board and IC components into the hub of the steering wheel. Due to safety concerns, different methods of mounting the board and different types of circuit boards should be investigated.

6.2.1.3 Restricting Motion of the Multi-directional Switches

The travel of the multi-directional switches is not restricted purely to the four compass directions. As illustrated in the figure below, the switch may move in the quadrants between compass direction resulting in a 'double hit' of two characters, rather than one. Attempts to physically restrict the motion were unsuccessful during the development of the *Textura* prototype. An alternative approach to restrict the motion would be to 'debounce' the signal from the switch, only accepting the first character.

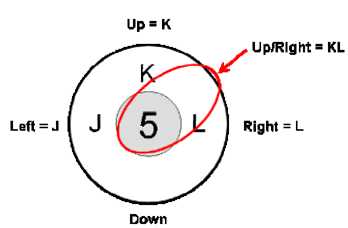


Fig. 45: Example of a 'double hit' resulting from the Multi-directional switch being moved in an non-compass direction

6.2.1.4 Dedicated 'Space,' 'Delete,' and 'Next' Keys

During text entry operation, the keys used most often were the space and delete keys. Currently these keys are integrated into the 12-key layout on the '0' and '#' keys. Since these keys are used so frequently, some users suggested it would be beneficial if 'space' and 'delete' functions were assigned to keys outside of the 12-key layout. Perhaps, these dedicated keys would be larger and in a different shape than the other alphanumeric keys. Users also desired a 'next' key to advance the cursor when using the multi-tap text entry method. The 'next' function could also be assigned to a dedicated key like the 'space' and 'delete' functions. The cursor could also be controlled by alternative input mechanisms like a jog wheel, track stick, or touch pad.

6.2.1.5 Additional Multi-directional Key Layouts

One area the team wanted to explore further, but did not have enough time to incorporate into the user testing was the use of different multi-directional key layouts. The figure below illustrates two different key layout profiles, where the alphabetic sequence assignment begins at different compass point orientations. In addition to varying the orientation of the alphabetic sequence, some users indicated they might be interested in starting the alphabetic sequence on the '1' key rather than the '2' key. It may also be interesting to investigate an alphanumeric layout based on the frequency the characters are used, such as employed in the LessTap cellular phone input method[20].

	.			A			D	
~	1	-	~	2	B	~	3	E
	1			C			F	
	G			J			M	
~	4	H	~	5	K	~	6	N
	I			L			O	
	P			T			W	
S	7	Q	~	8	U	Z	9	X
	R			V			Y	
	TAB			SPACE			~	
~	*	~	~	0	~	~	BS	~
	ENTER			~			~	

	.			B			E	
~	1	-	A	2	C	D	3	F
	1			~			~	
	H			K			N	
G	4	I	J	5	L	M	6	O
	~			~			~	
	Q			U			X	
P	7	R	T	8	V	W	9	Y
	S			~			Z	
	TAB			SPACE			~	
~	*	~	~	0	~	~	BS	~
	ENTER			~			~	

Fig. 46: Example of an 'Up' starting alphabetic sequence profile and a 'Left' starting alphabetic sequence profile for the Multi-directional text entry method.

6.2.1.6 Multi-directional Button/Switch Technologies

In addition to exploring different key layouts, the Multi-directional text entry method could be explored in more depth by investigating different Multi-directional switch activation technologies. Several formal and informal users commented on how they liked the 'feel' of the switches as they latched into the different compass point positions. This physical sensation of the switch keying into position gave the users tactile feedback that the switch had been activated. Other physical methods of Multi-directional application could be explored using 5 distinct miniature push button switches or rubber dome – carbon switches, as well as using a haptic feedback touch surface, such as those being developed by Immersion Corporation[21].

6.2.1.7 '3 – Key/6-Key' Double Hit

A phenomenon observed in a small subgroup of formal and informal users was the simultaneous activation of the '3' and '6' keys. More analysis is need to identify the cause of this problem, but the hypotheses it is a combination of factors can be attributed to the '3-6' double hit including the proximity of these keys to the edge of the steering wheel hub, the size of these key positions, the size of the user's hand, as well as and how the user holds the device.

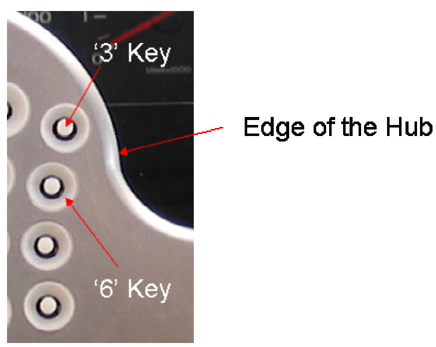


Fig. 47: The proximity of the '3' and '6' to the edge of the center hub of the steering wheel

6.2.1.8 Labeling and Illuminating the Keypad Switches

One issue not addressed in the current *Textura* design is clearly labeling the keypad with information regarding the alphanumeric assignment of the keys. One avenue to pursue would be labeling method to add labels to button tops as well as cones enclosed in the button hole to indicate the alphanumeric assignments/designations as illustrated in the figure below.

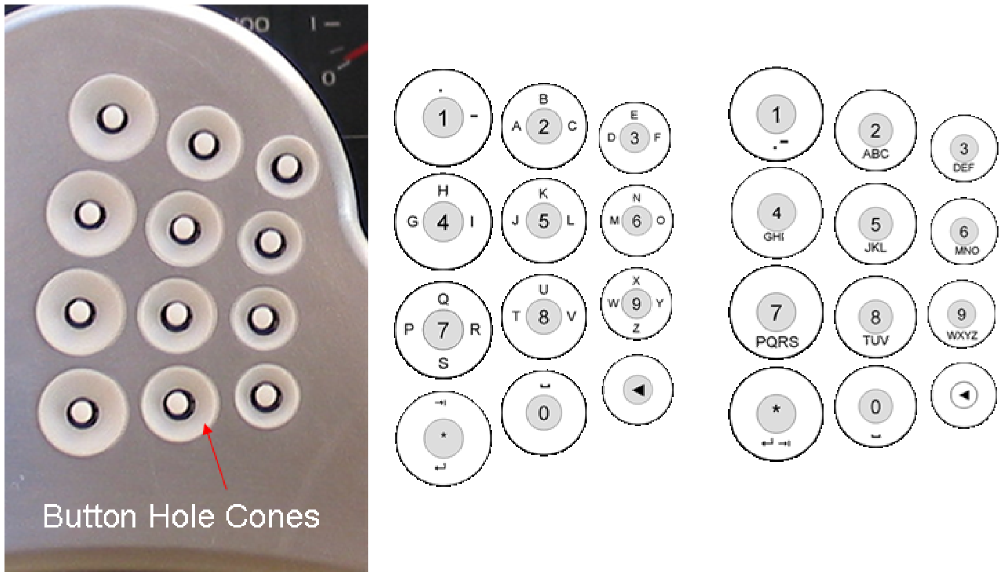


Fig. 48: Example representation of labeling of the keypad switches and button hole cones for multi-directional switch and multi-tap key layouts.

The users indicated that labeling the switches as well as illuminating either the individual switches or labels would greatly enhance the interface, particularly when using the device at night. The labeling method should be easily adaptable to the different multi-tap and multi-directional key layouts.

6.2.1.9 Accommodations for Left and Right Handed Texting

In order to demonstrate the feasibility of in-vehicle texting, the current prototype of the *Textura* is designed for the user to steer with the left hand while either texting and/or steering with the right. In production, the interface should accommodate users who wish to steer primarily with their right hand and text with the left, for example, accommodating vehicles with multiple users with different handedness. This feature could also be used to in vehicles with right side rather than left side driver vehicles. This functionality could be accomplished in a variety of ways, including packaging two separate keypads into the steering wheel or designing a single keypad that might be rotated or slid into a right or left handed position. An alternative avenue would be packaging the keypad as an aftermarket device that the user may attach to the steering wheel.

6.2.1.10 User Profiles and User Defined Text Entry Layouts

One of the characteristics common to car owners as well as members of the IT Generation is the ability to personalize or customize possessions. This is epitomized by user profiles for seating configurations and temperature settings in luxury vehicles and 'skins' and antennae trinkets used to personalize cellular phones. Some observations from the user testing pointed to the fact that different users had different preferences for attributes associated with the text entry layouts and features. A convenient feature to add to the device would be enable different users to define their personal profile for the device, such as the keypad layout and input method

6.2.1.11 Refinement of Input-Output Logic Core

The final prototype of the *Textura 310* utilizes a KeyWiz Eco keyboard emulator. The benefits of using the KeyWiz include the ability to easily configure keypad layouts using a graphical user interface, allowing for the control of the layouts to be done entirely in software as pictured below:

Fig. 49: Screenshot of KeyWiz software used to assign characters to 56 inputs of the KeyWiz Eco keyboard emulator.

Some of the limitations of the KeyWiz, however, include it only has the ability to accept 56 distinct inputs, though the Multi-directional switches have the ability to have 60 outputs, and its necessity of a PS/2 connection. Another shortcoming of the KeyWiz is its limited character set. The KeyWiz only supports English language characters, and it supports a limited range of symbols and punctuation. For instance, it does not support popular text messaging characters such as the '@', '!', '?' symbols. To extend the range of texting possibilities of the *Textura,* alternative keyboard emulation technologies warrant investigation.

6.2.2 Enhancements of the *Textura 310* Test System and Procedures for Additional Research

As previously noted, the Textura 310 represents a huge leap forward in the development of interfaces for texting while driving. The unique entry method, combined with its physical features, makes it the most appropriate text interface for in car use today. While the testing completed and discussed above establishes metrics for the safety of the device, additional improvements to the test system will enable additional insight into the inherent safety features of the interface.

6.2.2.1 Night/Day Testing Operation

The current set-up of the system is optimized for daytime testing, and several components of the system require enhancement in order to better accommodate system testing at night. The surrounding awareness and reaction LEDs were installed because of their intensity and low current draw, which enabled them to be detected during both daytime operation as well as at night when the test vehicle is on the road with the headlights of other vehicles. The result is that at night, the LEDs may be easier to detect than testing conducted during the day. The intensity of the LEDs should automatically be adjusted depending on the light levels in the test vehicle. On the other hand, the reaction button the users must press when the awareness and reaction LEDs are triggered is also more difficult to find at night because it is not illuminated. The button should be illuminated so that it is easier for the users to detect at night. Lastly, the driver and passenger side road observation cameras are mounted in a reflective clear acrylic housing. The ring of infrared LEDs the cameras use during night operation reflect off of the housing, causing glare in the surveillance video which blocks the view of the lane markings. This problem can be addressed by using a less reflective housing or a cover for the ring of infrared LEDs.

6.2.2.2 Permanent Integration of Surrounding Awareness LEDs

In the current design of the instrumented test vehicle, the surrounding awareness LEDs are housed in free standing black acrylic boxes positioned around the interior of the vehicle. Since the housings are not rigidly fastened in place, minor adjustments to the location and orientation of the LED boxes have to be made to enable different users to clearly see the LEDs. A more permanent integration of the side view mirror awareness LEDs into the exterior mirror housing would resolve this issue. This would also better simulate the user checking their side view mirrors. The rear view mirrors could also be permanently fixed in either the housing of the rear view mirror or the interior of the roof inside the vehicle.

6.2.2.3 Development of Independent Surrounding Awareness and Reaction Time System

The reaction time system, simulating the brake lights of a preceding vehicle consist of a cluster of 3 LEDs on the center dashboard of the vehicle and is currently integrated with the surrounding awareness LEDs system. Since reaction time is somewhat different than the surrounding awareness time, decoupling these two systems would be a rewarding enrichment of the test vehicle system. The surrounding awareness system could be adjusted as noted in the previous section. The reaction system could be refined by replacing the LED cluster with three larger LED clusters such as those bicyclists use as brake lights. These three clusters would be placed on the hood of the vehicle, below the line of sight of the driver, on the front driver side, middle and passenger side of the vehicle to simulate objects encroaching in the zone ahead of the vehicle, from either side or directly ahead. In the case stationary testing, the driver's reaction time could be captured by adding sensors to detect evasive or defensive maneuvers of driver, such as steering corrections, and decreases in vehicle speed resulting from the driver stepping on the brake or releasing the gas pedal.

6.2.2.4 Simulation System Testing the Boundaries of the *Textura 310*

Based on the limited in vehicle testing conducted, the following boundary conditions have preliminarily been identified as safe to use the *Textura*: 'stationary' vehicles, some highway use (i.e. during traffic), and when the driver is using cruise control. The design of the *Textura* naturally limits the user for texting while performing intense driving maneuvers; however, there are several conditions that cannot be safely emulated by using the instrumented test vehicle to qualify this boundary. Such scenarios include adverse weather conditions, poor road conditions, or other situations that may require rapid steering. In these conditions, the use of a driving simulator rather than the test vehicle is warranted. Other scenarios which merit the use of a driving simulator include testing the device subjects who are inexperienced drivers or do not have a valid driver's license. Another interesting use of a driving simulator, would be to evaluate the effect of the *Textura* input system in combination with known in-vehicle distractions, such as talking on a cell phone, interacting with the vehicle entertainment system, engagement with passengers in the vehicle, and eating in the vehicle. All of these scenarios would help to further identify the boundaries between safe and unsafe use of the *Textura*.

6.2.2.5 Integration of Data Acquisition Programs into a Single Program

Currently, the instrumented test vehicle collects the following information, each with its own dedicated data acquisition program: time stamped character entries, GPS information (vehicle speed and position), LED reaction and awareness times, and video data. Assembling each of these independent systems as well as relating the acquired data is time consuming. In the next iteration of the vehicle, a single data acquisition program, such as Lab View[22] should be used to collect, relate, and analyze the data.

6.2.3 Output Feedback Algorithm Proposed by TMIT

The complement to the *Textura* 310 input device is an output system consisting of an algorithm for providing feedback to the user in addition to the output device. While Team YTPD garage lead the design of the input device, the TMIT team focused on developing the foundation for the feedback algorithm. The design of the algorithm is equally if not more important than the selection of an output device in order to prevent the user from being unduly distracted by the confirmation of the keyed text entry. Some of the initial key considerations in the designing the feedback system algorithm include:

- Identifying in what driving conditions the user should be provided with different types of feedback (i.e. when the vehicle is stationary, when the vehicle is moving above 60 km/h, etc.)
- Identifying the rate at which the user should be provided with feedback with respect to correcting the text entered (i.e. after each character, after each word, after each sentence, combinations there of, etc.)
- Identifying which methods of output should be provided to the user and when (i.e. visual display such as HUD or audio confirmation via text-to-speech technology)

TMIT has proposed the following feedback methods based on the following input modes derived from low to high safety considerations:

- Unrestricted text input mode – the user is free to enter text because the vehicle is stationary (low to no danger level), and receives only visual feedback. The user is also free to choose any feedback rate and correction method.
- Regular text input mode (mid-level danger) – the user is free to enter text during a mid-level safety scenario and visual feedback is provided after each character. The user is concerned with the grammar and spelling of the text entry, thus an audio feedback method is used after each word to check for spelling and grammar.
- 'Hurry' text input mode (mid-level danger) – the user is free to enter text during a mid-level safety scenario and audio feedback is provided after each character. The user is not as concerned with making mistakes, so the misspelled words are visually displayed and the user decides whether or not to correct the mistake.
- Regular text input mode (high risk danger level) – the user is free to enter text, but there is no real-time visual display of input, only audio feedback after each character. The user is concerned with grammar and spelling of the text entry, thus once again audio feedback is used after each word to check for spelling and grammar.

- ‘Hurry’ text input mode (high risk danger level) – the user is free to enter text, but there is no visual display of input, only audio feedback after an entire sentence is entered. Correcting mistakes is not allowed.

The context for feedback algorithm outlined above is summarized by the following figure:

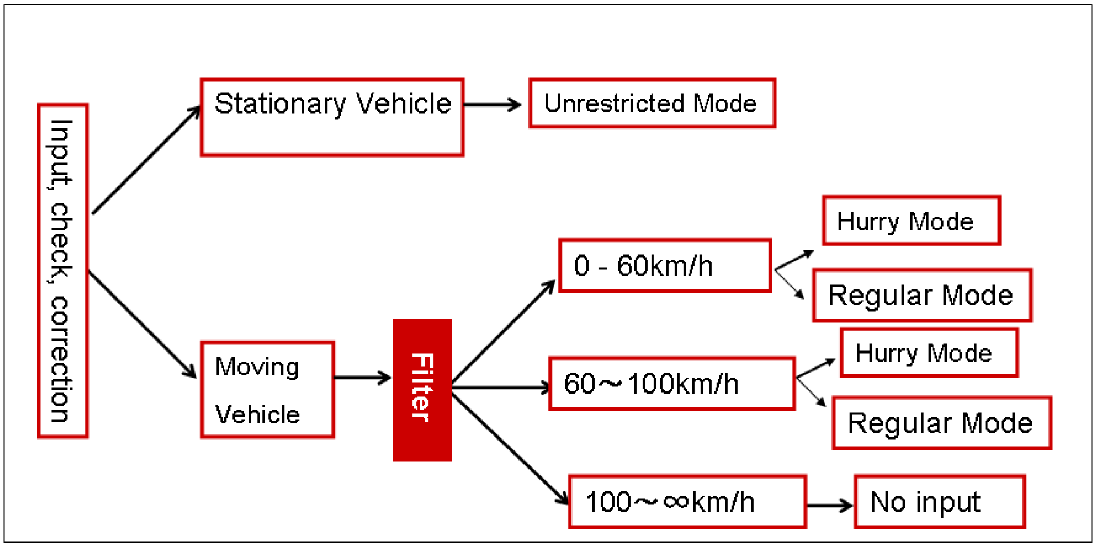


Fig. 50: Flow diagram outlining an example of the input modes (hurry, regular, unrestricted, and no input) that will correspond to different methods of output feedback and correction ability for the user to correct the text input.

An additional feature of the TMIT envisions is a feedback filter included in the algorithm. The filter would optimize such parameters as the size, color, and character refresh rate of the visual display character depending on the age, gender, and skill level of the user.

6.2.4 Recommended Extensions of the Textura System

6.2.4.1 Extending the System Commercial Vehicles and Emergency Service Vehicles

One place where the *Textura* system could possibly be implemented in the near future is as an input and output data entry interface system for use in commercial and emergency vehicles. Currently, these systems consist of QWERTY and LCD displays which are most effective when the driver is in a stationary vehicle. The *Textura* system could be used to replace these set-ups, enabling the users to do data entry while driving.

6.2.4.2 Extending the Functionality of the *Textura* Input System for Impaired Drivers

The unique layout of the keypad on the *Textura* enables a user to operate 12 distinct switches, representing 60 different inputs within the sweeping arc of their thumb. This functionality could be used to develop assistive steering devices for impaired drivers by mapping other vehicle controls, such as entertainment controls, navigation controls, and environmental controls for instance to the 12 multi-directional switches on the keypad. Another possible assistive technology extension of the device would be utilizing the system as a replacement for existing in-vehicle voice recognition interactions, such as navigation control, for hearing impaired individuals.

6.2.4.3

7 Project Planning

The Spring Quarter phase of the Toyota Optimum Human Machine Interface project was budgeted to be completed in 75 days with expenditures not to exceed a $15,000 budget (including previous quarter expenditures). The overall project was completed on time, however costs exceeded the budget by approximately 15%.

There were several major milestones for this project. The milestones included both presentations and design document deliverables.

Fig. 51 below identifies the milestones for this project. All of the milestones were completed on schedule.

ID	Task Name	Duration	Actual Start	Actual Finish
1	**ME310BC Toyota Project Plan**	**156 days**	**Tue 1/6/04**	**NA**
2	**Assignment Milestones**	**147 days**	**Thu 1/15/04**	**NA**
12	Assignment 11: final Deliverables Contract Due April 2	0 days	Wed 5/26/04	Wed 5/26/04
13	Assignment 13: Course Review Tues May 4, 6:15pm	0 days	Tue 5/4/04	Tue 5/4/04
14	Assignment 20: Parting Shots & disposal Due Thurs June 10th	0 days	NA	NA
101	**Design Input Interface**	**50 days**	**Thu 4/1/04**	**NA**
118	**Design Output Interface**	**38 days**	**Fri 3/26/04**	**NA**
126	**Procure Input Interface**	**31 days**	**Sun 4/18/04**	**NA**
133	**Build Final Input Interface**	**27 days**	**Fri 4/23/04**	**NA**
140	Test Final Interface	13 days	Sun 5/16/04	Fri 5/28/04
141	Assignment 14: Penultimate Hardware Reviews preview May 18, Rev	0 days	Tue 5/18/04	Tue 5/18/04
143	Deliver System to Client	1 day	Tue 6/1/04	Tue 6/1/04
149	Assignment 15: Penultimate Documentation Due Mon, May	0 days	Fri 5/28/04	Fri 5/28/04
150	Assignment 16: Final Brochures for EXPE Due Wed May 2	2 days	Wed 5/26/04	Thu 5/27/04
151	Assignment 17: Draft Final Document due May 28, 5pm	0 days	Fri 5/28/04	Fri 5/28/04
152	Assignment 18: Final Presentations & EXPE June 1, 3	0 days	Tue 6/1/04	Tue 6/1/04
153	Assignment 19: Final Documents (various hard, soft copies)	0 days	Mon 6/7/04	Mon 6/7/04

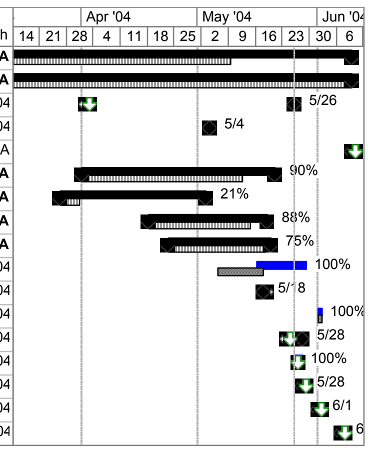


Fig. 51: Critical Milestones for Toyota Optimum Human Machine Interface Project.

7.1 Project Time Line

The overall project was completed on time, however not all of the tasks were completed as baselined in the original project plan. Some tasks started early, while many ran longer in duration that originally anticipated. Most of the extended durations are due to cyclical task iterations and project scope and direction changes. For example, the design/build/test cycle for prototypes was repeated many times with each cycle lengthening the overall task duration. The final testing approach was also modified in late May to eliminate user road testing. This late change extended the test documentation efforts far beyond the original completion dates. Resources were shifted between various YTPD Garage tasks to ensure the overall schedule and critical milestones were met.

The entire project plan, identifying baseline versus actual performance, is shown in Fig. 52 below. For each task, the gray bar on the bottom is the baseline duration. The blue bar on top is the actual duration.

ID	Task Name	Duration	Actual Start	Actual Finish
1	**ME310BC Toyota Project Plan**	**156 days**	**Tue 1/6/04**	**NA**
2	**Assignment Milestones**	**147 days**	**Thu 1/15/04**	**NA**
12	Assignment 11: final Deliverables Contract Due April 2	0 days	Wed 5/26/04	Wed 5/26/04
13	Assignment 13: Course Review Tues May 4, 6:15pm	0 days	Tue 5/4/04	Tue 5/4/04
14	Assignment 20: Parting Shots & disposal Due Thurs June 10th	0 days	NA	NA
15	**Winter Quarter**	**61 days**	**Tue 1/6/04**	**Sat 3/6/04**
74	**Travel**	**67 days**	**Sun 1/18/04**	**Wed 3/24/04**
76	Stanford Visit to TMIT	8 days	Wed 3/17/04	Wed 3/24/04
77	**Meetings**	**48 days**	**Tue 4/6/04**	**Mon 5/24/04**
78	4/6 TMIT videoconference	0 days	Tue 4/6/04	Tue 4/6/04
79	4/13 TMIT & TMC & ITC videoconference	0 days	Tue 4/13/04	Tue 4/13/04
80	4/20 TMIT videoconference	0 days	Tue 4/20/04	Tue 4/20/04
81	4/27 TMIT & TMC & ITC videoconference	0 days	Tue 4/27/04	Tue 4/27/04
82	5/4 TMIT videoconference	0 days	Tue 5/4/04	Tue 5/4/04
83	5/11 TMIT & TMC & ITC videoconference	0 days	Tue 5/11/04	Tue 5/11/04
84	5/18 TMIT videoconference	0 days	Tue 5/18/04	Tue 5/18/04
85	5/24 TMIT videoconference	0 days	Mon 5/24/04	Mon 5/24/04
86	**Design & Build Another Optimum Interface (Final Prototype)**	**63 days**	**Thu 3/25/04**	**NA**
87	**Testing Issues**	**63 days**	**Thu 3/25/04**	**NA**
88	**Testbed Shakedown**	**63 days**	**Thu 3/25/04**	**Wed 5/26/04**
89	Complete Driver Attention Module	47 days	Thu 3/25/04	Mon 5/10/04
90	Add functionality to data collection software	0 days	Thu 3/25/04	Thu 3/25/04
91	Data analysis methodology	5 days	Thu 3/25/04	Mon 3/29/04
92	Write detailed test procedure	55 days	Fri 4/2/04	Wed 5/26/04
93	**Simulator Software**	**7 days**	**NA**	**NA**
94	Install on PC	2 days	NA	NA
95	Learn software protocols	5 days	NA	NA
101	**Design Input Interface**	**50 days**	**Thu 4/1/04**	**NA**
103	**Iteration #1**	**5 days**	**Thu 4/1/04**	**Mon 4/5/04**
104	Design interface	5 days	Thu 4/1/04	Mon 4/5/04
105	Test interface	1 day	Mon 4/5/04	Mon 4/5/04
106	Evaluate interface	1 day	Mon 4/5/04	Mon 4/5/04
107	**Iteration #2**	**8 days**	**Thu 4/8/04**	**Thu 4/15/04**
108	Design interface	8 days	Thu 4/8/04	Thu 4/15/04
109	Test interface	1 day	Thu 4/15/04	Thu 4/15/04
110	Evaluate interface	1 day	Thu 4/15/04	Thu 4/15/04
111	Assignment 12: TAFKAMAD due April 20, 22	0 days	Tue 4/20/04	Tue 4/20/04
112	**Final Design Modifications**	**36 days**	**Thu 4/15/04**	**NA**
113	Design PCB	31 days	Thu 4/15/04	Sat 5/15/04
114	Design Keypad	36 days	Thu 4/15/04	Thu 5/20/04
115	Interconnection design	15 days	Sun 4/18/04	Sun 5/2/04
116	Design Interface box	12 days	Tue 4/20/04	Sat 5/1/04
118	**Design Output Interface**	**38 days**	**Fri 3/26/04**	**NA**
119	Implement Backspace Function	10 days	Fri 3/26/04	Sun 4/4/04
126	**Procure Input Interface**	**31 days**	**Sun 4/18/04**	**NA**
127	Fab PCB	16 days	Mon 5/3/04	Tue 5/18/04
128	Fab kepad	11 days	Wed 5/5/04	Sat 5/15/04
129	Order switches	5 days	Sun 4/18/04	Thu 4/22/04
130	Order cable parts	12 days	Tue 4/20/04	Sat 5/1/04
131	Order Interface box parts	5 days	Sun 5/2/04	Thu 5/6/04
133	**Build Final Input Interface**	**27 days**	**Fri 4/23/04**	**NA**
134	Build PCB	1 day	Tue 5/18/04	Tue 5/18/04
135	Build Keypad	1 day	Tue 5/18/04	Tue 5/18/04
136	Build Interconnection system	1 day	Fri 5/7/04	Fri 5/7/04
137	Build Interface box	1 day	Fri 4/23/04	Fri 4/23/04
139	Assemble Full System	2 days	Tue 5/18/04	Wed 5/19/04
140	Test Final Interface	13 days	Sun 5/16/04	Fri 5/28/04
141	Assignment 14: Penultimate Hardware Reviews preview May 18, Rev	0 days	Tue 5/18/04	Tue 5/18/04
142	**Deliver Optimum Interface**	**93 days**	**Sat 3/6/04**	**Mon 6/7/04**
143	Deliver System to Client	1 day	Tue 6/1/04	Tue 6/1/04
148	**Deliver Spring Documentation**	**12 days**	**Wed 5/26/04**	**Mon 6/7/04**
149	Assignment 15: Penultimate Documentation Due Mon, May	0 days	Fri 5/28/04	Fri 5/28/04
150	Assignment 16: Final Brochures for EXPE Due Wed May 26	2 days	Wed 5/26/04	Thu 5/27/04
151	Assignment 17: Draft Final Document due May 28, 5pm	0 days	Fri 5/28/04	Fri 5/28/04
152	Assignment 18: Final Presentations & EXPE June 1, 3	0 days	Tue 6/1/04	Tue 6/1/04
153	Assignment 19: Final Documents (various hard, soft copies)	0 days	Mon 6/7/04	Mon 6/7/04

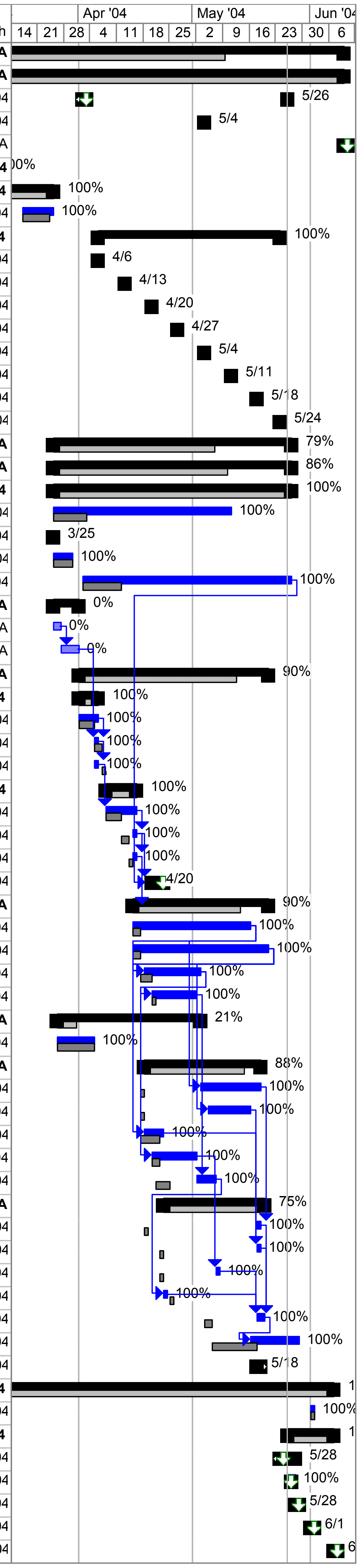


Fig. 52. Complete Project Plan for Toyota Optimum Human Machine Interface Project..

7.2 Project Budget

The total project expenditures exceeded the project budget by approximately 15%. The total project budget was $15,000, while expenses exceeded $17,000. The cost overrun can mainly be attributed to higher than anticipated travel expenses, along with additional outsourced parts for the final prototype.

Only expenditures for hardware and travel are considered project costs. Labor expenses and utilities are not considered in the project cost. The project expenses are broken down to provide detail on the amount and % of total expense for each prototype phase. Non-specific prototype costs are included in the Overhead category, which includes working meals, non-prototype specific supplies, printing and binding expenses, etc.. The project expenditures are summarized in Table 13 below and itemized in the appendix section 9.11.

Project Phase	Amount	% of Total	Winter	Spring
Critical Function Prototype	$ 173	1%	$ 173	$ -
First Functional Prototype	$ 519	3%	$ 519	$ -
Second Functional Prototype	$ 1,964	13%	$ 1,763	$ 201
Final Prototype	$ 7,942	53%	$ -	$ 7,942
Travel Expenses	$ 4,758	32%	$ 1,813	$ 2,945
Overhead (meals, non-prototype supplies, printing and binding)	$ 1,820	12%	$ 842	$ 978
Total Project Expense	**$ 17,176**	115%	$ 5,110	$ 12,067

Table 13: Summary of Project Expenditures.

The total travel expenses exceeded expectations, contributing to the cost overrun. The airline tickets to Japan were purchased in the Winter quarter, but the lodging and meals were not expensed until after the trip. Lodging and meals comprised approximately 62% of the total travel expenses.

The final prototype included additional outsourced parts that were not included in the original expectations. The steering wheel and bezel for the keypad combined for almost $6,000, approximately 75% of the total cost of the final prototype. These parts were needed to satisfy both the safety needs of road testing, and the fit and finish expectations of the final prototype.

8 Resources and Reference Materials

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34. IO2 Technology – Technology: http://www.io2technology.com/technology.htm
35. How Stuff Works – Augmented Reality: http://www.io2technology.com/technology.htm
36. How Stuff Works – First-Down Line: http://entertainment.howstuffworks.com/first-down-line.htm/printable
37. How Stuff Works – How Bluetooth Works: http://electronics.howstuffworks.com/bluetooth.htm/printable

8.2 Resources Consulted

- Steve Choate, Stanford Alumni • steve.choate@endwave.com
- Mark Cutkosky, Professor • cutkosky@stanford.edu
- Larry Leifer, Professor • leifer@cdr.stanford.edu
- Machiel van der Loos, Consultant Professor • vdl@stanford.edu
- Lawrence Neeley, Teaching Assistant • wlneeley@stanford.edu
- Chuck Niemoth, Teaching Assistant • cniemoth@stanford.edu
- Doug Platt, CyKey Developer • dplatt@aptalaska.net
- Vic Scheinman, Consulting Professor • vds@stanford.edu

8.3 Vendors

Amazon.Com

1600 East Newlands Dr.

Fernley, NV 89408

Fry's Electronics

1077 East Arques

Sunnyvale, CA 94085

(408) 617-1300

Fry's Electronics

340 Portage Ave.

Palo Alto, CA 94306

(650) 496-6000

Groovy Game Gear

www.groovygamegear.com

Halted Specialties

3500 Ryder St

Santa Clara, CA 95051

(408) 732-1573

Home Depot

480 E. Hamilton Ave.

Campbell, CA 95008

(408) 866-1900

Home Depot

1781 East Bayshore Road

East Palo Alto, CA 94303

(650) 462-6800

Jameco Electronics

1355 Shoreway Road

Belmont, CA 94002

(650) 592-8097

Kmart

1155 Veteran's Blvd

Redwood City, CA 94063

(650) 364-7640

MegaSharp.com

P.O. Box 651

Craig, AK 99921

(907) 755.2594

Napa Auto Parts

1347 West El Camino Real

Mountain View, CA 94041

(650) 968-1651

Orchard Supply Hardware

777 Sunnyvale Saratoga

Sunnyvale, CA 94037

(408) 732-7734

PCBexpress, a division of ECD, Inc.

13626 S. Freeman Road

Mulino, OR 97042

Fax: 503-829-5482

www.pcbexpress.com

SageHill Engineering

Machining & Fabrication Services

180-4 Constitution Drive

Menlo Park, CA 94025

Sharon Heights Shell

125 Sharon Park Drive

Menlo Park, CA 94025

Sommer & Maca

870 Aldo Ave.

Santa Clara, CA 95054

Systems Technology, Inc.

13766 South Hawthorne Blvd.

Hawthorne, CA 90250-7083

(310) 679-2281

Tangible Designs

CNC Fabrication

808 Burlway Rd,

Burlingame, CA 94010

(650) 401-6988

TAP Plastics Inc.

312 Castro Street

Mountain View, CA 94041

Target

555 Showers Dr.

Mountain View, CA 94040-1432

(650) 965-7764

Walgreens

1570 West Campbell Ave.

Campbell, CA 95008

9 Appendices

9.1 Team Composition Personality Profile

Each member of the team completed a leadership questionnaire based on the work of Doug Wilde as well as a Myers-Briggs personality preference inventory. The results of these personality preference evaluations illustrate that YTPD Garage is a fairly well balanced team:

- Tori is a Ne*Ti with a NORTH *(INFP)* personality preference.
- Dave is a SeFi with a CENTRAL *(INTP)* personality preference.
- Philipp is a SiTe* with a WEST *(ISTJ)* personality preference.

```
####################################
#                50                #
#         (Is)####|####(In)        #
#      Inspector##|##Strategist    #
#       #\########|########/       #
#      ####\#|#####|######/        #
#  (Si)#####\####|####/##     (Ni) #
# Investigator\##|##/####Visionary #
#  #############\|/#######         #
#-50 --------Observer----------- 50#
#               /|\#######         #
# MockupMaker /  |##\##Innovator   #
#  (Se)      /   |####\##     (Ne) #
#           /    |##### \          #
#         /      |       \         #
#      TestPilot |  Entrepreneur   #
#         (Es)   |     (En)        #
#               -50                #
####################################
```

```
####################################
#                50                #
#         (It)####|####(If)        #
#       Reviewer##|##Critic        #
#       #\########|########/#      #
#      ####\######|######/####     #
#  (Ti)#####\####|####/######(Fi)  #
# Simulator###\##|##/###Needfinder #
#  #############\|/#############   #
#-50 --------Mediator----------- 50#
#  #############/|\                #
# Scheduler###/##|  \  Conciliator #
#  (Te)#####/####|    \       (Fe) #
#      ####/ #####|     \          #
#       #/        |      \         #
#     Coordinator |    Diplomat    #
#         (Et)    |    (Ef)        #
#               -50                #
####################################
```

Fig. 53: Graphical illustration of the team's personality composition.

9.2 Benchmarking

9.2.1 Vehicle Interfaces

9.2.1.1 Audi MMI

The Audi Multimedia Interface (MMI) is the interface, which is currently used in Audi's A8 and the new A6 and in a slightly modified version also in Volkswagen's Phaeton and Touareg.

MMI consists of a retracting screen in the middle of the center console, a knob just afterward the gear selection lever, eight hard buttons and four soft buttons in addition to a "return" button as displayed in Fig. 54.

Fig. 54: Picture of Audi MMI Interface[23]

The hard buttons allow the user to select between Radio, CD/TV, Internet, Phone, Navigation, Traffic Information and Car Settings. The eighth hard button "Setup" can be used in conjunction with any of the other buttons for more advanced setup operations such as programming the address book. The four soft keys surrounding the main controller are used to select the option displayed graphically on the screen as shown in the screenshot below:

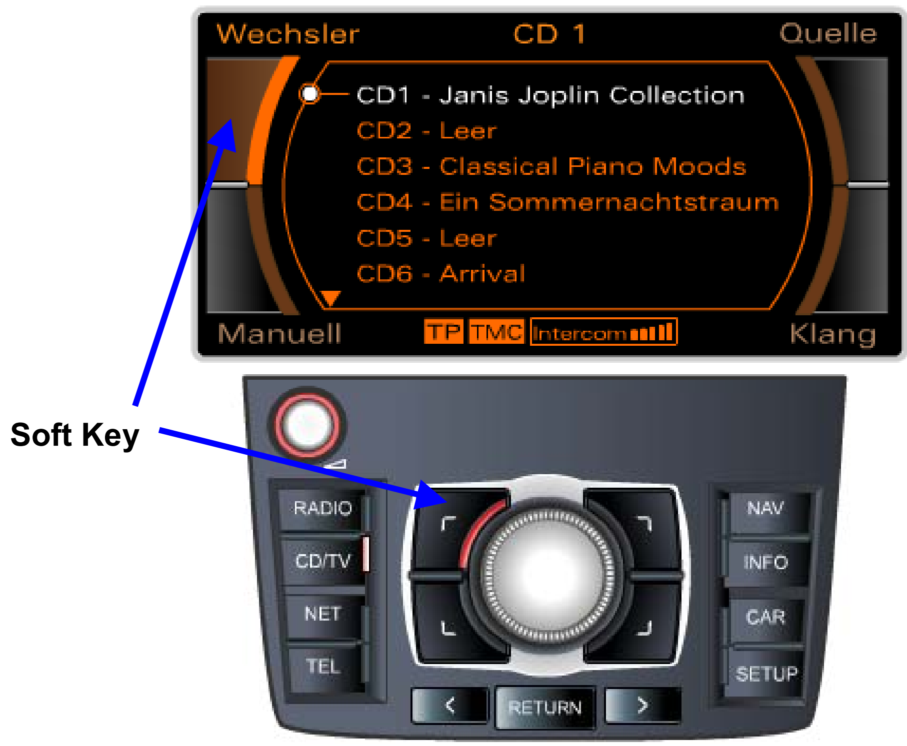


Fig. 55: Screenshot of MMI Display with Soft-Keys[24]

Once the desired menu is selected using a combination of the hard and soft keys, the operator can scroll through the menu by turning the main controller and select items by pressing it downwards. So if one wants to change the radio station, he/she hits the "radio" button, and the screen changes to the show the available options. At this main function screen, the main knob is turned to scroll through the various available stations and pushed down for selection. To get to another function, like the CD player, the dedicated button is to be selected in a similar fashion.

The system seems to work well because there are no long hierarchical trees to meander through in order to get to the desired menu. The "hot keys" act like bookmarks, and take one directly to the appropriate screen, thus eliminating "up/down" and forward/back" actions.

Another feature is the option to fold the screen away and not use the main knob. In that mode, there is a small screen in the gage cluster that shows mileage, temperature, navigation commands. All minor selections such as dialing numbers out of the phone book or selecting radio stations can be done on here too. Two small roller wheel and buttons on the steering wheel are to be used for selection in this mode, which is also available as a secondary display when the main display is used.

The system, however, still requires a great deal of visual attention to use, since the screen is in the middle of the dashboard and thus still not in the line of vision of the driver.

Other impressions and features:

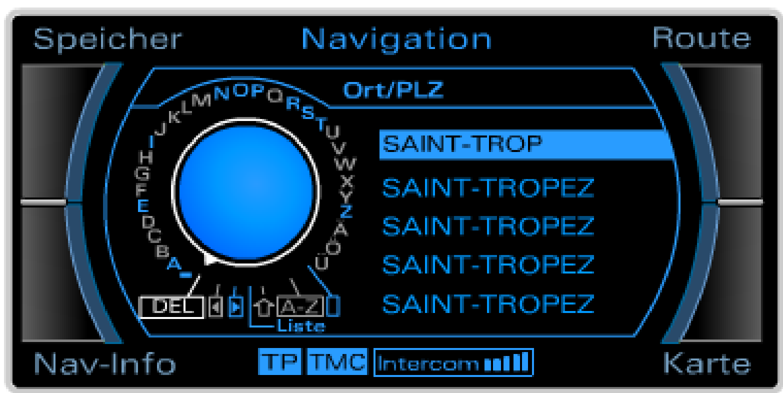
- Radio has a dynamic station list (with frequencies and station name)
- Return button allows user to go back to previous screen instead of having to start at the top of the menu every time.
- Navigation system
    - Initially shows current position on map
    - The destination name is entered using a dial keypad and only selectable letters are shown while a list on the right updates automatically to allow quick selection before the destination is completely spelled out.
    - 

Fig. 56: MMI Screenshot showing dial keypad, selectable letters, and quick selection list on right[24]

-
    - Once the destination city is selected, the user can choose between particular street addresses or select types of destinations such as city center, airports or hotels as displayed on the screen.
    - While using the map one only needs to turn the main knob to zoom.
    - Audible and pictorial commands (both on the primary and secondary screen) are used to direct the driver to the destination.

- MMI states upon startup that Audi is not responsible for any consequences resulting from the operation of MMI and warns the driver not to use the system while driving.
- Roller switches on steering wheel are easy to use and intuitive.
- Volume can be adjusted on the steering wheel (roller switch) and on the center console with the knob highlighted in Fig. 57.

Fig. 57:Center console volume adjust knob[23]

- The drive mechanism on the foldout LCD is quite noisy and thus seems too rickety for a car in this class.

9.2.1.2 BMW I-Drive

I-drive is the interface used by BMW in two different versions in the 7series and the 5series. A picture of the system used in the 7series is shown below:

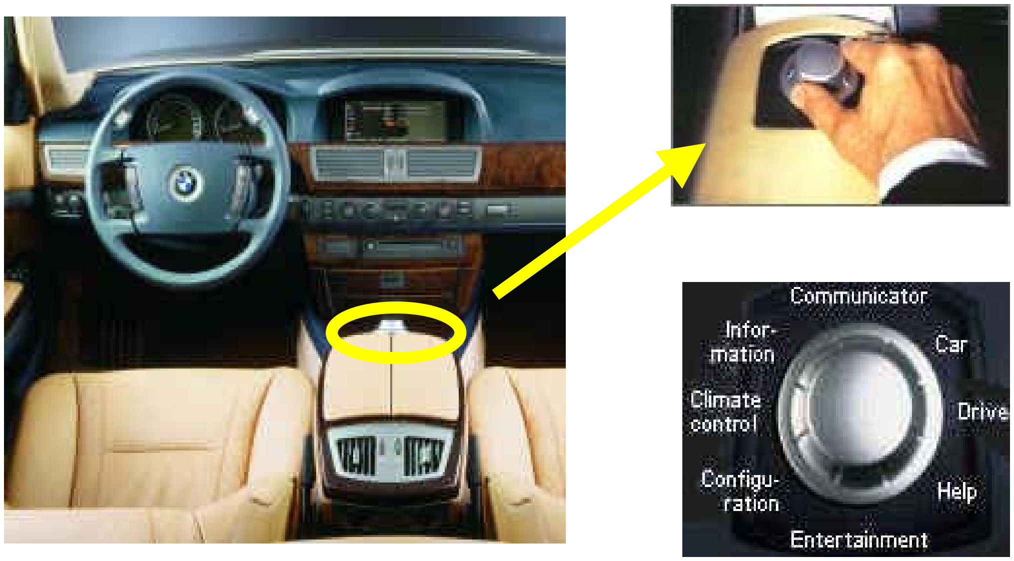


Fig. 58: BMW's I-Drive as used in the 7series[25]

I-Drive consists of a multi-directional knob, which is shifted and rotated to deliver command and an LCD screen in the center of the dashboard. The two versions of I-Drive differ in complexity with the more complex version installed in the 7series and a simplified version in the 5series.

Starting from the main menu the 7series's version has 8 options available as shown on the right in the figure above. These 8 options are accessed by shifting the control knob in the specific direction of a category (i.e. shift up for navigation menu). After accessing a specific category, sub-categories can be chosen. The system is list driven, and the user must go through a complete tree structure before the final command can be delivered. For example, to change the heating distribution in a 7-series right seat, the following command sequence would take place:

Action	**Result**
hit menu button	system goes to main menu, 8 options available
shift left, choose interior	screen goes to interior menu
shift down to heated seat opt	places cursor on heated seat option
push knob inward	selects heated seat option
shift right	places cursor on right seat
push knob inward	selects right heated seat for adjustment
rotate left/right	change distribution +/- to preference
push knob inward	approve change

The 5-series version of I-drive works the same, but has less options, which makes the system more simple. Overall, one cannot go as "deep in the menus" as in the 7series' version.

In conclusion, the system allows a lot of detailed control over the vehicle but one can easily get lost in the deep hierarchy of menus. Since there is no return button, one must always start from scratch in order to get into a different submenu. In addition, the multidirectional knob is easily moved to the wrong point since it is difficult to differentiate movement in 45 degree angles, especially while driving. This is improved in the 5series' system with only four main options and thus only four directions to chose from. Advantages of the system are the force feedback in the control knob and the split screen, which allows the display of two functions at the same time as shown in the picture below:

Fig. 59: BMW I-Drive split screen showing Park Distance Control and navigation map at the same time[26]

9.2.1.3 Mercedes-Benz Command System

Mercedes Benz uses the Command System, a much more traditional approach to driver-vehicle interfacing, for all of its cars. The system consists of a screen surrounded by button in dashboard between the front seats at the place where radios are traditionally placed as shown below.

Fig. 60: Mercedes-Benz Command System[27]

The Command System appears much less high-tech and has fewer options and menus to select from. This makes it much more simple to use at first, especially for people who are not used to the "windows" pattern of most modern computers. Due to the limitation of menu options and the use of more buttons (see figure below) than either I-Drive or MMI, the system can quickly become more confusing; particularly when the user attempts to perform setup tasks. In addition, the placement of the screen and the small size of the buttons require the driver to fully look away from traffic when using the system, thus posing a great risk.

Fig. 61: Close-up of Mercedes-Benz Command System[27]

9.2.1.4 OnStar

OnStar is a technology developed by General Motors that incorporates emergency assistance, theft protection and many other features. The interface consists of three buttons only as displayed below:

Fig. 62: OnStar interface in roof module of Audi A8[28]

The OnStar systems consists of a vehicle equipped with the interface, GPS, a cellular phone, the control system and a central service station. It is operated almost solely through voice as explained in the following description of the three buttons:

The button with the blue OnStar symbol (A) is used to connect to the OnStar service center. The service center can provide roadside assistance, directions or give the caller restaurant recommendations based on their current position. In addition, the user can obtain sports or stock information using a voice-operated menu. The first options are available through a human operator on the other end while the later are only recorded messages.

The red emergency button (B) is used to connect to the nearest emergency station (911). This feature is also activated automatically if any of the airbags deploy. In this case, the vehicle automatically transmits its position to the emergency station and emergency crews are ordered to rush to the scene.

The third button with the dot on it (C) activates the voice activated cellular phone. Once the button has been pushed, the driver can speak the name of the contact to be called from the address book or speak the numbers and the system automatically makes the connection.

The OnStar system incorporates many of the features that are usually found in luxury vehicle navigation systems through a simple interface and relies almost entirely on voice recognition. The system is available for almost all new cars sold in North America but requires a monthly subscription fee after the first year of free service has expired.

9.2.1.5 Summary of Vehicle Interface Benchmarking

All of the current vehicle interfaces create an immense amount of distraction for the driver. The least distracting interface is OnStar, which is primarily voice activated.

The complex menus in all cases require the users to familiarize themselves with the interface. This process is rather short in the case of the Audi MMI interface – especially since one can always return to the previous screen using "return" – and takes the longest in the complex and deep hierarchical structure of BMW I-Drive where one always needs to start from the top.

Similarly, the location and layout of the screen in the center of the dashboard is a good solution but still distracts the driver. The screen used by Mercedes-Benz is positioned far too low but even the other concepts require the driver to take the eyes off the road. The side-by-side screen used by BMW provides the driver with two sets of information and thus reduces the distraction caused by searching for the button to switch back and forth between displays.

OnStar eliminates this problem in a simple way by removing the screen and using two-way voice as the input and output. This, however, might make the driver not use the system whenever there is a passenger in the car because it does not allow for conversations at the same time.

Testing of the various interfaces has shown that there is no such thing as a perfect system even though everyone agreed that Audi's MMI interface was the easiest to use due to its selection buttons similar to bookmarks.

9.2.2 Non-Automotive Input Interfaces

9.2.2.1 QWERTY Keyboard

QWERTY keyboards are the de-facto standard for text input into computers. Even though it was originally designed to slow people down due to the mechanical limits of mechanical typewriters, most users consider it the best input interface. Each letter and number is assigned an individual key and capital letters or symbols can be activated through a shift button. The stepped layout on desktop versions of QWERTY aids users in finding the home position. The typical experienced typist can achieve speeds of about sixty words per minute and professional users up to one hundred words per minute. The great advantage of using a QWERTY keyboard in an application is that it is almost the same in all languages and countries and that almost all users, especially the IT generation are well trained using it. The disadvantage, however, is that it requires the use of both hands at the same time. The following picture shows the QWERTY keyboard:

Fig. 63: QWERTY keyboard

9.2.2.2 Frogpad

The FrogPad (shown in Fig. 64) is a chorded-style one-handed keyboard. The designer's goal was to develop a keyboard that can be as fast as typical typists, while minimizing the repetitive stress created by typical QWERTY keyboards. Letters are generated by pressing either a single letter key, or one letter key plus a special shift key.

The device itself is as easy to use as a regular keyboard, although it does require training. The keys must be memorized just the same as the standard QWERTY keyboard. They keys are essentially the same size and spacing, and require essentially the same force to depress as a regular keyboard. Once learned, a FrogPad user can type 40 WPM, which is typical of most QWERTY typists. The FrogPad has the advantage that only one hand is required, which frees the other hand for taking notes, using a mouse, or driving.

However, a QWERTY keyboard definitely has an advantage when using the "hunt and peck" method of typing. The shift-selection method used by the FrogPad makes it difficult to search for specific letters with 2-3 characters available on each key. The user's hand essentially covers all of the silkscreened key identifiers when placed in the home position. If one cannot remember a key position, he or she must move the entire hand to try and find the key.

The key layout has been optimized to put the most used letters and symbols in the primary finger positions. The index finger covers six keys, which include all of the vowels, for example. The other fingers are responsible for 2-3 keys typically. The pinky positions seem to be equally difficult to master as the QWERTY layout. The pinky phenomenon is perhaps just a function of the human hand layout.

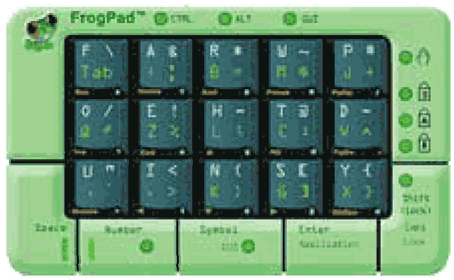


Fig. 64: Frogpad - a one handed input device

9.2.2.3 CyKey

Microwriting is a one handed chord keying scheme based on the mnemonic of the shape of the individual letters or numbers. The latest implementation of a Microwriter keyboard is the CyKey (shown in Fig. 66), a one handed keyboard designed for mobile computing. Like the QWERTY keyboard, the CyKey is designed to be used as a touch-typing keyboard. The CyKey uses the simultaneous presses of a combination of the 9 oval shaped buttons to represent different alphanumeric characters and commands. The forefinger, middle finger, and ring finger are each assigned a single button, while the pinky and thumb each have a home button, as well as two other optional buttons for commands functions.

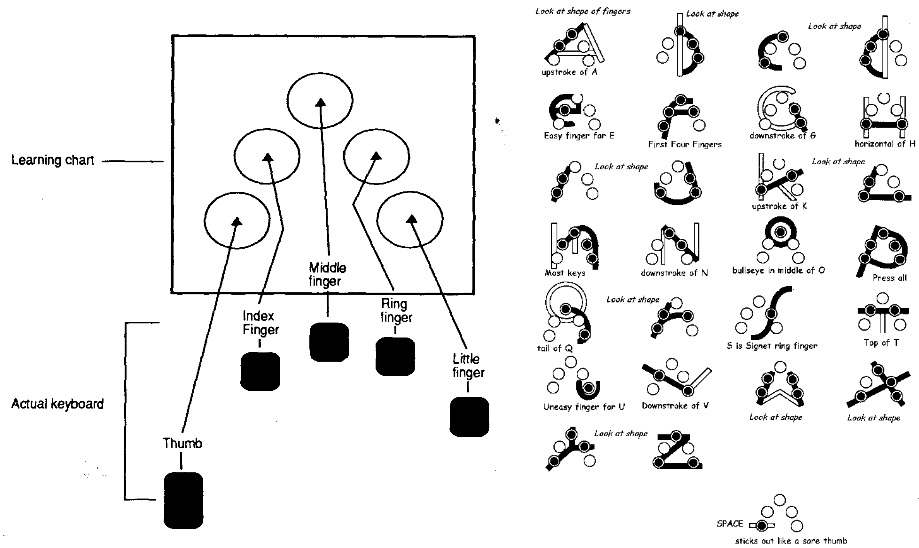


Fig. 65: The Microwriting chord key learning chart and corresponding key positions for the alphabet and space buttons. The combinations of buttons need to be pressed simultaneously for the correct character to register.

The CyKey can be programmed for use with either the right or left hand. The designer's of the input device estimate that after training, a user can touch type as fast as 30-60 words per minute, a rate slightly above that of the average QWERTY typist. The keyboard wirelessly transmits a signal to an infrared receiver. The receiver connects to the PS/2 keyboard port on a PC or adapted to connect to a PDA.

Fig. 66: The CyKey chorded-keyboard highlighted with the finger home positions and travel for right-handed use.

Independently learning the button patterns for the different letters and numbers is quite easy. The difficulty in mastering the CyKey involves recalling and applying those patterns while trying to simultaneously depressing combinations of buttons. The limited travel of the middle fingers makes the unit very comfortable to use.

9.2.2.4 Keiboard

The Keiboard (shown in Fig. 67) is a one handed input device for use with the thumb only. It has the standard 9+1 button layout of numeric keypads. Each button also serves to enter three text characters. In addition, the Keiboard has extra buttons as required for use on a computer and a joystick to control the mouse pointer. The Keiboard has been developed in Japan and is currently marketed only in Asia. The idea behind development was that many teenagers have a higher level of typing proficiency on their cell phone than on a standard QWERTY keyboard and would therefore prefer a cellular phone keyboard. The Keiboard can connect to any computer through the USB port.

Operation of the Keiboard is done with one or two thumbs while it is held like a cellular phone. Input speeds are considerably slower than with a QWERTY keyboard due to the need for multi-tap (press 2 twice for a B) but IT generation users are becoming increasingly faster. The use of T9 can also increase the efficiency in the use of the Keiboard but requires more visual feedback. Observations have shown that most users of portable messaging devices can write blindly with great accuracy on this keyboard.

There are two major advantages to using a Keiboard as an input device in a car. First, it can be operated with one finger only and second that it is becoming a standard interface, especially for IT generation users.

Fig. 67: Keiboard - One handed interface for use with the thumb

9.2.2.5 T9 Predictive Text

T9 predictive text is a feature found on most modern cell phones that eliminates the need for multi-tap. The user simply presses the button which corresponds to the desired letter and the software will predict the desired word based on the buttons pressed by using a database with commonly used words and a ranking of frequency. The software correctly predicts the desired word in most cases but if not, then the user can manually select from a list of words or revert to multi-tab. According to the developer of T9, AOL, T9 is twice as fast as multi-tap and adapts automatically to the user's preferences and language patterns.

T9 is available for over forty languages including Chinese, English, French, German, Hebrew, Hindi, Japanese, Korean, Malay, Russian, Spanish, Tagalog, Thai and Vietnamese.

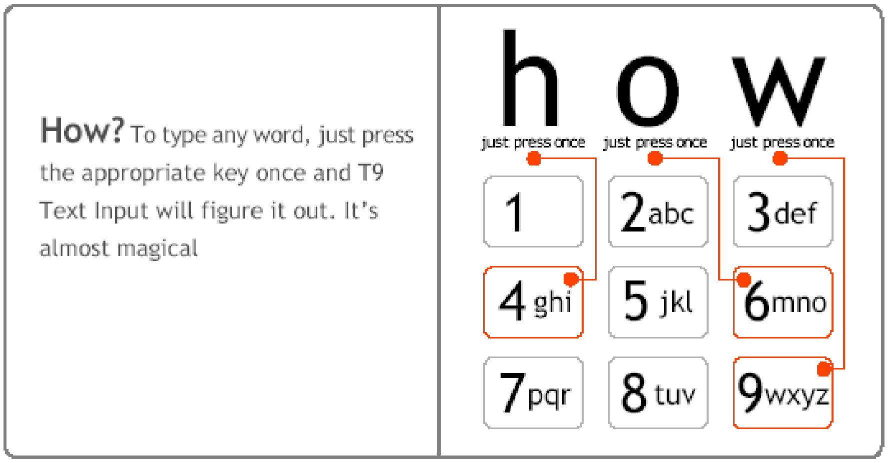


Fig. 68: Illustration of T9 predictive text[29]

9.2.2.6 Remote Controls

The team also benchmarked several multi-function remote controls for insight into potential interface designs (Fig. 69). The One For All remote has a unique lighting arrangement, where buttons are only illuminated when appropriate. The RCA unit combines traditional buttons with a touch screen that provides context sensitive menu selections. The context sensitive displays of these units avoid the confusion that might be caused by the multitude of buttons sported by many of the current remote control units.

Fig. 69: Multi-function remote controls: One For All (left)[30] and RCA (right)[31]

9.2.3 Non-Automotive Output Interfaces

9.2.3.1 Heliodisplay Technology[32]

The Heliodisplay modifies the properties of air within a localized environment. Air comes into the device, is ejected and illuminated to produce the image. There is no harmful gas or liquid, nothing needs to be refilled and there is no overall change in environmental properties of the room in which the device operates. The input for the «image» is just the air in the room.

Fig. 70: Heliodisplay[32]

The images are easily viewed in an office environment. Like any computer monitor or TV, they appear brighter the lower the ambient light is and viewing in direct sun light is almost impossible in the current prototype.

The image is planar (2D), not volumetric (3D) but it appears 3D when viewed more than a few feet away because there is no physical depth reference. Thus, like any computer monitor, it can project simulated 3D. Images can be seen up to 75°s off aspect for a total viewing area of 150°s. The images of the current prototypes are invisible (transparent) from behind. In future versions, the behind image will be togglable between invisible, same as front image or different from front image. Viewing requires no special glasses or background/foreground screening. In the current prototypes, the images float above the device. In future versions, the Heliodisplay will be rotatable, so that images can be projected to the side or even down.

Furthermore, the device can be interactive, like a virtual touch screen. A hand or finger can act as a mouse without the need for a special glove or pointing device.

Fig. 71: Example of interaction with heliodisplay[32]

The Heliodisplay projects full color-streaming video into free space (i.e. air). It is plug-and-play compatible with most video sources (TV, DVD, computer, etc.). When the device is commercialized, it is expected that the price will be very competitive with an equivalent sized plasma screen.

9.2.3.2 Augmented Reality[33] and First-Down Line

Augmented reality is a technology where computer generated graphics are laid over real vision in order to provide additional information to the user as shown in this example:

Fig. 72: Augmented reality display[33]

Unlike virtual reality, which creates immersible, computer-generated environments, augmented reality is closer to the real world. Augmented reality adds graphics, sounds, haptics and smell to the natural world, as it exists. Video games will probably drive the development of augmented reality but it has countless applications from tourists to military troops.

The basic idea of augmented reality is to superimpose graphics, audio and other sense enhancements over a real-world environment in real-time. Television networks currently do this with things such as the "First-Down Line" or the "Virtual Caddy" as shown here:

Fig. 73: First-Down Line and Virtual Caddy as examples of augmented reality[34]

Augmented reality is still in an early stage of research and development at various universities and high-tech companies. The current applications shown above require enormous computing power and thus are very expensive. Predictions say that possibly by the end of this decade, we will see the first mass-marketed augmented-reality system, which one researcher calls "the Walkman of the 21st century." Augmented reality attempts to not only superimpose graphics over a real environment in real-time, but also to change those graphics to accommodate a user's head- and eye- movements, so that the graphics always fit the perspective. This is extremely complex and requires a head-mounted display, a tracking system and lots of mobile computing power. An example of a prototype for such a system is shown here:

Fig. 74: Prototype of an augmented reality system[33]

Just as monitors allow one to see text and graphics generated by computers, head-mounted displays (HMDs) will enable one to view graphics and text created by augmented-reality systems. The two basic types of HMDS are video see-through and optical see-through.

Video see-through displays block out the wearer's surrounding environment, using small video cameras attached to the outside of the goggles to capture images. On the inside of the display, the video image is played in real-time and the graphics are superimposed on the video. One problem with the use of video cameras is that there is more lag, meaning that there is a delay in image-adjustment when the viewer moves his or her head.

Most companies who have made **optical see-through displays** have gone out of business. Sony makes a see-through display that some researchers use, called the Glasstron. According to some researches, Microvision's Virtual Retinal Display holds the most promise for an augmented-reality system. This device actually uses light to paint images onto the retina by rapidly moving the light source across and down the retina. The problem with the Microvision display is that it currently costs about $10,000. This system could be made very small - imagine an ordinary-looking pair of glasses that will have a light source on the side to project images on to the retina.

The biggest challenge facing developers of augmented reality is the need to know where the user is located in reference to his or her surroundings. There's also the additional problem of tracking the movement of users' eyes and heads. A tracking system has to recognize these movements and project the graphics related to the real-world environment the user is seeing at any given moment. Currently, both video see-through and optical see-through displays typically have lag in the overlaid material due to the tracking technologies currently available.

The best tracking technology currently available for large open areas is the Global Positioning System (GPS). However, GPS receivers have an accuracy of about 10 to 30 meters, which is not good enough for augmented reality, which needs accuracy measured in millimeters or smaller. A more accurate system being developed, known as real-time kinematic GPS, can achieve centimeter-level accuracy. Once researchers overcome the challenges that face them, augmented reality will likely pervade every corner of people's lives.

9.2.4 Bluetooth

Bluetooth[35] is a standard for a small, low-cost radio chip to be plugged into computers, printers, mobile phones, etc. It allows any sort of electronic equipment with a Bluetooth chip to make its own connections, without wires, cables or any direct action from a user. The low cost of a Bluetooth chip (~$5), and its low power consumption allow them to be incorporated into almost any electronic device.

9.3 Prototype Development

Given that voice recognition was not an option, the team decided that buttons mounted to the steering wheel would be easiest to use and follow Toyota's paradigm of "eyes on the road and hands on the wheel". Physical implementations of this idea could involve any number of buttons on the right or left and front or back of the steering wheel activated by any number of fingers. All of these ideas, however, assume the driver is able to move individual fingers independently and in no connection to the arm movement required to turn the steering wheel.

The following test was done to test this assumption: One shall sit down and start to rotate the right leg in a clockwise direction while at the same time drawing a large “6” into the air with the right hand (see illustration).

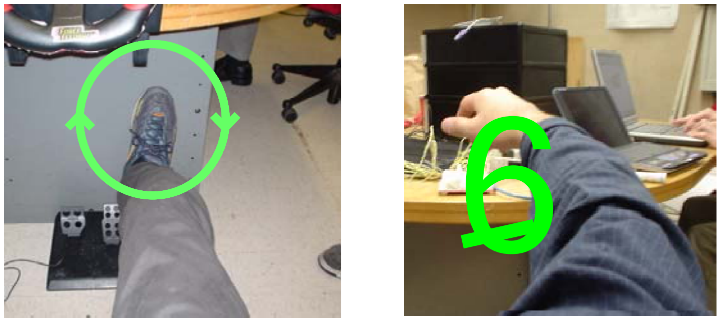
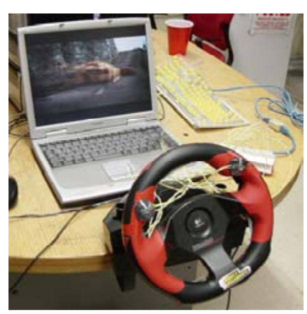


Fig. 75: Diagram of quick test that showed it is difficult to make independent motions simultaneously

The test quickly revealed that this ability cannot be assumed and therefore YTPD Garage decided that the average driver’s ability to do this “stereo” motion should be further investigated since it would be the underlying basis for all future development. A simple prototype was produced to test this critical function.

9.3.1 Critical Functional Prototype (CFP)

The critical function prototype was built using two laptop computers, a simulator steering wheel with pedals, and ten micro switches. The micro switches were attached to the steering wheel with one on the front and four on the back of the steering wheel on each side so that when the steering wheel is held in a quarter to three position, every finger would rest on one button. These buttons were wired to the number keys of a standard keyboard, which was connected to the first laptop so that activation of the buttons could be observed. The steering wheel and pedals were connected to the other laptop, on which a driving video game was run as shown in the pictures below:



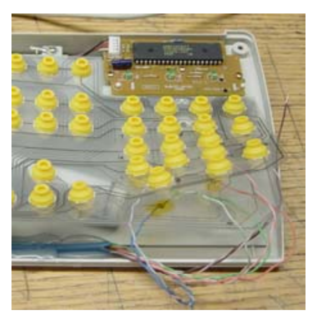


Fig. 76: CFP consisting of two laptops (for typing and video game), micro switches on a simulator steering wheel and a rewired keyboard

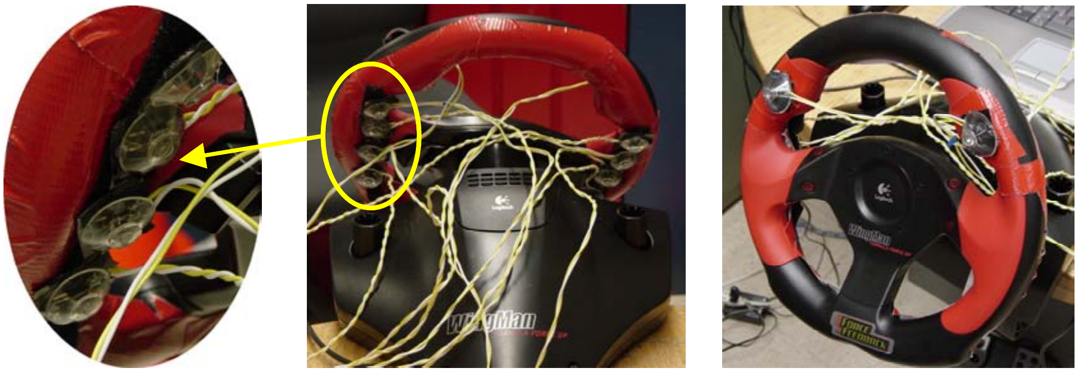


Fig. 77: Micro switches on front and back of simulator steering wheel

Every test candidate was then asked to “drive” the video game while entering numbers using the buttons on the steering wheel.

Testing of the CFP revealed that it is not possible to move all fingers independently while driving at the same time. It was observed that moving individual fingers requires so much attention, that it is not possible to concentrate on the main task of driving. In addition to the counter-intuitive motion, it was found that the unusual setup is counter-intuitive too. The number setup (1, 2, 3, 4, 5 and 6, 7, 8, 9, 0 on the right and left starting with the thumb to the pinky finger respectively) requires a tremendous amount of training since all users are used to the standard 9+1 key setup found on phones and full-size keyboards for number input.

Additionally, a health or comfort issue was found. After typing and steering at the same time for about five minutes, all users were greatly fatigued and felt pain either in their shoulders or forearms, which could lead to carpal tunnel syndrome.

The team also made the following observations, which would be important for consideration in the following designs:

- The layout and size of the buttons must accommodate hands of various sizes.
- All users admitted that it took them a long time (sometimes years) to become familiar with the standard QWERTY keyboard but they were questioning their and the final users’ willingness to learn a new keyboard for use in their car only. Therefore, a standard layout, which the operator is familiar with is desirable.

- Other keys such as a backspace and function keys must be easily accessible too.
- Moving individual fingers is very difficult. It is hard to wiggle the ring finger without moving any other fingers if one is not used to this motion from playing piano or performing similar tasks.
- The simulation should be more realistic rather than based on a difficult to use computer game.

The team concluded that the two-thumb operation on the steering wheel should be further investigated but that any additional motion on the steering wheel would require too much attention to be safe while driving.

The test was repeated in a real car since there was a great deal of concern that the test was not sufficiently realistic due to the small size of the simulator steering wheel and the video game's unrealistic high demand for attention. The setup is shown below:

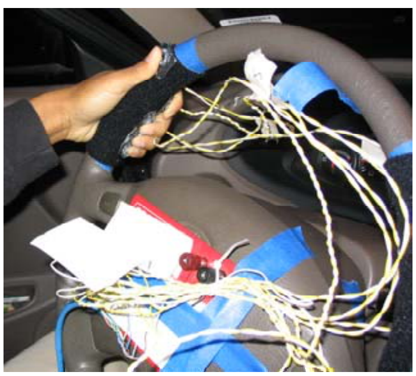


Fig. 78: Steering wheel with buttons on front and back

Testing of the system verified the findings from the simulation but showed that the large steering wheel and less motion in traffic required considerably less attention than the simulator. Therefore it was concluded that the human is not used to or not even able to perform the two unrelated motions required to steer and type with the same hands at the same time. This is especially true when the buttons are placed on the front and back of the steering wheel since the fingers have to move against each other.

Another test was done by placing five buttons on the center console and typing with one hand only as shown in Fig. 79. This approach was much more intuitive and easy to use since the workload was split up between the two hands and whenever the right hand was removed from the buttons, the user was able to relocate on the "keyboard" easily and quickly since the keyboard remained in the same place. In the test before, the steering wheel, on the other hand was constantly moving and thus it was difficult to correctly relocate the hands on the buttons.

Fig. 79: Buttons on center console for one-handed input

The one handed method worked well when using five buttons (one for each finger) but quickly reached its limits when the user wanted to enter all characters of the alphabet and numbers. Therefore, other methods had to be considered as well. Ideas included various keyboards such as the FrogPad, CyKey or QWERTY (standard) keyboard, or a brand new method.

Fig. 80: Possible input devices: CyKey, Frogpad and QWERTY keyboard (respectively)

During testing it was found that it is necessary to provide unique mapping (one possibility per key) if the input should be efficient and not require visual attention and that there must be sufficient feedback for the user to know what has been entered. In addition, the input method must be sufficiently easy to use or learn so that there is no added risk during the initial training period. After a great deal of testing, the design team concluded that a standard QWERTY keyboard would be the best solution for data input since it provides unique mapping and good feedback (most users realize that they typed the wrong letter before it even appears on the screen). In addition, most IT generation users can use the keyboard blindly thus eliminating an initial training period and satisfying Toyota's request for similar interfaces in and outside the car.

The QWERTY keyboard requires the use of both hands for typing. Therefore, the challenge is to find a way to steer while using both hands to type. This would require a keyboard, which is mounted to the steering wheel, or some alternative method for steering. Eye or head movement cannot be considered for driving since the driver must be able to move these over a great range to view the surrounding for safety reasons. The only part of the human body left to move while restrained in a car seat would be the feet. The design team considered this a possible solution given that the technology for variable steering is available now.

In order to overcome this challenge, YTPD Garage developed two approaches that allow steering while typing with two hands as the First Functional Prototype. The first approach uses both hands to steer and type at the same time by integrating the keyboard into the steering wheel. Two modified steering wheel/keyboard combinations were built and tested. The second approach allows the hands to type by using the driver's feet to steer. A custom interface for steering/accelerating/braking by foot was built and tested as well.

9.3.2 First Functional Prototype (FFP)

Two variations of the keyboard integrated steering wheel were built and tested. The first design incorporates a keyboard into an alcove in the center hub of the steering wheel. The keyboard rotates with the wheel, but can be adjusted for tilt and depth. This approach adapts the keyboard to the typical steering wheel position, as shown on the right in Fig. 81.

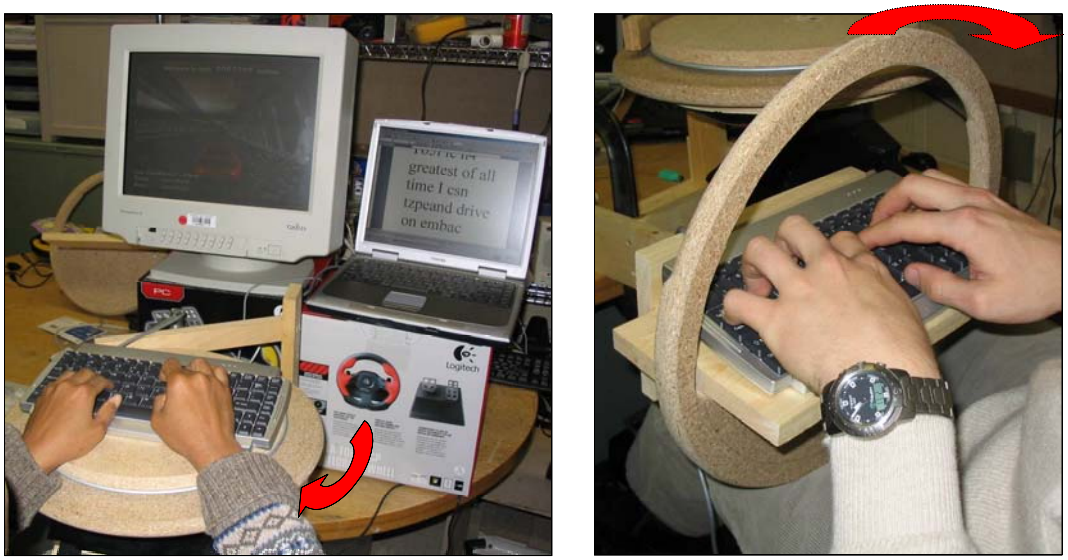


Fig. 81: Steering wheel with integrated keyboard in two configurations

The second design adapts the steering wheel to the typical keyboard position as shown on the left in Fig. 81. The steering wheel is tilted up to a flat position, much like the steering configuration of a bus or large truck. The keyboard is mounted to the center of the steering wheel and is affixed to the wheel through a rotary joint, while a strut keeps the keyboard from spinning. This configuration allows the keyboard to remain in a fixed position to the driver while the steering wheel is free to rotate independently.

In addition, a foot steering system was developed in order to free the hands to operate the keyboard only. The foot steering system incorporates all the steering, accelerating and braking functions of the pedals and steering wheel combined. A diagram of the foot steering system is shown below:

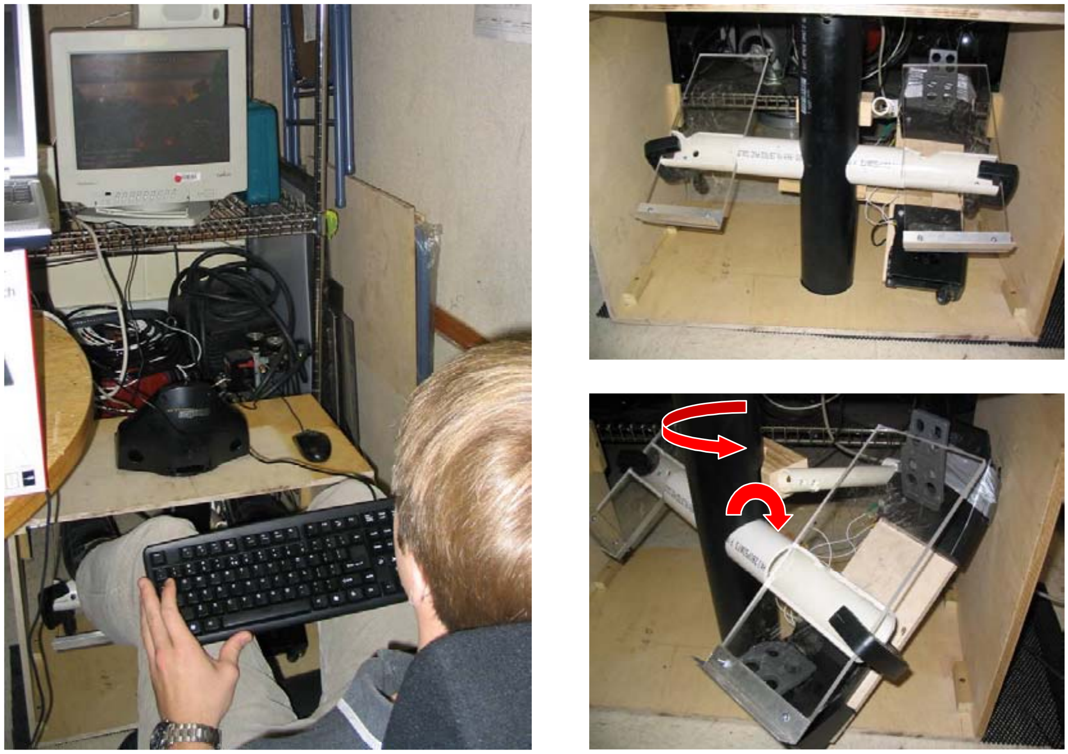


Fig. 82: Prototype of foot driving system

The foot steering system made typing with both hands much easier but steering became exponentially more difficult. In addition, Toyota did not think that foot steering would ever become a solution for the general market and thus asked the team to refrain from continuation of this idea.

Even though the First Functional Prototype was not much more than a super Critical Functional Prototype, the design team learned many important lessons from it. These lessons are summarized below:

- Typing on a moving keyboard is difficult.
- A complete system for driving and typing is required to draw useful conclusions.
- Driving requires a great deal of attention and thus any text input cannot be expected to reach efficiencies close to that of typing outside the car on a standard computer.
- The motion feedback felt from acceleration and turning is a vital component of driving and no simulation can provide this.

- Driving games are no adequate simulation since they are inherently faster paced than real driving.

Next, YTPD Garage expanded its scope because of the lessons learned from the first functional prototype and a meeting with the client, Toyota. Until now the team had focused primarily on the input portion of the interface. Now, the team in collaboration with TMIT planned to develop an entire interface system. In addition, it was decided that the team will greatly emphasize user testing using a simulator and an actual vehicle in traffic.

The expanded design consists of the following blocks:

Fig. 83: Building blocks for interface system

The input portion has been explained in detail above and consists of a character input device. The process will be performed by a CPU, which is integrated into the vehicle's backbone and also used for other computing operations. This CPU would have to run the various software programs required to email, instant message or a word processor. For the purpose of this design, the CPU will be a separate Windows based PC, which is connected to the input and output devices.

On the output side, the user would receive feedback and information through a visual display. This display could be a combination of various technologies such as a heads-up display complemented with a small LCD screen to only show a few characters at a time.

Based on the two global team's strengths, the teams decided that Stanford would work on the input portion while TMIT would be responsible for the software and output portion of the system. The Stanford team would do final assembly and testing.

The lessons learned in the earlier prototypes pointed towards a one-handed input device. To aid the decision for going forward, the team constructed a Pugh's selection chart, which is shown below and decided to go forward with the winners. Pugh's method use pair wise selection with rotating datums to identify optimum solutions.

9.3.3 Second Functional Prototype (SFP)

The second functional prototype was the design team's move into an actual vehicle. A preliminary interface was designed with standardized parts, implemented in the test bed and tested to gather initial data. The interface system consists of an interchangeable Keiboard and CyKey input device, a Windows PC and an LCD display.

The Keiboard and CyKey had been selected as the most promising approaches for moving forward as explained before and were therefore installed in the vehicle as shown in the picture below. All connections were standard PC interfaces so that it took only seconds to change between them.

Fig. 84: Keyboard and CyKey mounted to center console

An LCD display with large characters was used as an initial output and feedback system. The display is driven through the computer's serial port and placed directly below the line of vision between the dashboard and windshield as shown here:

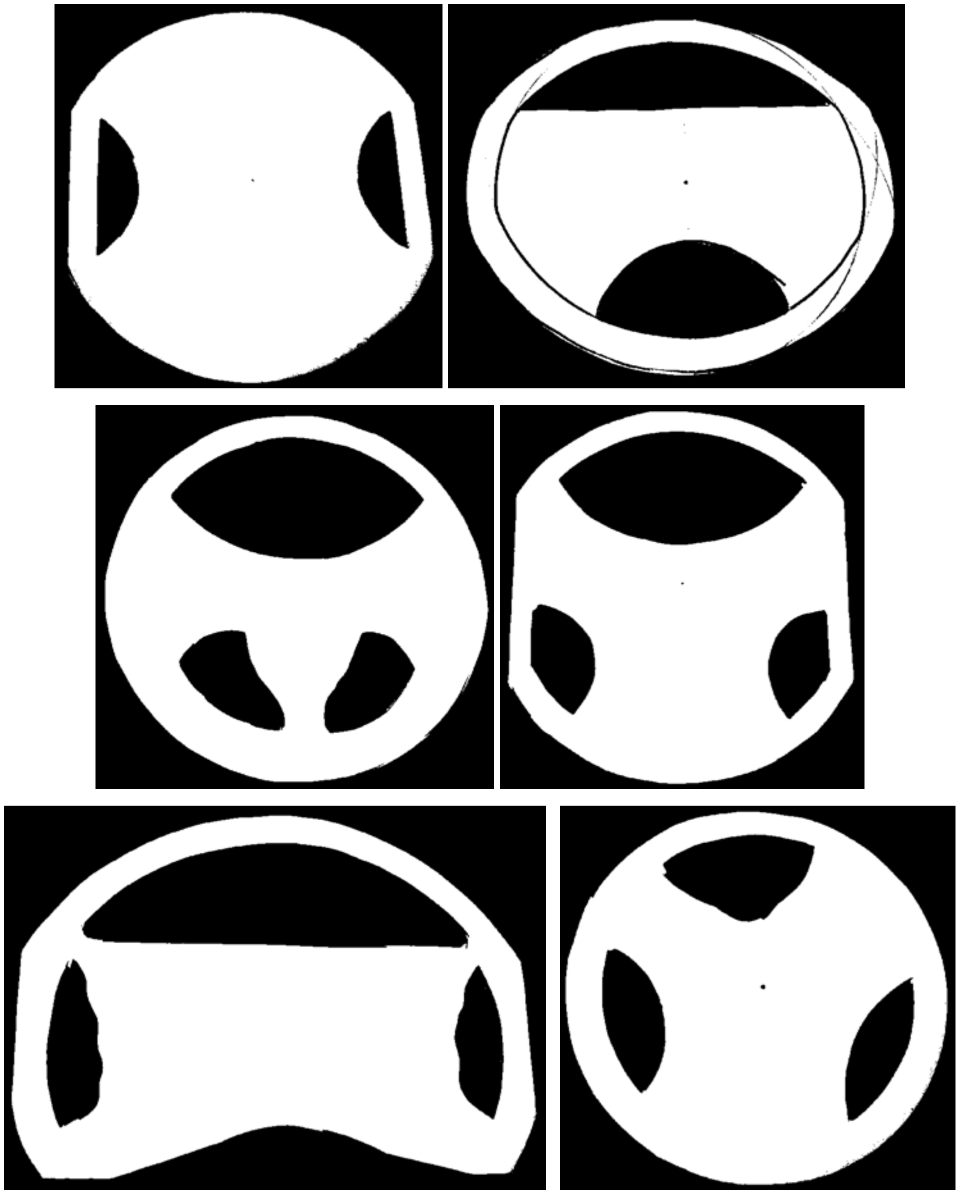
Fig. 85: LCD display below line of vision for limited character display

All computations were done by the PC cluster that is also used for analysis and logging of the test data.

The following lessons were learned from the testing of the second functional prototype:

- Data entry rates are fairly slow: 3-8 words per minute, which is typical for cell phone text entry even while not driving.
- Data entry rates vary widely with driving situations.
- Drivers will naturally modulate their text entry focus.
- Method works well with asynchronous communication methods like SMS and email.
- Efficiency is not the primary objective.
- Safety of typing while driving is at least comparable to talking on a cell phone while driving.

9.4 Foam Mock-Ups of Steering Wheel Shapes



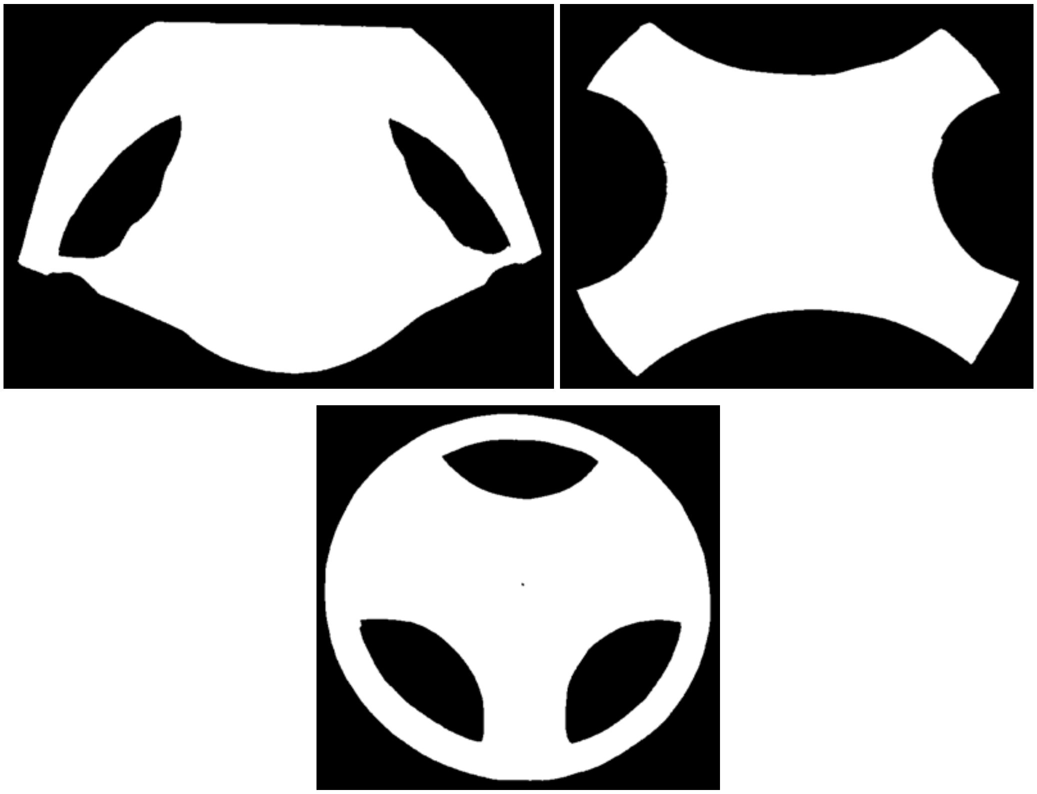


Fig. 86: Foam mock-ups of possible shapes for steering wheel.

9.5 Test Procedure

9.5.1 Test Instructions and Protocol

Please see next page.

Introduction

Thank you for participating. We will be doing a couple of different tests today to evaluate an in-vehicle text input system. The entire session should last about 30 minutes. The majority of the testing will occur in a stationary vehicle. You will be using two different input devices during the tests. You will be receiving some instruction and training on how to use each of these devices. Before we begin please fill out the **Text Input System User Questionnaire**.

[Hand user a questionnaire and pen]
[User ID = First letter of Name+First letter of Nickname|Age|Handedness]

Thank you for filling out the questionnaire.

Baseline User Exercises

Keypad Layout Exam (2 – 5 minutes)

First we want to evaluate how familiar you are with the layout the alphabet on a telephone keypad. I am going to give you a sentence on a piece of paper. For each letter in the sentence, please write down the following information: the number key corresponding to the letter and its position in the sequence of letters on the key. For example, if the number '2' corresponds to the letter sequence 'P-L-M,' then 'L' would be 2 – 2. You may skip over any punctuation in the sentence. This exercise will be timed.

User:	
Start Time:	
End Time:	
Notes:	

Character	T	H	E		Q	U	I	C	K		B	R	O	W	N		F	O	X
End Time																			
	J	U	M	P	S		O	V	E	R		T	H	E		L	A	Z	Y
End Time																			
	D	O	G	.															
End Time																			

Keypad Layout Exam

1	2	3
4	5	6
7	8	9
*	0	#

Character	T	H	E		Q	U	I	C	K		B	R	O	W	N		F	O	X
Keypad #																			
Key Pos.																			
	J	U	M	P	S		O	V	E	R		T	H	E		L	A	Z	Y
Keypad #																			
Key Pos.																			
	D	O	G	.															
Keypad #																			
Key Pos.																			

Driver Reaction and Awareness Exam (10 minutes)

Now we want to establish your baseline reaction and awareness in the vehicle. Please sit in the driver's seat of the vehicle and fasten the seat belt. Please place both hands on the steering wheel at the "10" and "2" positions as marked.

LEDs in 5 different locations in the interior of the vehicle will randomly be illuminated. When you see an LED has been turned on, press the red button on the dashboard. The LEDs are located in small black boxes in 5 different positions around the interior of the vehicle: driver's side mirror (single LED), center of the dashboard (three LEDs), passenger's side mirror (single LED), passenger side rear mirror (single LED), and driver's side rear mirror (single LED).

This exercise is timed. Once an LED is illuminated, you will only have 30 seconds to react by pressing the red button.

Before we begin the exercise, we will turn on all of the LEDs to ensure you can adjust their orientation. When you are satisfied with the orientation of all the LEDs, press the red button to begin the reaction test. We will verbally instruct you when you have completed the test.

Name:			
LED Program:			
Start Time:		End Time:	
Notes:			

Multi-tap Baseline Exams [15 minutes]

Now we want to establish your baseline performance with [the steering wheel text input interface]. The input device emulates the form and function a cell phone keypad. You can enter text using the input device using the multi-tap method. To enter a letter, you must press the corresponding number multiple times. For example, since the number '2' corresponds to the letter sequence 'A-B-C,' then '2' would be hit once for a '2', twice for an 'A', three times for a 'B' and four times for a 'C.' If you pass your intended character, you will have to continue tapping through the sequence until you once again reach the character.

[If using timed multitap – inform the user the key hits need to occur within 500 ms in order to advance the cursor will automatically move to the next space.]

[If using untimed multitap – inform the user they will need to hit the '->' key in order to advance the cursor.]

1 **shift._!**	**2** **ABC**	**3** **DEF**
4 **GHI**	**5** **JKL**	**6** **MNO**
7 **PQRS**	**8** **TUV**	**9** **WXYZ**
***** **Enter Tab**	**0** **Space**	**#** **Delete**

The characters will be displayed on the LCD display on the dashboard. This exercise will be timed. For the next 5 to 7 minutes, enter the following phrase as many times as possible:

The quick brown fox jumps over the lazy dog

Your goal should be both speed and accuracy. You will be verbally instructed when to stop.

Name:	
LED Program:	**No**
Panagram:	**The quick brown fox jumps over the lazy dog**
Start Time:	
#1 End Time	
#2 End Time	
#3 End Time	
#4 End Time	
Notes:	

Now, we will repeat the exercise for 5 to 7 minutes, while running the LEDs. Please press the red button when you see a LED turn on.

Name:	
LED Program:	**No**
Panagram:	**The quick brown fox jumps over the lazy dog**
Start Time:	
#1 End Time	
#2 End Time	
#3 End Time	
#4 End Time	
Notes:	

Multi-Switch Baseline Exams [15 minutes]

Now we want to establish your baseline performance with [the steering wheel text input interface]. The input device follows the layout of a cell phone keypad except each key button switch has 5 positions: left, right, up, down and select. You can enter text using the input device using the multi-switch method by pushing the key in to select the number, and pushing key the in the up, left, down or direction for a letter or character. [Layout L]

- Pushing the number '2' key in (select) = 2
- pushing the number '2' key up = A
- pushing the number '2' key right = B
- pushing the number '2' key down = C

The letter sequence for the letter corresponds to both the sequence and direction of the switch, with the first letter starting in the 'up' position, then moving clockwise around the key. For example, since the number '2' corresponds to the letter sequence 'A-B-C,'

	.			A			D	
~	1	-	~	2	B	~	3	E
	1			C			F	
	G			J			M	
~	4	H	~	5	K	~	6	N
	I			L			O	
	P			T			W	
S	7	Q	~	8	U	Z	9	X
	R			V			Y	
	TAB		SPACE				~	
~	*	~	~	0	~	~	BS	~
ENTER				~			~	

The characters will be displayed on the LCD display on the dashboard. This exercise will be timed. For the next 5 to 7 minutes, enter the following phrase as many times as possible:

The quick brown fox jumps over the lazy dog

Your goal should be both speed and accuracy. You will be verbally instructed when to stop.

Name:	
LED Program:	**No**
Panagram:	**The quick brown fox jumps over the lazy dog**
Start Time:	
#1 End Time	
#2 End Time	
#3 End Time	
#4 End Time	
Notes:	

Now, we will repeat the exercise for 5 to 7 minutes, while running the LEDs. Please press the red button when you see a LED turn on.

Name:	
LED Program:	**No**
Panagram:	**The quick brown fox jumps over the lazy dog**
Start Time:	
#1 End Time	
#2 End Time	
#3 End Time	
#4 End Time	
Notes:	

[That concludes our test. Thank you for your participation. Please fill out this usability survey about the design.

Thank you.

Please accept this candy bar as a token of our gratitude]

9.5.2 Test Subject Questionnaire

Please see next page.

Text Input System User Questionaire - Post Multi-Tap

Usability Comments

Difficulty (1=Extremely Easy, 10=Extremely Difficult)

It was difficult to enter to enter phone numbers while parked	1	2	3	4	5	6	7	8	9	10
It was difficult to enter to multi-tap text while parked	1	2	3	4	5	6	7	8	9	10
It would be difficult to enter to enter phone numbers while driving	1	2	3	4	5	6	7	8	9	10
It would be difficult to enter to multi-tap text while driving	1	2	3	4	5	6	7	8	9	10
It would be difficult to drive while entering phone numbers	1	2	3	4	5	6	7	8	9	10
It would be difficult to drive while entering multi-tap text	1	2	3	4	5	6	7	8	9	10

Safety (1=Strongly Disagree, 10=Strongly Agree)

It is unsafe for me to enter phone numbers while driving	1	2	3	4	5	6	7	8	9	10
It is unsafe for me to enter multi-tap text while driving	1	2	3	4	5	6	7	8	9	10

General (1=Strongly Disagree, 10=Strongly Agree)

If this system were installed in my car, I would consider using it while driving	1	2	3	4	5	6	7	8	9	10
If this system were installed in my car, I would consider using it while parked	1	2	3	4	5	6	7	8	9	10
Do you feel the input device will interfere with standard driving functions?	1	2	3	4	5	6	7	8	9	10
Do you feel the input device is comfortably positioned?	1	2	3	4	5	6	7	8	9	10

Additional Comments

Text Input System User Questionaire

Biographical Information

Name:					
Age:					
Handedness:		Left	Right	Ambidexterous	
Education					
	High School				
	Some College				
	College (major):				
	Graduate School:				
Native language:					
Nickname:			Favorite Color:		
Friend's Name:			Friend's Name:		
Phone #:			Phone #:		

Car Information

What car do you drive most often?					
Make:		Model:		Year:	
Transmission:		Automatic		Manual	
How many hours per day do you spend driving your car?					
		hours			
How many accidents have you had in the last 5 years?					
How many tickets have you had in the last 5 years?					
On an expressway with 3 lanes per side, in which lane do you normally drive?					
	Left	Middle	Right		

Cell Phone Information

Do you own a cell phone?				Yes	No
If Yes, how much do you use it per week?					
	Calls		Hours		
How do you dial phone numbers on your phone? (select one)				Speed Dial	Voice Recognition
Enter Numbers - Thumb		Enter Numbers - Thumbs		Enter Numbers - Finger(s)	
Do you use your cell phone while driving?				Yes	No
Do you text message on your cell phone?				Yes	No
	How often?				
If you use your, thumb(s) or finger(s) to input phone numbers or text, which hand do you use?					
Most Often Left		Most Often Right		Most Often Both	
How do you input text on your cell phone?				Multi-tap	T9
Jog-Scroll Menu		Other:			

PDA Information

Do you own a PDA/Sidekick?				Yes	No
If Yes, how much do you use it per week?					
	Emails		Hours		
	Other		Hours		
How do you input text on your PDA/Sidekick?				thumbpad	stylus-grafitti
external keyboard		jog-scroll-select menu		other:	
Do you use your PDA/Sidekick while driving?				Yes	No
Do you text message on your PDA/Sidekick?				Yes	No
	How often?				

9.6 Compiled Test Data

The raw data collected during testing has been compiled and summarized in the Table 14 below for both the static testing and driving testing. The data sheets for each test are provided in the sections following.

Test Configuration	Subject	Input Method	Avg. Response Time	Avg. Reaction Time	Avg. Awareness Time	Avg. WPM	Change from Baseline		
							Response	Reaction	Awareness
Stationary Baseline	Brett	Multi-Tap	2.4 sec	2.8 sec	2.2 sec	3.4	1.6 sec	2.3 sec	1.7 sec
		Multi-Switch	2.3 sec	1.1 sec	2.5 sec	5.6	1.5 sec	0.5 sec	2.0 sec
		Baseline	0.8 sec	0.6 sec	0.6 sec	-			
Driving Baseline	Chris	Multi-Tap	2.5 sec	0.9 sec	3.3 sec	4.5	0.6 sec	-0.1 sec	-0.6 sec
		Multi-Switch	4.8 sec	1.1 sec	5.5 sec	5.7	2.9 sec	0.2 sec	1.5 sec
		Baseline	1.9 sec	0.9 sec	4.0 sec	-			
	Nikki	Multi-Tap	1.6 sec	1.4 sec	1.6 sec	4.8	-0.1 sec	0.2 sec	-5.0 sec
		Multi-Switch	8.7 sec	10.6 sec	8.5 sec	7	7.1 sec	9.4 sec	1.9 sec
		Baseline	1.7 sec	1.2 sec	6.6 sec				
	Philipp	Multi-Tap	1.6 sec	1.4 sec	1.6 sec	4.8	0.4 sec	0.5 sec	0.5 sec
		Multi-Switch	2.1 sec	0.9 sec	2.5 sec	4.4	1.0 sec	0.1 sec	1.4 sec
		Baseline	1.2 sec	0.9 sec	1.1 sec				
Advanced User	Nikki	Multi-Tap					0.0 sec	0.0 sec	0.0 sec
		Multi-Switch				9.7	0.0 sec	0.0 sec	0.0 sec
		Baseline							
Comparison to Radio	Chris	Using Radio	2.5 sec	1.6 sec	2.9 sec		0.6 sec	0.7 sec	-1.1 sec
		Baseline	1.9 sec	0.9 sec	4.0 sec				

Test Configuration	Subject	Input Method	Avg. Response Time	Avg. Reaction Time	Avg. Awareness Time	Avg. WPM	Change from Baseline		
							Response	Reaction	Awareness
Driving Multitap	Dave	Multi-Tap	10.5 sec	1.5 sec	12.0 sec	2.3	7.3 sec	-0.2 sec	10.8 sec
		Baseline	3.1 sec	1.7 sec	1.3 sec				
Driving MultiSwitch	Dave	Multi-Switch	12.9 sec	2.3 sec	15.9 sec	4.7	9.8 sec	0.6 sec	14.6 sec
		Baseline	3.1 sec	1.7 sec	1.3 sec				
	Philipp	Multi-Switch	1.2 sec	1.0 sec	1.3 sec	6.8	0.1 sec	0.2 sec	0.1 sec
		Baseline	1.2 sec	0.9 sec	1.1 sec				

Table 14. Summary of response time and average WPM data collected for all users and all tests.

9.6.1 Stationary Baseline Data – Brett

Input Test Summary

Brett Multitap Data.xls

YTPD Garage
Stanford University

Test Conditions

Start Time of Test:	4:05:09 AM	Date of Test:	5/30/2004
Driver:	Brett		
Configuration:	Joysticks on Final Aluminum Bezel (In Car Stationary) ** Multi-tap Entry Method ** (Stationary Baseline)		

Summary Statistics

Total Test Time:	0:07:47	Total Char. Typed:	399
		Max. WPM	6
		Average WPM:	3.4

Reaction Conditions

Baseline Total		Delta	Typing Total	
Avg. Reaction Time	0.84 Sec	1.55 Sec	Avg. Reaction Time	2.39 Sec
Max. Reaction Time	1.09 Sec	3.47 Sec	Max. Reaction Time	4.55 Sec
Min. Reaction Time	0.34 Sec	0.26 Sec	Min. Reaction Time	0.61 Sec

Baseline Reaction		Delta	Typing Reaction	
Avg. Reaction Time	0.59 Sec	2.25 Sec	Avg. Reaction Time	2.84 Sec
Max. Reaction Time	0.84 Sec	3.13 Sec	Max. Reaction Time	3.97 Sec
Min. Reaction Time	0.34 Sec	0.26 Sec	Min. Reaction Time	0.61 Sec

Baseline Surrounding Awareness		Delta	Typing Surrounding Awareness	
Avg. Reaction Time	0.55 Sec	1.66 Sec	Avg. Reaction Time	2.21 Sec
Max. Reaction Time	1.09 Sec	3.47 Sec	Max. Reaction Time	4.55 Sec
Min. Reaction Time	0.34 Sec	0.32 Sec	Min. Reaction Time	0.66 Sec

Input Test Summary -- Page 2

YTPD Garage
Stanford University

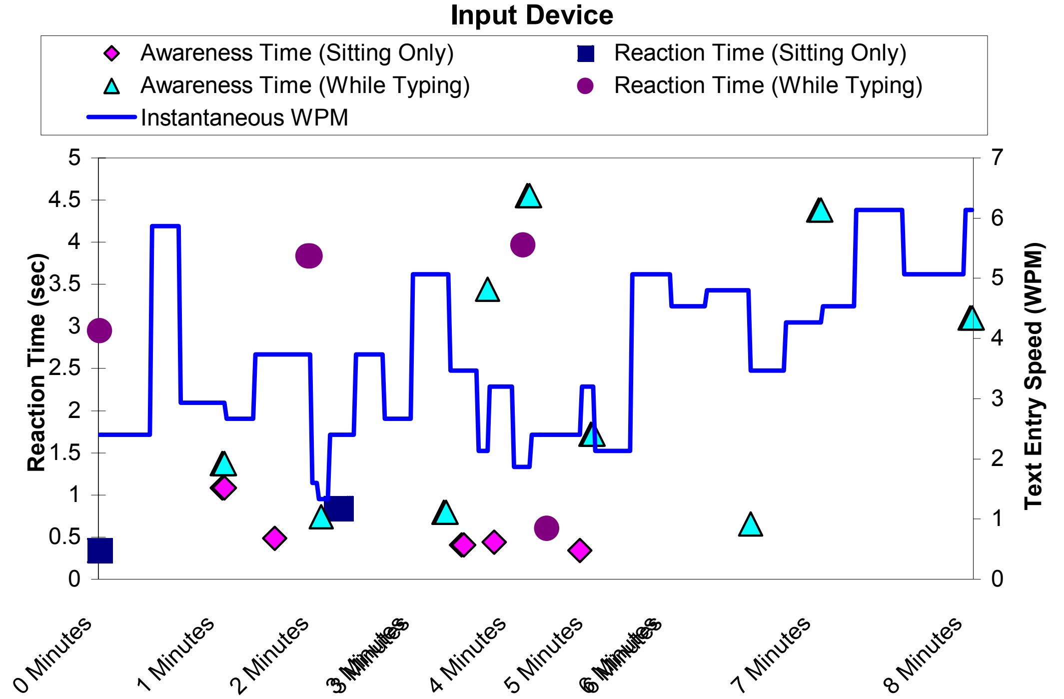
Test Conditions

Start Time of Test:	4:05:09		Date of Test:	5/30/2004
Driver:	Brett			
Configuration:	Joysticks on Final Aluminum Bezel (In Car Stationary) ** Multi-tap Entry Method ** (Stationary Baseline)			

Total Typed Text:

88444444433300787778□□□□88880□□03□330077708□□88□777888445□□4444222245□□55□2222555000
02227777666699666003333666636□666□66669990055888866770□777770066668888333888880□7□□770□3
□□3□6□888833377770088444333005555222999990□99990033666644884444363□□36□33□33333007770□8
884444222255500222777766669999999666003333666699900005588866770□7777700666688883337777008
84443330055552229999990□99990033666645445□□□45445□□□□4□□4

Comparison of Reaction Time Variation and Typing Using Text Input Device



Input Test Summary

Brett MultiSwitch Data.xls

YTPD Garage
Stanford University

Test Conditions

Start Time of Test:	4:24:20 AM	Date of Test:	5/30/2004
Driver:	Brett		
Configuration:	Joysticks on Final Aluminum Bezel (In Car Stationary) ** Multi-switch Entry Method ** (Stationary Baseline)		

Summary Statistics

Total Test Time:	0:05:32	Total Char. Typed:	155
		Max. WPM	10
		Average WPM:	5.6

Reaction Conditions

Baseline Total		Delta	Typing Total	
Avg. Reaction Time	0.84 Sec	1.45 Sec	Avg. Reaction Time	2.29 Sec
Max. Reaction Time	1.09 Sec	5.01 Sec	Max. Reaction Time	6.09 Sec
Min. Reaction Time	0.34 Sec	0.38 Sec	Min. Reaction Time	0.72 Sec

Baseline Reaction		Delta	Typing Reaction	
Avg. Reaction Time	0.59 Sec	0.52 Sec	Avg. Reaction Time	1.11 Sec
Max. Reaction Time	0.84 Sec	0.67 Sec	Max. Reaction Time	1.51 Sec
Min. Reaction Time	0.34 Sec	0.38 Sec	Min. Reaction Time	0.72 Sec

Baseline Surrounding Awareness		Delta	Typing Surrounding Awareness	
Avg. Reaction Time	0.55 Sec	1.97 Sec	Avg. Reaction Time	2.52 Sec
Max. Reaction Time	1.09 Sec	5.01 Sec	Max. Reaction Time	6.09 Sec
Min. Reaction Time	0.34 Sec	0.83 Sec	Min. Reaction Time	1.17 Sec

Input Test Summary -- Page 2

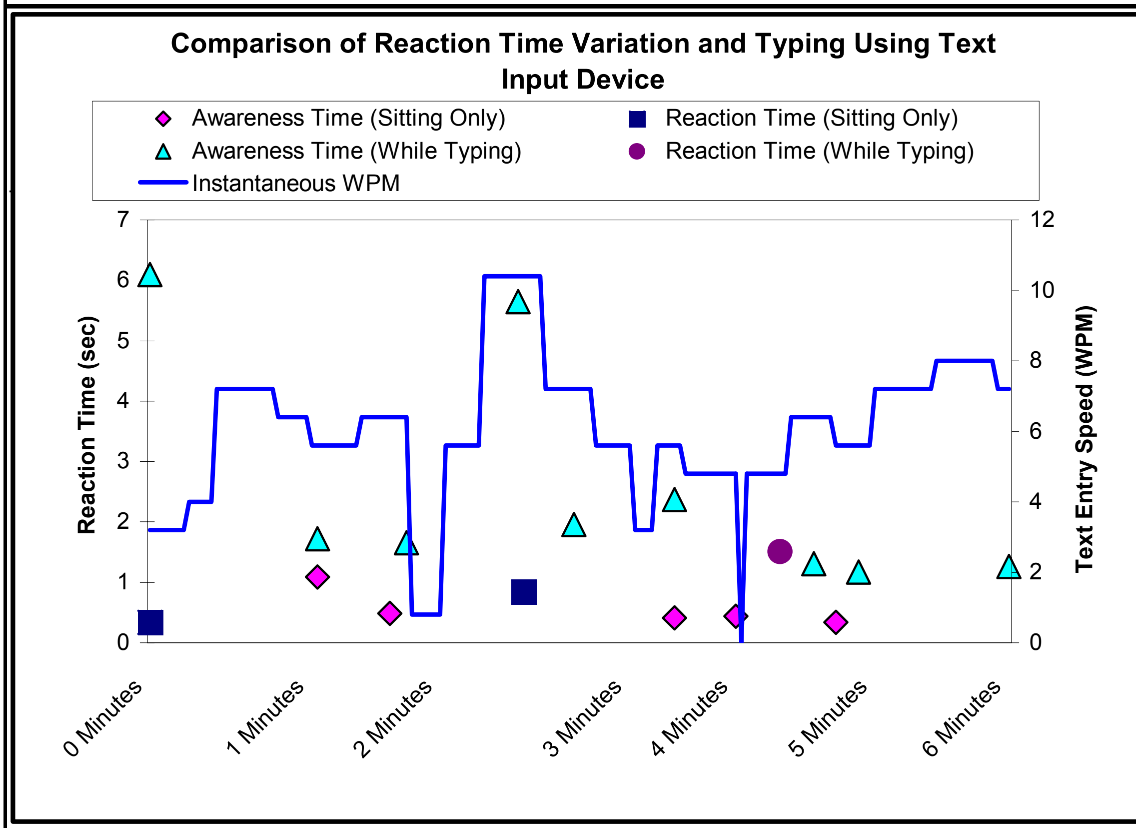
YTPD Garage
Stanford University

Test Conditions

Start Time of Test:	4:24:20	Date of Test:	5/30/2004
Driver:	Brett		
Configuration:	Joysticks on Final Aluminum Bezel (In Car Stationary) ** Multi-switch Entry Method ** (Stationary Baseline)		

Total Typed Text:

the quick brown fox jumps yn□□over the lazy dogj□the quick bgi□□i□rown oy□□fox0□ jumps over the lb□azy dogthe quick brown fox jumps over the oa□□lazy dog



9.6.2 Driving Baseline Data – Chris

Input Test Summary

Chris Multitap Data.xls

YTPD Garage
Stanford University

Test Conditions

Start Time of Test:	3:05:49 AM		Date of Test:	5/30/2004
Driver:	Chris			
Configuration:	Joysticks on Final Aluminum Bezel (In Car Stationary) ** Multi-tap Entry Method ** (Driving Baseline)			

Summary Statistics

Total Test Time:	0:06:24		Total Char. Typed:	431
			Max. WPM	7
			Average WPM:	4.5

Reaction Conditions

Baseline Total		Delta	Typing Total	
Avg. Reaction Time	1.89 Sec	0.61 Sec	Avg. Reaction Time	2.50 Sec
Max. Reaction Time	26.59 Sec	-18.57 Sec	Max. Reaction Time	8.02 Sec
Min. Reaction Time	0.63 Sec	0.12 Sec	Min. Reaction Time	0.75 Sec

Baseline Reaction		Delta	Typing Reaction	
Avg. Reaction Time	0.92 Sec	-0.06 Sec	Avg. Reaction Time	0.86 Sec
Max. Reaction Time	1.89 Sec	-0.86 Sec	Max. Reaction Time	1.03 Sec
Min. Reaction Time	0.63 Sec	0.12 Sec	Min. Reaction Time	0.75 Sec

Baseline Surrounding Awareness		Delta	Typing Surrounding Awareness	
Avg. Reaction Time	3.95 Sec	-0.62 Sec	Avg. Reaction Time	3.32 Sec
Max. Reaction Time	26.59 Sec	-18.57 Sec	Max. Reaction Time	8.02 Sec
Min. Reaction Time	0.87 Sec	0.29 Sec	Min. Reaction Time	1.16 Sec

Input Test Summary -- Page 2

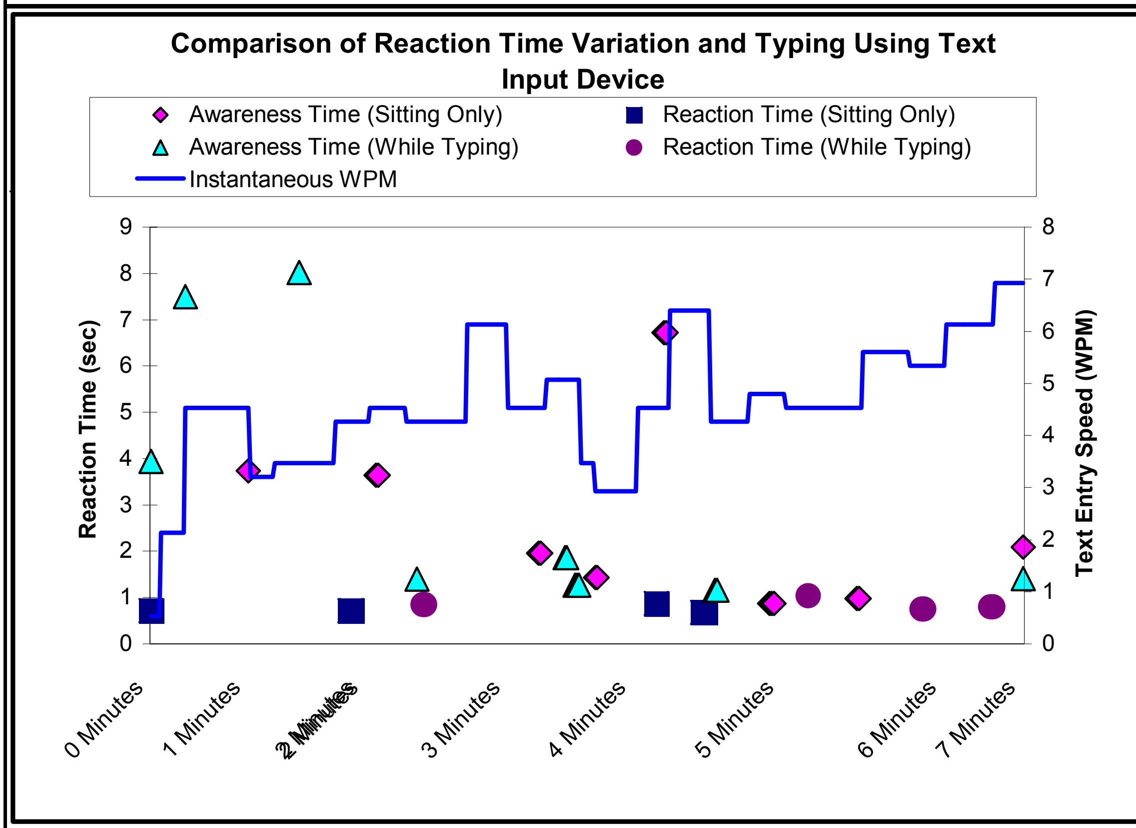
YTPD Garage
Stanford University

Test Conditions

Start Time of Test:	3:05:49		Date of Test:	5/30/2004
Driver:	Chris			
Configuration:	Joysticks on Final Aluminum Bezel (In Car Stationary) ** Multi-tap Entry Method ** (Driving Baseline)			

Total Typed Text:

88444333007778□88□778□□77877□□□7□0077787□□8884444222255550033□2227777666699660033336666
99900558886677333□7787□□□7777778□77877777□□□7777777777778□777770066668888333777777777
0088444333333300555522999998□999900339999□6666444443363□□□□777□4443330077788888888888844
443333333□2222555002227877□□□7766669966600333366669990088888□55555588866775□787□□□7777
77777775□77777006666888833377770088444333005555222222999995□9999003333339999□6666666644



Input Test Summary

Chris Multiswitch Data.xls

YTPD Garage
Stanford University

Test Conditions

Start Time of Test:	3:23:52 AM		Date of Test:	5/30/2004
Driver:	Chris			
Configuration:	Joysticks on Final Aluminum Bezel (In Car Stationary) ** Multi-switch Entry Method ** (Driving Baseline)			

Summary Statistics

Total Test Time:	0:03:53		Total Char. Typed:	110
			Max. WPM	12
			Average WPM:	5.7

Reaction Conditions

Baseline Total		Delta	Typing Total	
Avg. Reaction Time	1.89 Sec	2.94 Sec	Avg. Reaction Time	4.83 Sec
Max. Reaction Time	26.59 Sec	-15.63 Sec	Max. Reaction Time	10.96 Sec
Min. Reaction Time	0.63 Sec	0.44 Sec	Min. Reaction Time	1.07 Sec

Baseline Reaction		Delta	Typing Reaction	
Avg. Reaction Time	0.92 Sec	0.14 Sec	Avg. Reaction Time	1.07 Sec
Max. Reaction Time	1.89 Sec	-0.83 Sec	Max. Reaction Time	1.07 Sec
Min. Reaction Time	0.63 Sec	0.44 Sec	Min. Reaction Time	1.07 Sec

Baseline Surrounding Awareness		Delta	Typing Surrounding Awareness	
Avg. Reaction Time	3.95 Sec	1.52 Sec	Avg. Reaction Time	5.46 Sec
Max. Reaction Time	26.59 Sec	-15.63 Sec	Max. Reaction Time	10.96 Sec
Min. Reaction Time	0.87 Sec	0.69 Sec	Min. Reaction Time	1.56 Sec

Input Test Summary -- Page 2

YTPD Garage
Stanford University

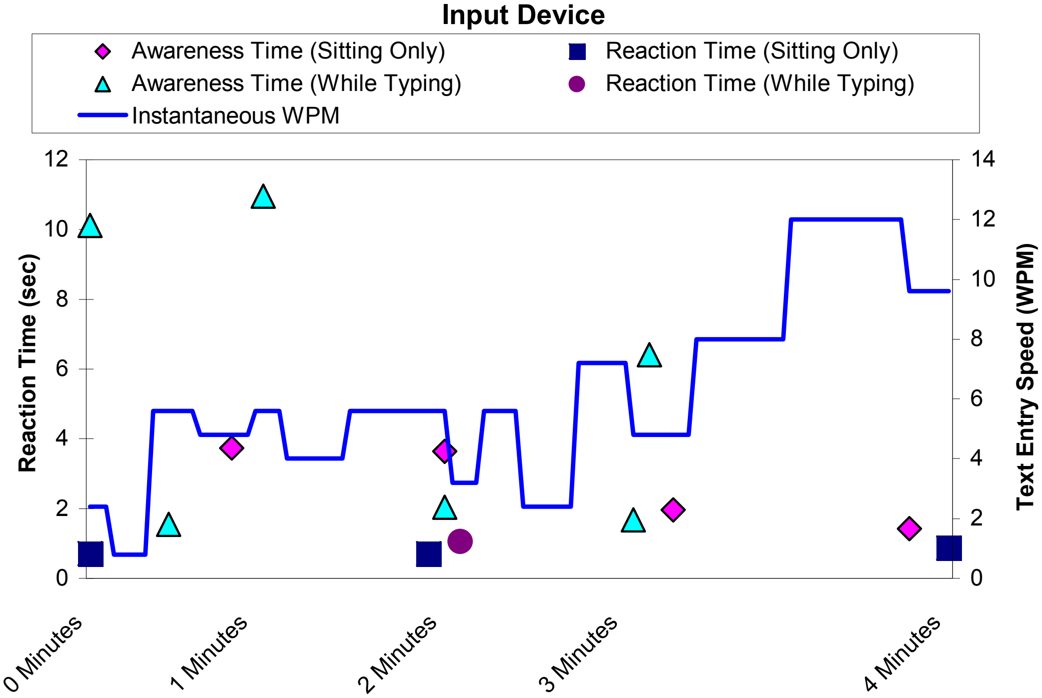
Test Conditions

Start Time of Test:	3:23:52	Date of Test:	5/30/2004
Driver:	Chris		
Configuration:	Joysticks on Final Aluminum Bezel (In Car Stationary) ** Multi-switch Entry Method ** (Driving Baseline)		

Total Typed Text:

the quick brown fyo□□ox jumps over tkk□□he lazy b□dy□ogthe quick brown fyo□□ox jumps over tkff□□□he lb□azy dog

Comparison of Reaction Time Variation and Typing Using Text Input Device



9.6.3 Driving Baseline Data – Nikki

Input Test Summary

Nikki Multitap Data.xls

YTPD Garage
Stanford University

Test Conditions

Start Time of Test:	1:34:02 AM		Date of Test:	5/30/2004
Driver:	Nikki			
Configuration:	Joysticks on Final Aluminum Bezel (In Car Stationary) ** Multi-tap Entry Method ** (Driving Baseline)			

Summary Statistics

Total Test Time:	0:06:28		Total Char. Typed:	464
			Max. WPM	8
			Average WPM:	4.8

Reaction Conditions

Baseline Total		Delta	Typing Total	
Avg. Reaction Time	1.67 Sec	-0.10 Sec	Avg. Reaction Time	1.57 Sec
Max. Reaction Time	30.00 Sec	-26.14 Sec	Max. Reaction Time	3.86 Sec
Min. Reaction Time	0.75 Sec	0.12 Sec	Min. Reaction Time	0.87 Sec

Baseline Reaction		Delta	Typing Reaction	
Avg. Reaction Time	1.19 Sec	0.18 Sec	Avg. Reaction Time	1.38 Sec
Max. Reaction Time	1.67 Sec	0.21 Sec	Max. Reaction Time	1.89 Sec
Min. Reaction Time	0.75 Sec	0.12 Sec	Min. Reaction Time	0.87 Sec

Baseline Surrounding Awareness		Delta	Typing Surrounding Awareness	
Avg. Reaction Time	6.61 Sec	-5.00 Sec	Avg. Reaction Time	1.61 Sec
Max. Reaction Time	30.00 Sec	-26.14 Sec	Max. Reaction Time	3.86 Sec
Min. Reaction Time	1.12 Sec	-0.25 Sec	Min. Reaction Time	0.87 Sec

Input Test Summary -- Page 2

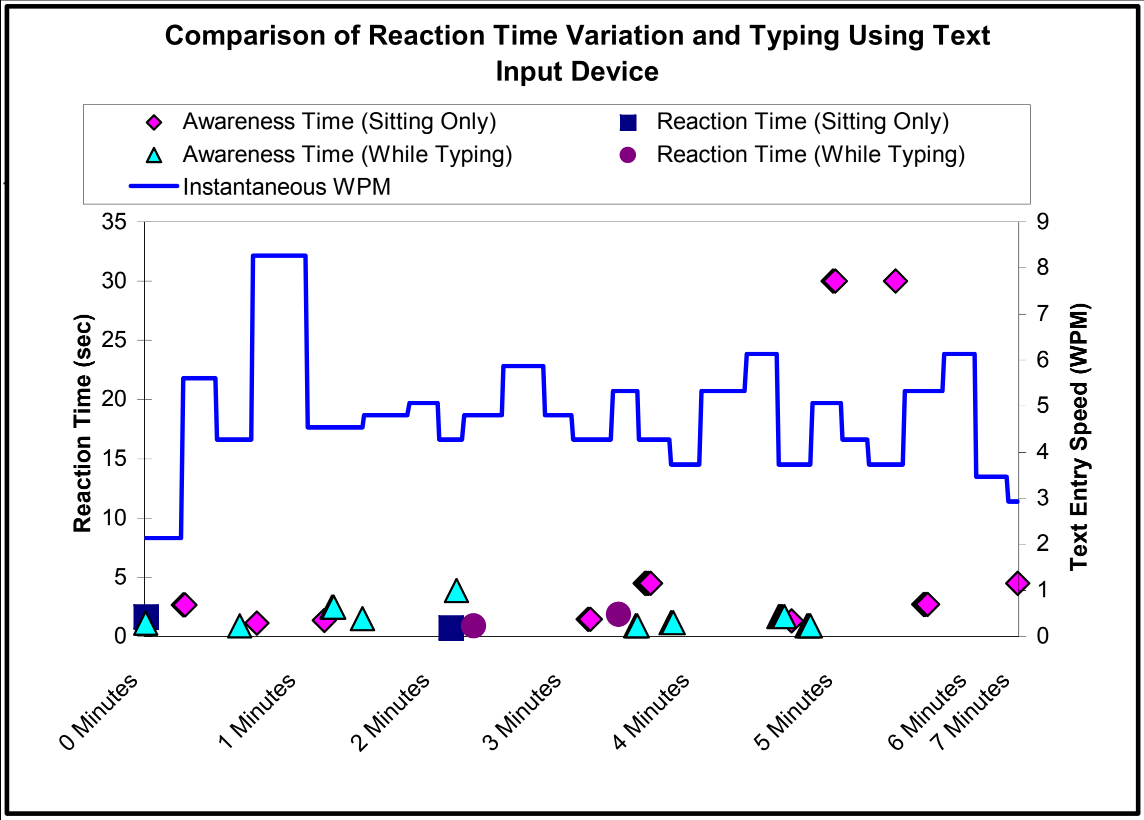
YTPD Garage
Stanford University

Test Conditions

Start Time of Test:	1:34:02		Date of Test:	5/30/2004
Driver:	Nikki			
Configuration:	Joysticks on Final Aluminum Bezel (In Car Stationary) ** Multi-tap Entry Method ** (Driving Baseline)			

Total Typed Text:

888□□8884545□□□□4443330077787□□88844442222555002227777787□□□77877787□□□□□7776666999
□99□666699666□□□99666□□666600333366669999999900555555555588866777770066668888333777700
□□000□7777008888884443663□□□33□4443633□□□3333300555229999999999900363□□□33□003333336
6664400884443363□□□□44433300777888444422225550022277766636□□666□□666669999999966600333
36666999005588866666677777777777006666688883338□7777005□888888444333005555229999999999990063
□□333333□00363□□□3333366□666666446663



Input Test Summary

Nikki Multiswitch Data.xls

YTPD Garage
Stanford University

Test Conditions

Start Time of Test:	8:27:41 PM	Date of Test:	6/2/2004
Driver:	Nikki		
Configuration:	Joysticks on Final Aluminum Bezel (In Car Stationary) ** Multi-switch Entry Method ** (Driving Baseline)		

Summary Statistics

Total Test Time:	0:11:08	Total Char. Typed:	389
		Max. WPM	16
		Average WPM:	7.0

Reaction Conditions

Baseline Total		Delta	Typing Total	
Avg. Reaction Time	1.67 Sec	7.05 Sec	Avg. Reaction Time	8.72 Sec
Max. Reaction Time	30.00 Sec	0.00 Sec	Max. Reaction Time	30.00 Sec
Min. Reaction Time	0.75 Sec	0.82 Sec	Min. Reaction Time	1.57 Sec

Baseline Reaction		Delta	Typing Reaction	
Avg. Reaction Time	1.19 Sec	9.38 Sec	Avg. Reaction Time	10.57 Sec
Max. Reaction Time	1.67 Sec	8.90 Sec	Max. Reaction Time	10.57 Sec
Min. Reaction Time	0.75 Sec	9.82 Sec	Min. Reaction Time	10.57 Sec

Baseline Surrounding Awareness		Delta	Typing Surrounding Awareness	
Avg. Reaction Time	6.61 Sec	1.93 Sec	Avg. Reaction Time	8.54 Sec
Max. Reaction Time	30.00 Sec	0.00 Sec	Max. Reaction Time	30.00 Sec
Min. Reaction Time	1.12 Sec	0.45 Sec	Min. Reaction Time	1.57 Sec

Input Test Summary -- Page 2

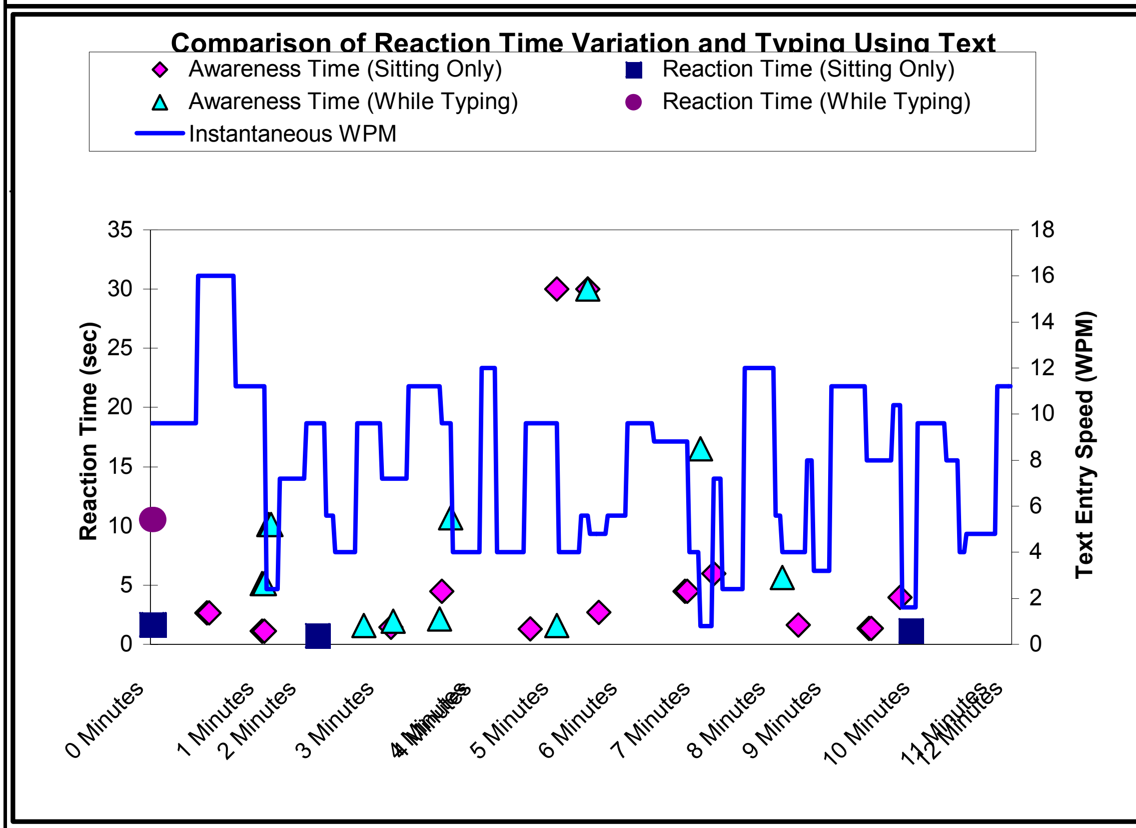
YTPD Garage
Stanford University

Test Conditions

Start Time of Test:	20:27:41	Date of Test:	6/2/2004
Driver:	Nikki		
Configuration:	Joysticks on Final Aluminum Bezel (In Car Stationary) ** Multi-switch Entry Method ** (Driving Baseline)		

Total Typed Text:

the quick ewn fy□ox k□jumps over the lazxy□□y dog. the quick brown o□fox jumps over the lazy dog. tk□he quick brown o□fox jumps over the layxyx□□□□zy dog. the layx□□zy brown e□d□fox thequ□□ quick erown fox jumps over the lazy dog. theq □□q□ quick e □□□brown fmo□□ox t□jumps over the v□lazy dog.   thequ □□□□ quick brown fox jumps oveq□r the la□□lazyx□ doh□g. the quick brown fox j



9.6.4 Driving Baseline Data – Philipp

Input Test Summary

Philipp Multitap Data_280.xls

YTPD Garage
Stanford University

Test Conditions

Start Time of Test:	1:34:02 AM	Date of Test:	5/30/2004
Driver:	Philipp		
Configuration:	Joysticks on Final Aluminum Bezel (In Car Stationary) ** Multi-tap Entry Method ** (Driving Baseline)		

Summary Statistics

Total Test Time:	0:06:28	Total Char. Typed:	464
		Max. WPM	8
		Average WPM:	4.8

Reaction Conditions

Baseline Total		Delta	Typing Total	
Avg. Reaction Time	1.15 Sec	0.42 Sec	Avg. Reaction Time	1.57 Sec
Max. Reaction Time	2.14 Sec	1.72 Sec	Max. Reaction Time	3.86 Sec
Min. Reaction Time	0.60 Sec	0.26 Sec	Min. Reaction Time	0.87 Sec

Baseline Reaction		Delta	Typing Reaction	
Avg. Reaction Time	0.85 Sec	0.53 Sec	Avg. Reaction Time	1.38 Sec
Max. Reaction Time	1.15 Sec	0.74 Sec	Max. Reaction Time	1.89 Sec
Min. Reaction Time	0.60 Sec	0.26 Sec	Min. Reaction Time	0.87 Sec

Baseline Surrounding Awareness		Delta	Typing Surrounding Awareness	
Avg. Reaction Time	1.13 Sec	0.48 Sec	Avg. Reaction Time	1.61 Sec
Max. Reaction Time	2.14 Sec	1.72 Sec	Max. Reaction Time	3.86 Sec
Min. Reaction Time	0.70 Sec	0.17 Sec	Min. Reaction Time	0.87 Sec

Input Test Summary -- Page 2

YTPD Garage
Stanford University

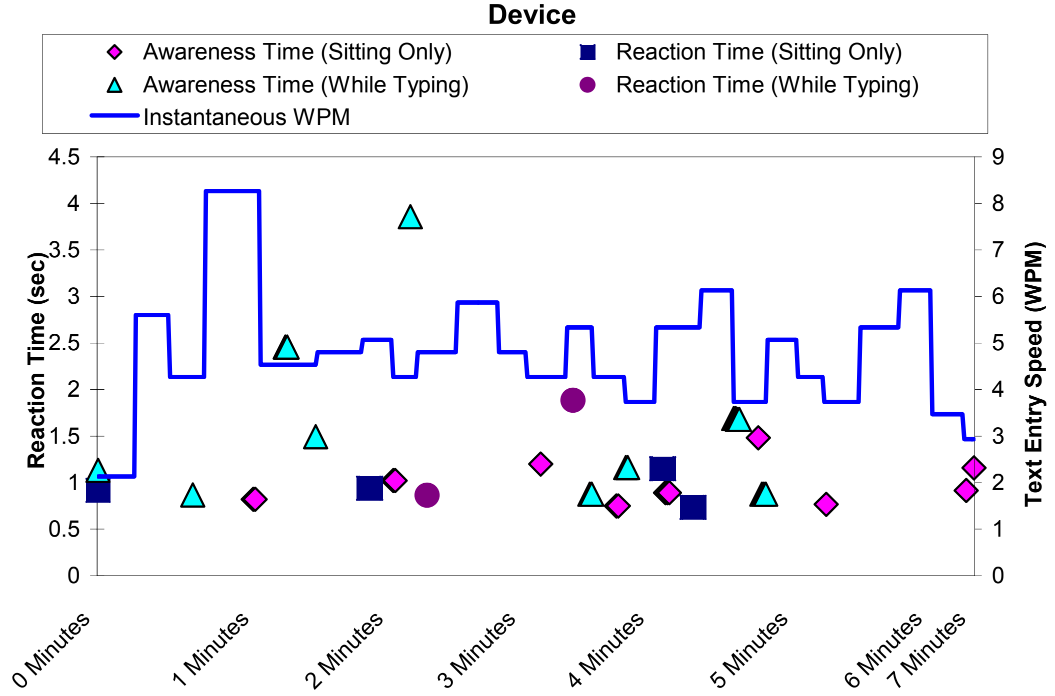
Test Conditions

Start Time of Test:	1:34:02		Date of Test:	5/30/2004
Driver:	Philipp			
Configuration:	Joysticks on Final Aluminum Bezel (In Car Stationary) ** Multi-tap Entry Method ** (Driving Baseline)			

Total Typed Text:

888□□8884545□□□□4443330077787□□88844442222555002227777787□□□77877787□□□□□7776666999□
99□666699666□□□99666□□666600333366669999999900555555555588866777770066668888333777700□□
000□7777008888884443663□□□33□4443633□□□33333005555229999999999900363□□□33□003333336666
4400884443363□□□□444333007778884444222255500222777766636□□666□□666669999999666003333666
699900558886666667777777777006666888833338□7777005□888888444333005555229999999999990063□□33
3333□00363□□□3333366□666666446663

Comparison of Reaction Time Variation and Typing Using Text Input Device



Input Test Summary

Philipp Multiswitch Data_280.xls

YTPD Garage
Stanford University

Test Conditions

Start Time of Test:	1:23:18 AM		Date of Test:	5/30/2004
Driver:	Philipp			
Configuration:	Joysticks on Final Aluminum Bezel (In Car Stationary) ** Multi-switch Entry Method ** (Driving Baseline)			

Summary Statistics

Total Test Time:	0:04:09		Total Char. Typed:	91
			Max. WPM	6
			Average WPM:	4.4

Reaction Conditions

Baseline Total		Delta	Typing Total	
Avg. Reaction Time	1.15 Sec	0.98 Sec	Avg. Reaction Time	2.13 Sec
Max. Reaction Time	2.14 Sec	2.13 Sec	Max. Reaction Time	4.27 Sec
Min. Reaction Time	0.60 Sec	0.23 Sec	Min. Reaction Time	0.83 Sec

Baseline Reaction		Delta	Typing Reaction	
Avg. Reaction Time	0.85 Sec	0.06 Sec	Avg. Reaction Time	0.91 Sec
Max. Reaction Time	1.15 Sec	-0.17 Sec	Max. Reaction Time	0.98 Sec
Min. Reaction Time	0.60 Sec	0.23 Sec	Min. Reaction Time	0.83 Sec

Baseline Surrounding Awareness		Delta	Typing Surrounding Awareness	
Avg. Reaction Time	1.13 Sec	1.35 Sec	Avg. Reaction Time	2.48 Sec
Max. Reaction Time	2.14 Sec	2.13 Sec	Max. Reaction Time	4.27 Sec
Min. Reaction Time	0.70 Sec	0.58 Sec	Min. Reaction Time	1.28 Sec

Input Test Summary -- Page 2

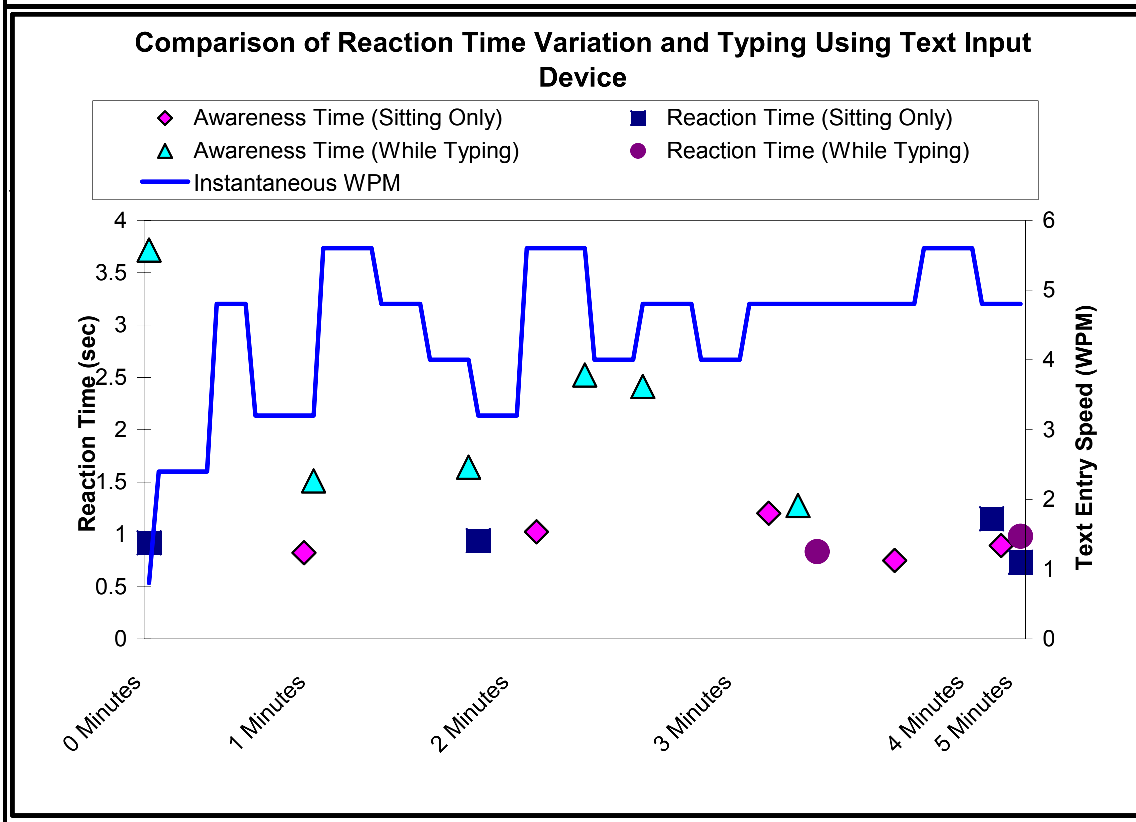
YTPD Garage
Stanford University

Test Conditions

Start Time of Test:	1:23:18	Date of Test:	5/30/2004
Driver:	Philipp		
Configuration:	Joysticks on Final Aluminum Bezel (In Car Stationary) ** Multi-switch Entry Method ** (Driving Baseline)		

Total Typed Text:

the quick brown fy□ox j □umps over the lazy dog the quick brown fox jumps over the lazy dog



9.6.5 Advanced User Data – Nikki

Input Test Summary

YTPD Garage
Stanford University

Test Conditions

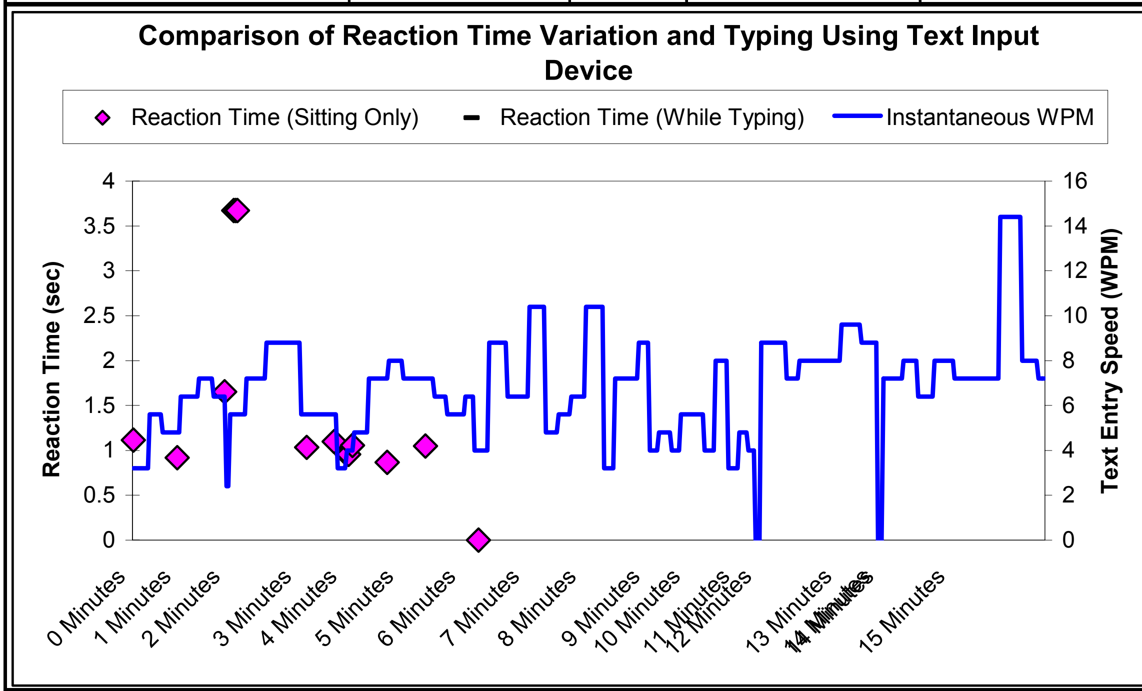
Start Time of Test:	6:09:35 PM		Date of Test:	5/25/2004
Driver:	Nikki			
Configuration:	Joysticks on Final Aluminum Bezel (In Car Stationary) ** Multi-switch Entry Method **			

Summary Statistics

Total Test Time:	0:31:07		Total Char. Typed:	1,001
			Max. WPM	14
			Average WPM:	6.4

Reaction Conditions

Baseline			Typing	
Avg. Reaction Time	1.3 Sec		Avg. Reaction Time	#DIV/0!
Max. Reaction Time	3.7 Sec		Max. Reaction Time	0.0 Sec
Min. Reaction Time	0.9 Sec		Min. Reaction Time	0.0 Sec



Input Test Summary

YTPD Garage
Stanford University

Test Conditions

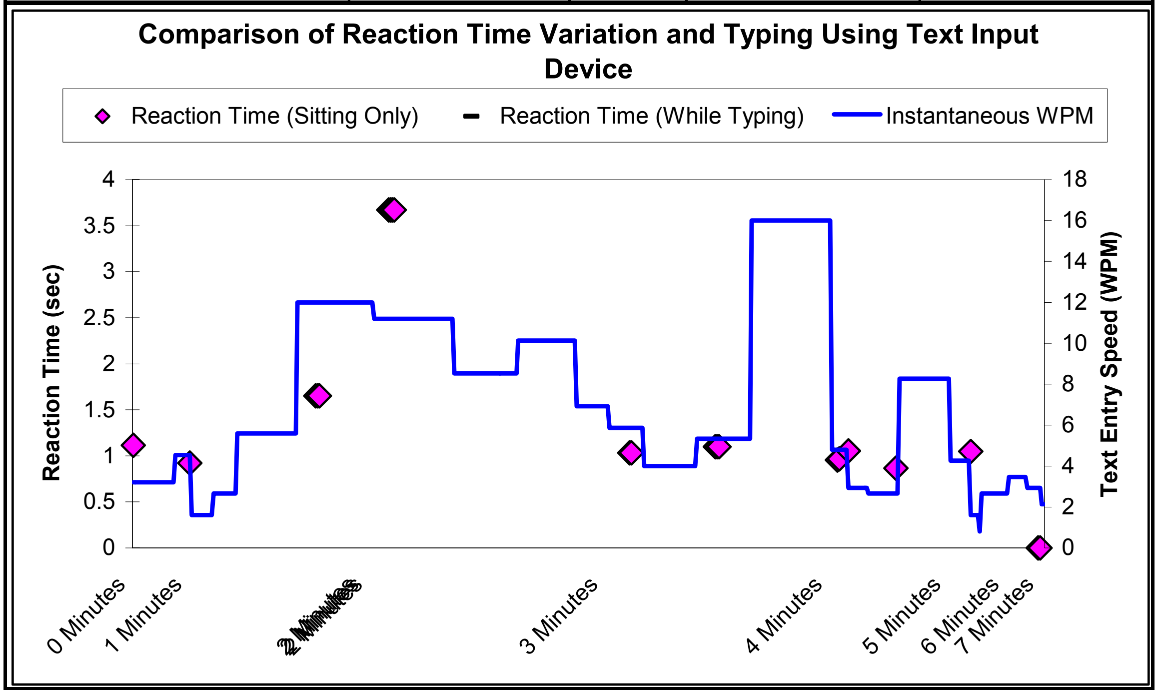
Start Time of Test:	1:54:27 AM	Date of Test:	5/28/2004
Driver:	Nikki		
Configuration:	Joysticks on Final Aluminum Bezel (In Car Stationary) ** Multi-tap Entry Method **		

Summary Statistics

Total Test Time:	0:11:10	Total Char. Typed:	788
		Max. WPM	16
		Average WPM:	4.7

Reaction Conditions

Baseline		Typing	
Avg. Reaction Time	1.3 Sec	Avg. Reaction Time	#DIV/0!
Max. Reaction Time	3.7 Sec	Max. Reaction Time	0.0 Sec
Min. Reaction Time	0.9 Sec	Min. Reaction Time	0.0 Sec



Input Test Summary

YTPD Garage
Stanford University

Test Conditions

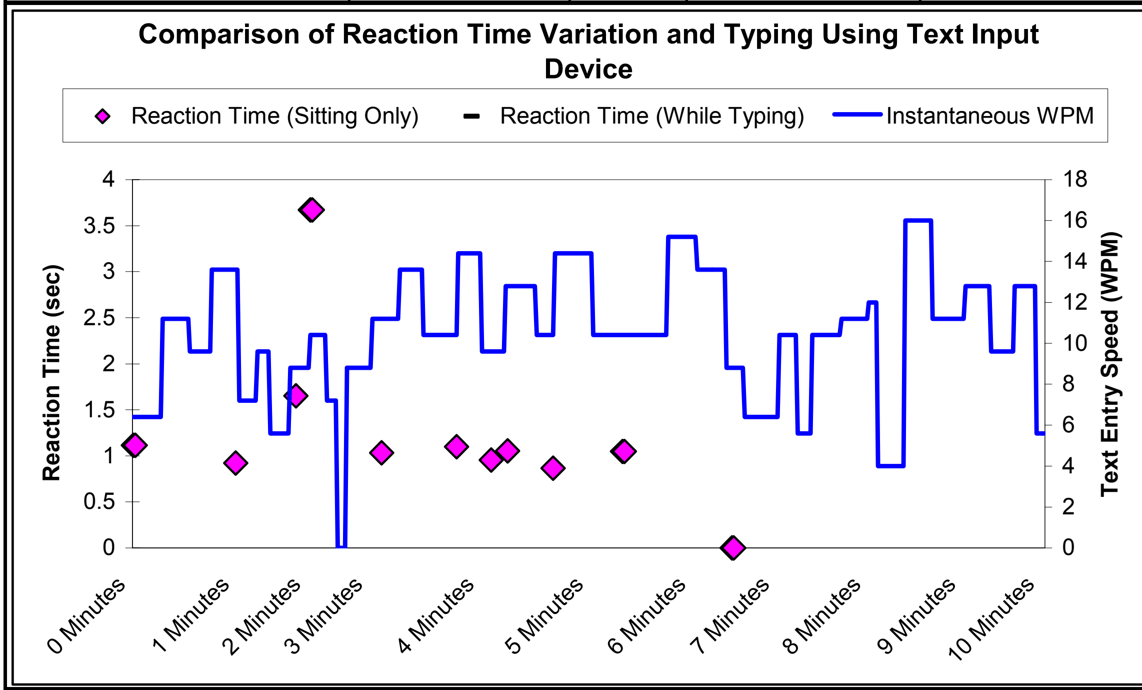
Start Time of Test:	6:36:37 PM		Date of Test:	5/31/2004
Driver:	Nikki			
Configuration:	Joysticks on Final Aluminum Bezel (In Car Stationary) ** Multi-switch Entry Method **			

Summary Statistics

Total Test Time:	0:20:32		Total Char. Typed:	1,000
			Max. WPM	18
			Average WPM:	9.7

Reaction Conditions

Baseline			Typing	
Avg. Reaction Time	1.3 Sec		Avg. Reaction Time	#DIV/0!
Max. Reaction Time	3.7 Sec		Max. Reaction Time	0.0 Sec
Min. Reaction Time	0.9 Sec		Min. Reaction Time	0.0 Sec



9.6.6 Comparison to Radio Data – Chris

Input Test Summary

Chris radio comparison.xls

YTPD Garage
Stanford University

Test Conditions

Start Time of Test:	10:52:18 PM		Date of Test:	6/2/2004
Driver:	Chris			
Configuration:	Comparison of Driving VS. Operating Radio			

Summary Statistics

Total Test Time:	0:16:52		Total Char. Typed:	28
			Max. WPM	2
			Average WPM:	0.3

Reaction Conditions

Baseline Total		Delta	Typing Total	
Avg. Reaction Time	1.89 Sec	0.57 Sec	Avg. Reaction Time	2.46 Sec
Max. Reaction Time	26.59 Sec	-7.34 Sec	Max. Reaction Time	19.26 Sec
Min. Reaction Time	0.63 Sec	0.07 Sec	Min. Reaction Time	0.70 Sec

Baseline Reaction		Delta	Typing Reaction	
Avg. Reaction Time	0.92 Sec	0.65 Sec	Avg. Reaction Time	1.58 Sec
Max. Reaction Time	1.89 Sec	1.15 Sec	Max. Reaction Time	3.04 Sec
Min. Reaction Time	0.63 Sec	0.12 Sec	Min. Reaction Time	0.75 Sec

Baseline Surrounding Awareness		Delta	Typing Surrounding Awareness	
Avg. Reaction Time	3.95 Sec	-1.06 Sec	Avg. Reaction Time	2.88 Sec
Max. Reaction Time	26.59 Sec	-7.34 Sec	Max. Reaction Time	19.26 Sec
Min. Reaction Time	0.87 Sec	-0.16 Sec	Min. Reaction Time	0.70 Sec

Input Test Summary -- Page 2

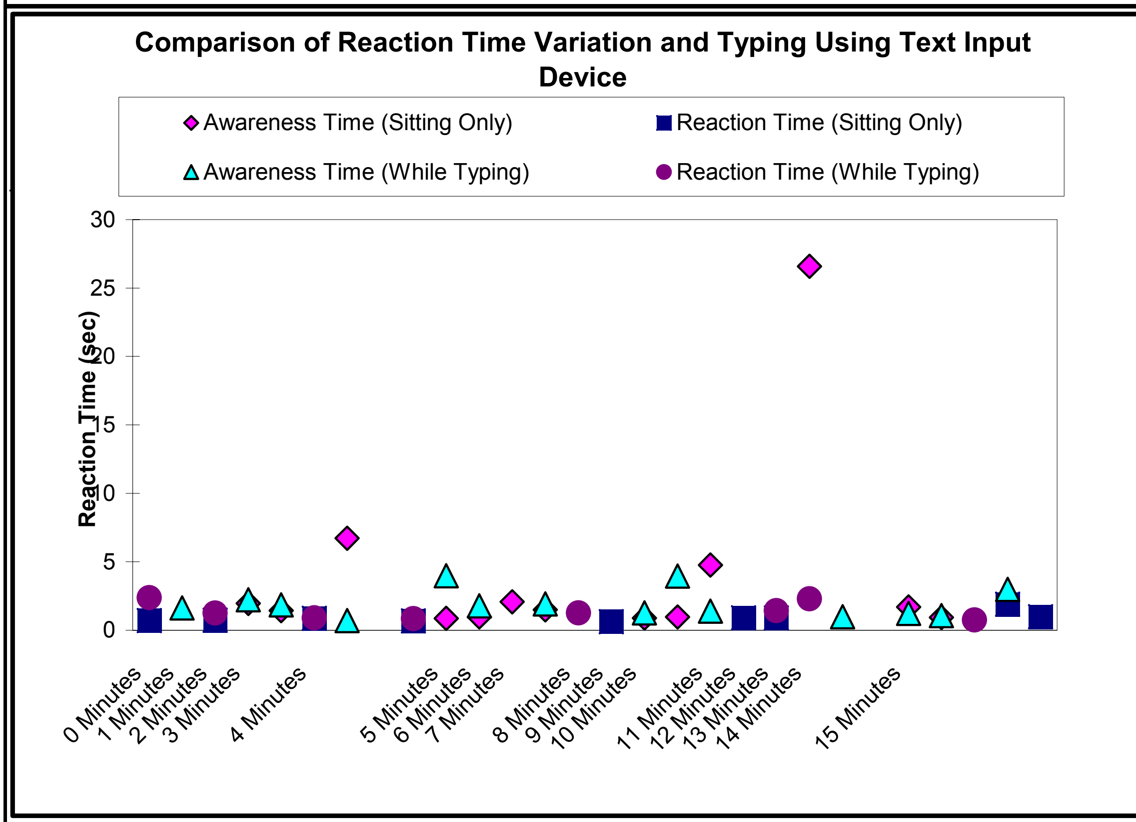
YTPD Garage
Stanford University

Test Conditions

Start Time of Test:	22:52:18	Date of Test:	6/2/2004
Driver:	Chris		
Configuration:	Comparison of Driving VS. Operating Radio		

Total Typed Text:

#N/A



9.6.7 Driving Data – Dave

Input Test Summary

Dave_280_Mulitap.xls

YTPD Garage
Stanford University

Test Conditions

Start Time of Test:	5:19:49 AM	Date of Test:	5/31/2004
Driver:	Dave		
Configuration:	Joysticks on Final Aluminum Bezel (In Car Driving Hwy280) ** Multi-tap Entry Method **		

Summary Statistics

Total Test Time:	0:17:04	Total Char. Typed:	576
		Max. WPM	4
		Average WPM:	2.3

Reaction Conditions

Baseline Total		Delta	Typing Total	
Avg. Reaction Time	3.11 Sec	7.35 Sec	Avg. Reaction Time	10.45 Sec
Max. Reaction Time	3.11 Sec	26.89 Sec	Max. Reaction Time	30.00 Sec
Min. Reaction Time	1.13 Sec	0.27 Sec	Min. Reaction Time	1.40 Sec

Baseline Reaction		Delta	Typing Reaction	
Avg. Reaction Time	1.69 Sec	-0.19 Sec	Avg. Reaction Time	1.51 Sec
Max. Reaction Time	3.11 Sec	-1.49 Sec	Max. Reaction Time	1.62 Sec
Min. Reaction Time	1.16 Sec	0.24 Sec	Min. Reaction Time	1.40 Sec

Baseline Surrounding Awareness		Delta	Typing Surrounding Awareness	
Avg. Reaction Time	1.26 Sec	10.78 Sec	Avg. Reaction Time	12.04 Sec
Max. Reaction Time	1.43 Sec	28.57 Sec	Max. Reaction Time	30.00 Sec
Min. Reaction Time	1.13 Sec	0.60 Sec	Min. Reaction Time	1.73 Sec

Input Test Summary -- Page 2

YTPD Garage
Stanford University

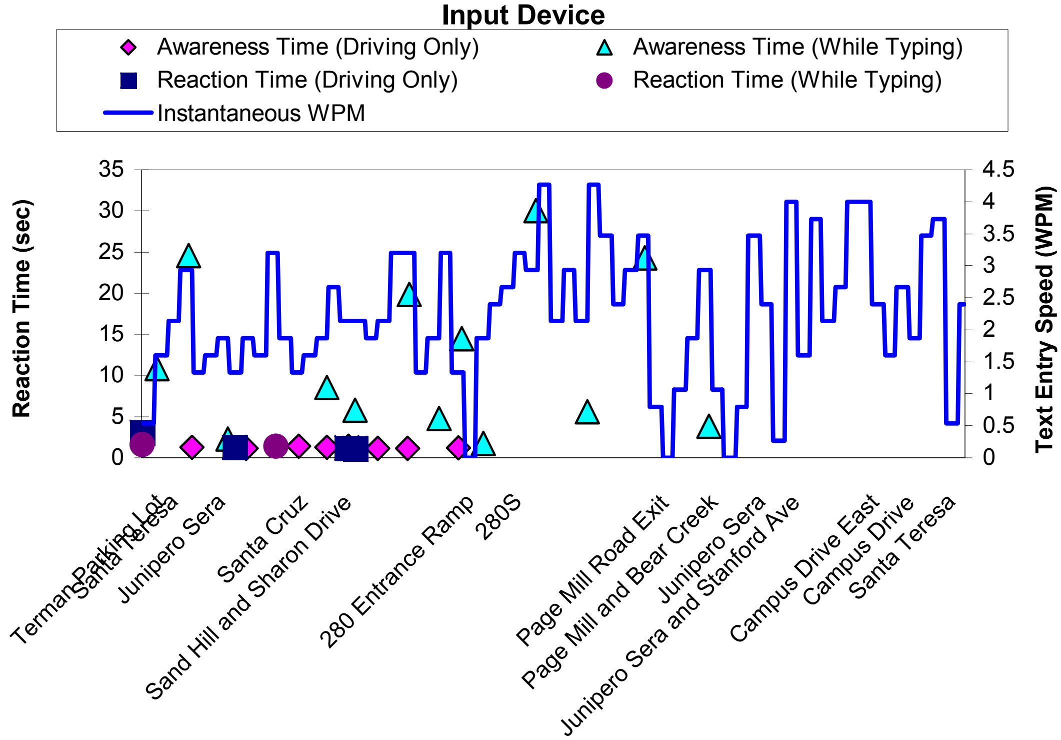
Test Conditions

Start Time of Test:	5:19:49		Date of Test:	5/31/2004
Driver:	Dave			
Configuration:	Joysticks on Final Aluminum Bezel (In Car Driving Hwy280) ** Multi-tap Entry Method **			

Total Typed Text:

00888444333007778884444222255500222777766669966600333366666999005588866666666666770□7777766
6□00666688883337777008844433300660□6666□□555522999990□99990033666688888□440088444333007
77888444422225550022277776666996660033333666699900558886670□7777700666688883337770007□□□7
77□33377770088444333005555222222999990□999900336666440088444333007778884444222255500222777
776666□6□77776666999999966600333366669990055888667777770□77777006666888833377770088443
3300555522999990□999900333333666644444400884443337777□7□333007778884444222255500222777766
6699999999666666600333366669990055888667770□77777

Comparison of Response Time Variation and Typing Using Text Input Device



Input Test Summary -- Page 3

YTPD Garage
Stanford University

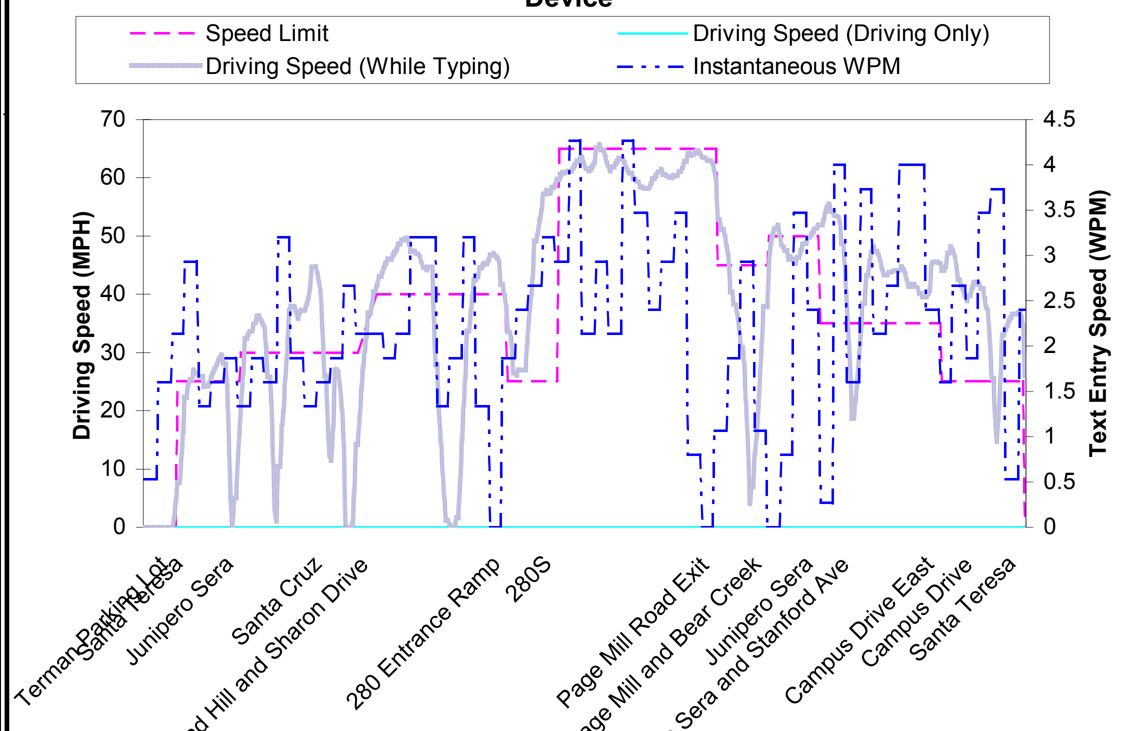
Test Conditions

Start Time of Test:	5:19:49	Date of Test:	5/31/2004
Driver:	Dave		
Configuration:	Joysticks on Final Aluminum Bezel (In Car Driving Hwy280) ** Multi-tap Entry Method **		

Total Typed Text:

00888444333007778884444222255500222777766669966600333366669990055888666666666770□7777766
6□00666688883337777008844433300660□6666□□555522999990□9999003366668888□440088444333007
77888444422225550022277776666996660033336666999005588866770□7777700666688883337770070□□□7
77□3337777008844433300555522222299990□99990033666644008844433300777888444422225550022277
776666□6□777766669999999666003333666699900558886677777770□777770066668888333777700884443
3300555522999990□99990033333366664444440088444333777□7□333007778884444222255500222777766
66999999966666660033336666999005588866770□77777

Comparison of Speed Variations and Typing Using Text Input Device



Input Test Summary

Dave_280_Multiswitch.xls

YTPD Garage
Stanford University

Test Conditions

Start Time of Test:	5:45:18 AM		Date of Test:	5/31/2004
Driver:	Dave			
Configuration:	Joysticks on Final Aluminum Bezel (In Car Driving Hwy280) ** Multi-switch Entry Method **			

Summary Statistics

Total Test Time:	0:18:03		Total Char. Typed:	423
			Max. WPM	9
			Average WPM:	4.7

Reaction Conditions

Baseline Total		Delta	Typing Total	
Avg. Reaction Time	3.11 Sec	9.81 Sec	Avg. Reaction Time	12.91 Sec
Max. Reaction Time	3.11 Sec	26.89 Sec	Max. Reaction Time	30.00 Sec
Min. Reaction Time	1.13 Sec	-0.12 Sec	Min. Reaction Time	1.01 Sec

Baseline Reaction		Delta	Typing Reaction	
Avg. Reaction Time	1.69 Sec	0.57 Sec	Avg. Reaction Time	2.27 Sec
Max. Reaction Time	3.11 Sec	2.50 Sec	Max. Reaction Time	5.61 Sec
Min. Reaction Time	1.16 Sec	-0.15 Sec	Min. Reaction Time	1.01 Sec

Baseline Surrounding Awareness		Delta	Typing Surrounding Awareness	
Avg. Reaction Time	1.26 Sec	14.61 Sec	Avg. Reaction Time	15.87 Sec
Max. Reaction Time	1.43 Sec	28.57 Sec	Max. Reaction Time	30.00 Sec
Min. Reaction Time	1.13 Sec	0.19 Sec	Min. Reaction Time	1.32 Sec

Input Test Summary -- Page 2

YTPD Garage
Stanford University

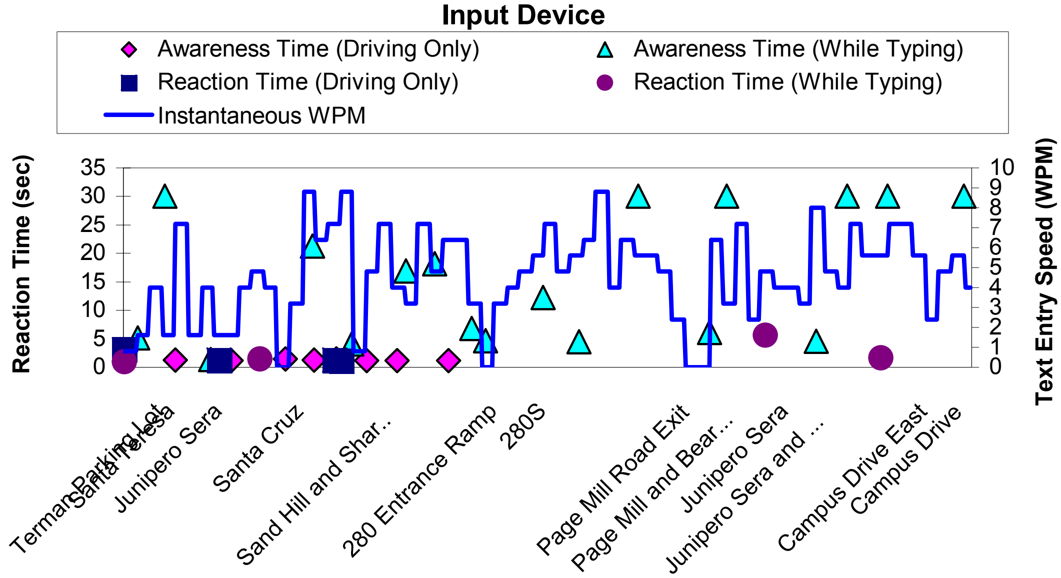
Test Conditions

Start Time of Test:	5:45:18	Date of Test:	5/31/2004
Driver:	Dave		
Configuration:	Joysticks on Final Aluminum Bezel (In Car Driving Hwy280) ** Multi-switch Entry Method **		

Total Typed Text:

the quii□d□dfd□□□d□dk browo□n fox jumps over the lazy dog the quicj□k brown fox jumps over the lazy dog uhe quicj□tu□□k broy□wn fox jumps over the lazy dog the quia□ck brown fox jumps overs the lazy dog the quick bq□rownfox jumps ovdr u□the lazy dog the quick brown fox jumps over the lazy dog tthe quick brown fox jumpr□s0□ over the lazy dog the quick brown fox jun□o□mps over the lazy dog the quick biown fox jkumrs ove

Comparison of Response Time Variation and Typing Using Text Input Device



Input Test Summary -- Page 3

YTPD Garage
Stanford University

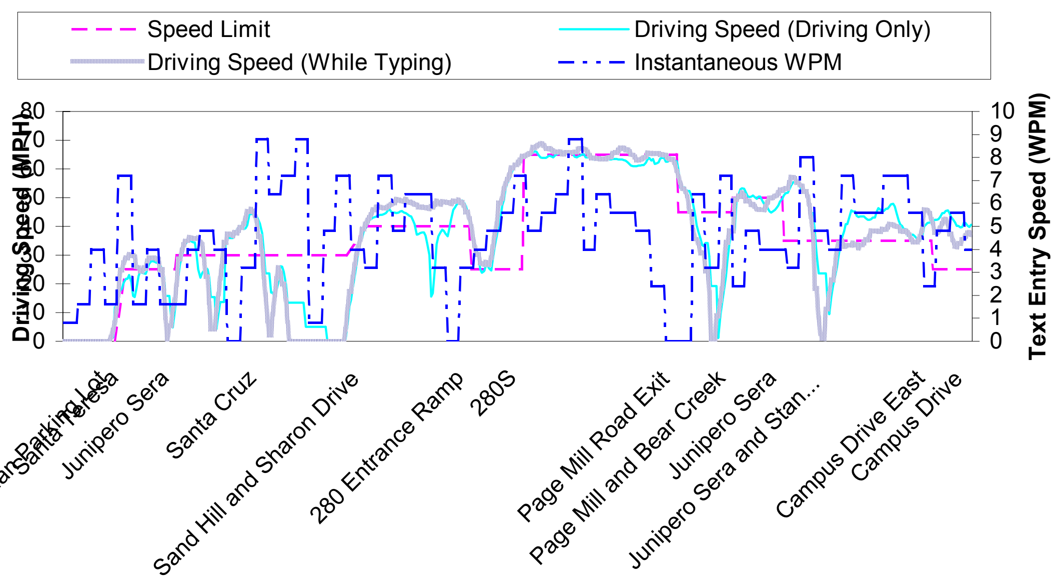
Test Conditions

Start Time of Test:	5:45:18		Date of Test:	5/31/2004
Driver:	Dave			
Configuration:	Joysticks on Final Aluminum Bezel (In Car Driving Hwy280) ** Multi-switch Entry Method **			

Total Typed Text:

the quii□d□dfd□□□d□dk browo□n fox jumps over the lazy dog the quicj□k brown fox jumps over the lazy dog uhe quicj□tu□□k broy□wn fox jumps over the lazy dog the quia□ck brown fox jumps overs the lazy dog the quick bq□rownfox jumps ovdr u□the lazy dog the quick brown fox jumps over the lazy dog tthe quick brown fox jumpr□s0□ over the lazy dog the quick brown fox jun□o□mps over the lazy dog the quick biown fox jkumrs ove

Comparison of Speed Variations and Typing Using Text Input Device



9.6.8 Driving Data – Philipp

Input Test Summary

Philipp_280_Multiswitch.xls

YTPD Garage
Stanford University

Test Conditions

Start Time of Test:	12:00:00 AM	Date of Test:	6/2/2004
Driver:	Philipp		
Configuration:	Joysticks on Final Aluminum Bezel (In Car Driving) ** Multi-tap Entry Method **		

Summary Statistics

Total Test Time:	0:16:02	Total Char. Typed:	543
		Max. WPM	14
		Average WPM:	6.8

Reaction Conditions

Baseline Total		Delta	Typing Total	
Avg. Reaction Time	1.15 Sec	0.05 Sec	Avg. Reaction Time	1.20 Sec
Max. Reaction Time	2.14 Sec	0.94 Sec	Max. Reaction Time	3.07 Sec
Min. Reaction Time	0.60 Sec	0.01 Sec	Min. Reaction Time	0.61 Sec

Baseline Reaction		Delta	Typing Reaction	
Avg. Reaction Time	0.85 Sec	0.15 Sec	Avg. Reaction Time	1.00 Sec
Max. Reaction Time	1.15 Sec	0.40 Sec	Max. Reaction Time	1.55 Sec
Min. Reaction Time	0.60 Sec	0.01 Sec	Min. Reaction Time	0.61 Sec

Baseline Surrounding Awareness		Delta	Typing Surrounding Awareness	
Avg. Reaction Time	1.13 Sec	0.13 Sec	Avg. Reaction Time	1.26 Sec
Max. Reaction Time	2.14 Sec	0.94 Sec	Max. Reaction Time	3.07 Sec
Min. Reaction Time	0.70 Sec	0.02 Sec	Min. Reaction Time	0.72 Sec

Input Test Summary -- Page 2

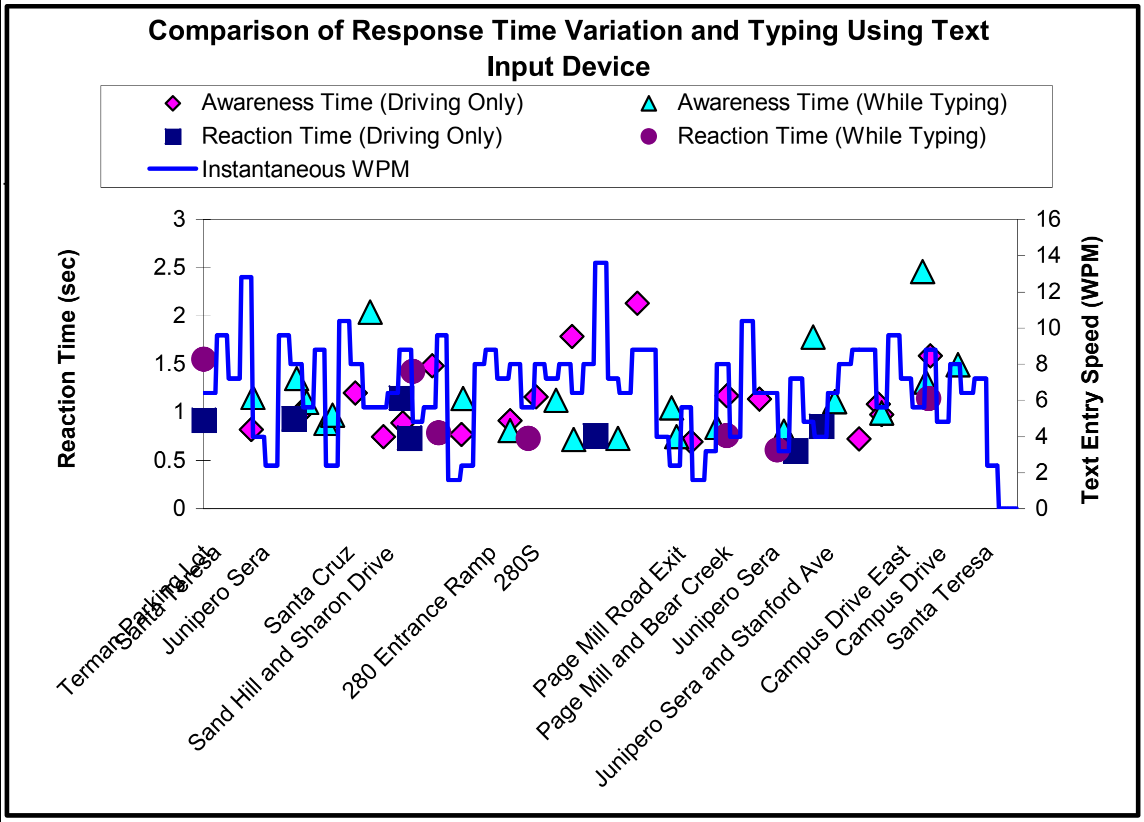
YTPD Garage
Stanford University

Test Conditions

Start Time of Test:	0:00:00	Date of Test:	6/2/2004
Driver:	Philipp		
Configuration:	Joysticks on Final Aluminum Bezel (In Car Driving) ** Multi-tap Entry Method **		

Total Typed Text:

xyz□□□u□rsr□□□uuvvut□□□□□□v□t□vvtutt□□□□□□wo□u□k□l□v□ljl□□□l□omn□□□n0□
fwyz□□□ow□□oy□w□x00□□ jr□pq□□qr□□umpq□eby9□□□e□d y□ou□vf□ev□pr□□r
q□fo□□q□p□tu□hd□e□e h□ut□□j□kkl□□□lazx□y dog pq□□q□p□thfdf□□□e p□quh□ich□i□k
by□qr□□ry□ou□wn e□fyz□□o 0000□□□□□□u□v□w□w□x
p□gh□□jumt□□n□mu□jlk□□□ommon□□□□□□pd□fe□□ed ot□u□vev□t□r q□u□the u□kl□□lb□azx□y dog
u□tt□he p□quh□ick bt□rou□v□u□wk□o□jj□□k□m□n fy□o □w□v□x i□juw□n□mr□peed□□d ou□ver
u□thf□e g□j□k□lazyz□ dy□og q□r□vt□□u□u□v□u□u□tu□g□qp□□he quicu□k
by□rs□z□ou□v□□yo□□ou□v□y□w d□df□□fow□y□x k□jumpq□ede□ o



Input Test Summary -- Page 3

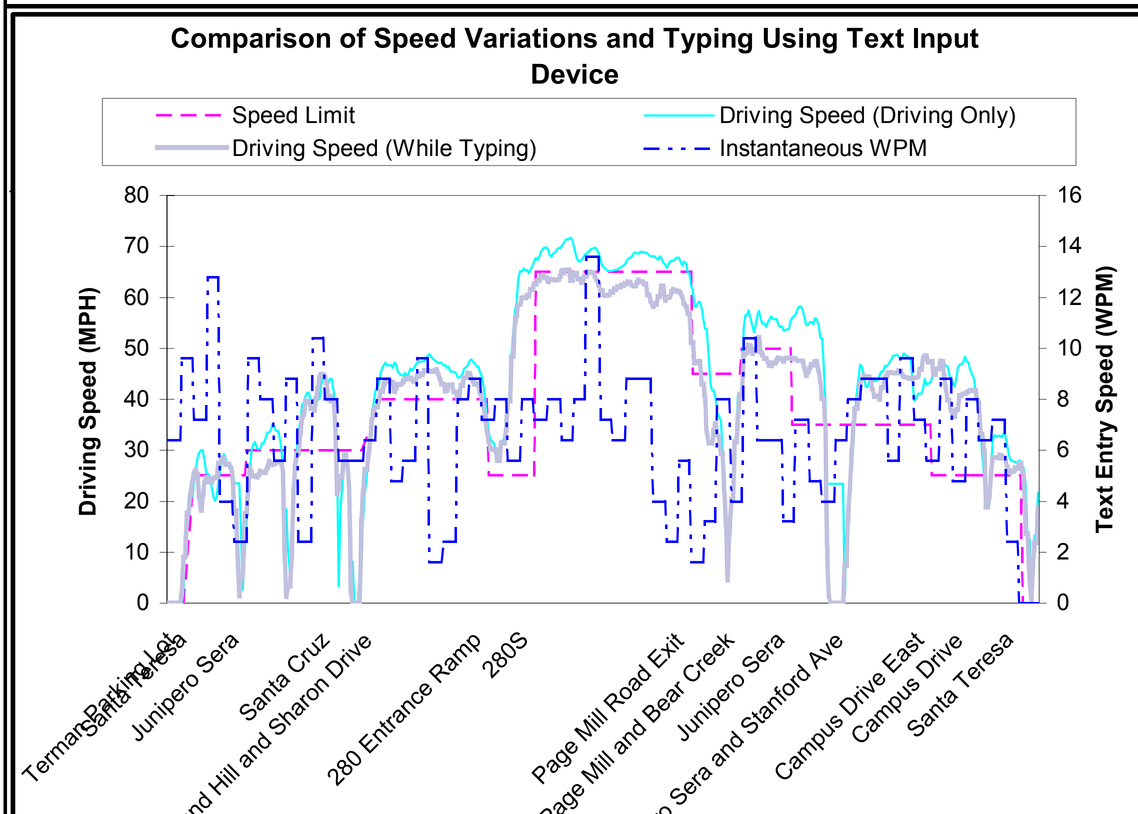
YTPD Garage
Stanford University

Test Conditions

Start Time of Test:	0:00:00	Date of Test:	6/2/2004
Driver:	Philipp		
Configuration:	Joysticks on Final Aluminum Bezel (In Car Driving) ** Multi-tap Entry Method **		

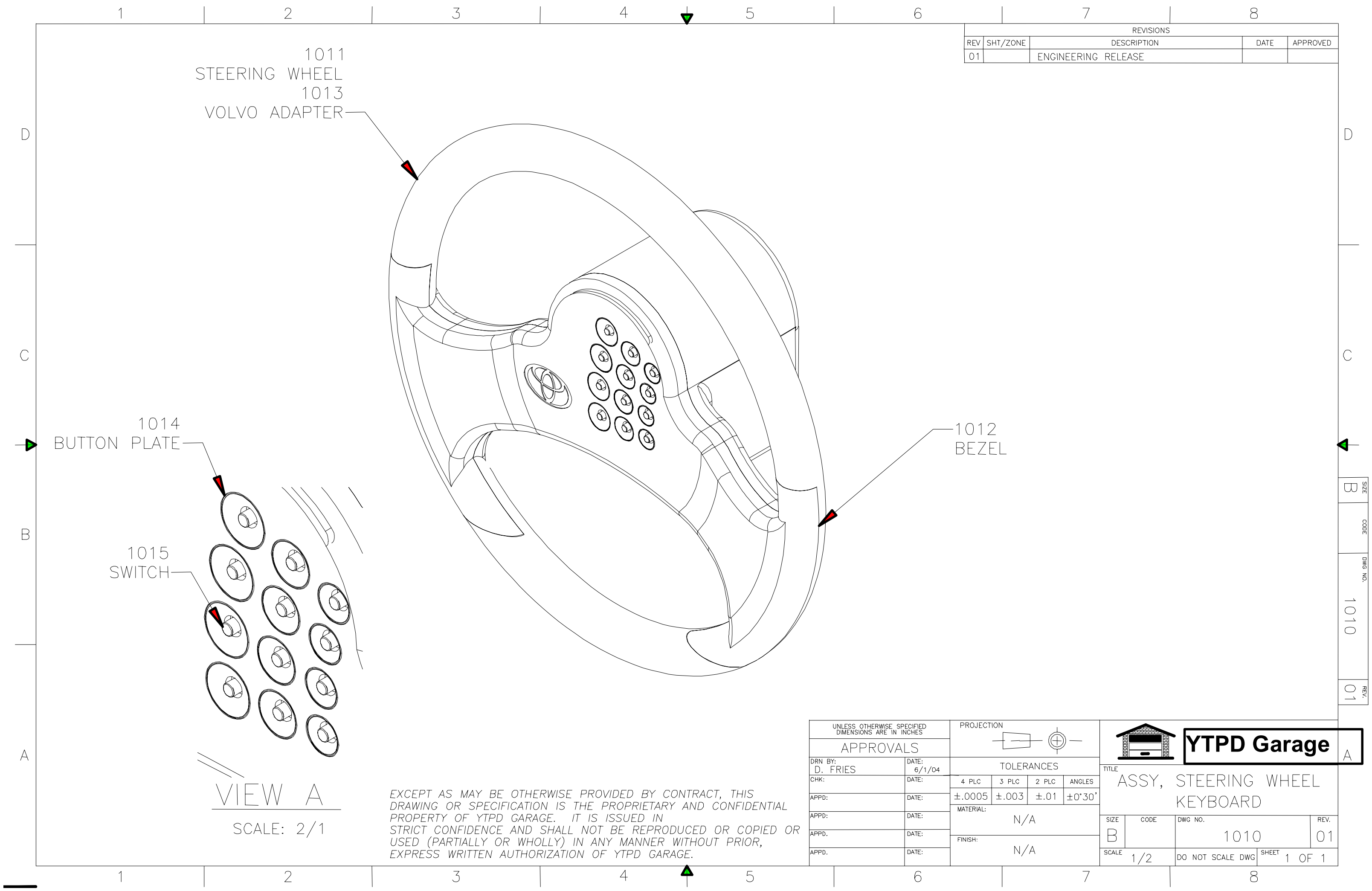
Total Typed Text:

xyz□□□u□rsr□□□uuvvut□□□□□□v□t□vvtutt□□□□□□wo□u□k□l□v□ljl□□□l□omn□□□n0□
fwyz□□□ow□□oy□w□x00□□ jr□pq□□qr□□umpq□eby9□□□e□d y□ou□vf□ev□pr□□r
q□fo□□q□p□tu□hd□e□e h□ut□□j□kkl□□□lazx□y dog pq□□q□p□thfdf□□□e p□quh□ich□i□k
by□qr□□ry□ou□wn e□fyz□□o 0000□□□□□□u□v□w□w□x
p□gh□□jumt□□n□mu□jlk□□□ommon□□□□□□pd□fe□□ed ot□u□vev□t□r q□u□the u□kl□□lb□azx□y dog
u□tt□he p□quh□ick bt□rou□v□u□wk□o□jj□□k□m□n fy□o □w□v□x i□juw□n□mr□peed□□d ou□ver
u□thf□e g□j□k□lazyz□ dy□og q□r□vt□□u□u□v□u□u□tu□g□qp□□he quicu□k
by□rs□z□ou□v□□yo□□ou□v□y□w d□df□□fow□y□x k□jumpq□ede□ o



9.7 CAD Drawings

9.7.1 Assembly

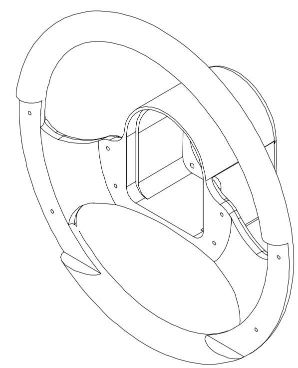


9.7.2 Steering Wheel

NOTES: UNLESS OTHERWISE SPECIFIED

1. INTERPRET DRAWING PER ANSI STANDARD Y14.5.M–1994. ALL DIMENSIONS ARE IN INCHES.
2. THIS DRAWING (1011) DEFINES THE FABRICATION REQUIREMENTS FOR PART NUMBER 1011.
3. MATERIAL: 6061–T6 ALUMINUM ALLOY PER ASTM B–209.
4. FINISH: NONE.
5. PROPER PACKAGING MATERIAL AND PACKAGING METHODS SHALL BE USED TO PROTECT THE CLEANLINESS AND INTEGRITY OF THE FINISHED PART. PACKAGE SHALL BE MARKED WITH PART NUMBER, DASH NUMBER. REVISION LEVEL, AND DATE CODE (1011 XX WK/YY).
6. NO RESIDUAL CUTTING OILS, FINGERPRINTS, SILICONE, OR OTHER FLUIDS ALLOWED ON FINISHED PART.
7. ENGRAVE PART NUMBER, DASH NUMBER, REVISION LEVEL AND DATE CODE (1011 XX WK/YY) IN AREA INDICATED. TEXT HEIGHT TO BE AS REQUIRED TO FIT IN SPACE ALLOWED. ENGRAVING TO BE FLUSH OR BELOW FLUSH.
8. ALL SURFACES MUST BE FREE OF LOOSE PARTICLES, CHIPS, AND BURRS. DEBURR OUTER CORNERS .010 MAX PRIOR TO FINISH.
9. FEATURES ARE GOVERNED BY ELECTRONIC DATABASE, FILE 1011r01.STL. TOLERANCES ON .XXX DIMENSIONS AND UNDIMENSIONED FEATURES ARE ±.003.
10. ALL CORNER RADII .033 MAX. ALL BOTTOM RADII .015 MAX.
11. SURFACE FINISH TO BE 63 MICROINCH MAXIMUM.

REV	SHT/ZONE	DESCRIPTION	DATE	APPROVED
01		ENGINEERING RELEASE		



ENGINEERING RELEASE

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES

APPROVALS

DRN BY: D. FRIES	DATE: 6/1/04	
CHK:	DATE:	
APPD:	DATE:	
APPD:	DATE:	
APPD.	DATE:	
APPD.	DATE:	

PROJECTION

TOLERANCES

4 PLC	3 PLC	2 PLC	ANGLES
±.0005	±.003	±.01	±0°30'

MATERIAL: SEE NOTE 3

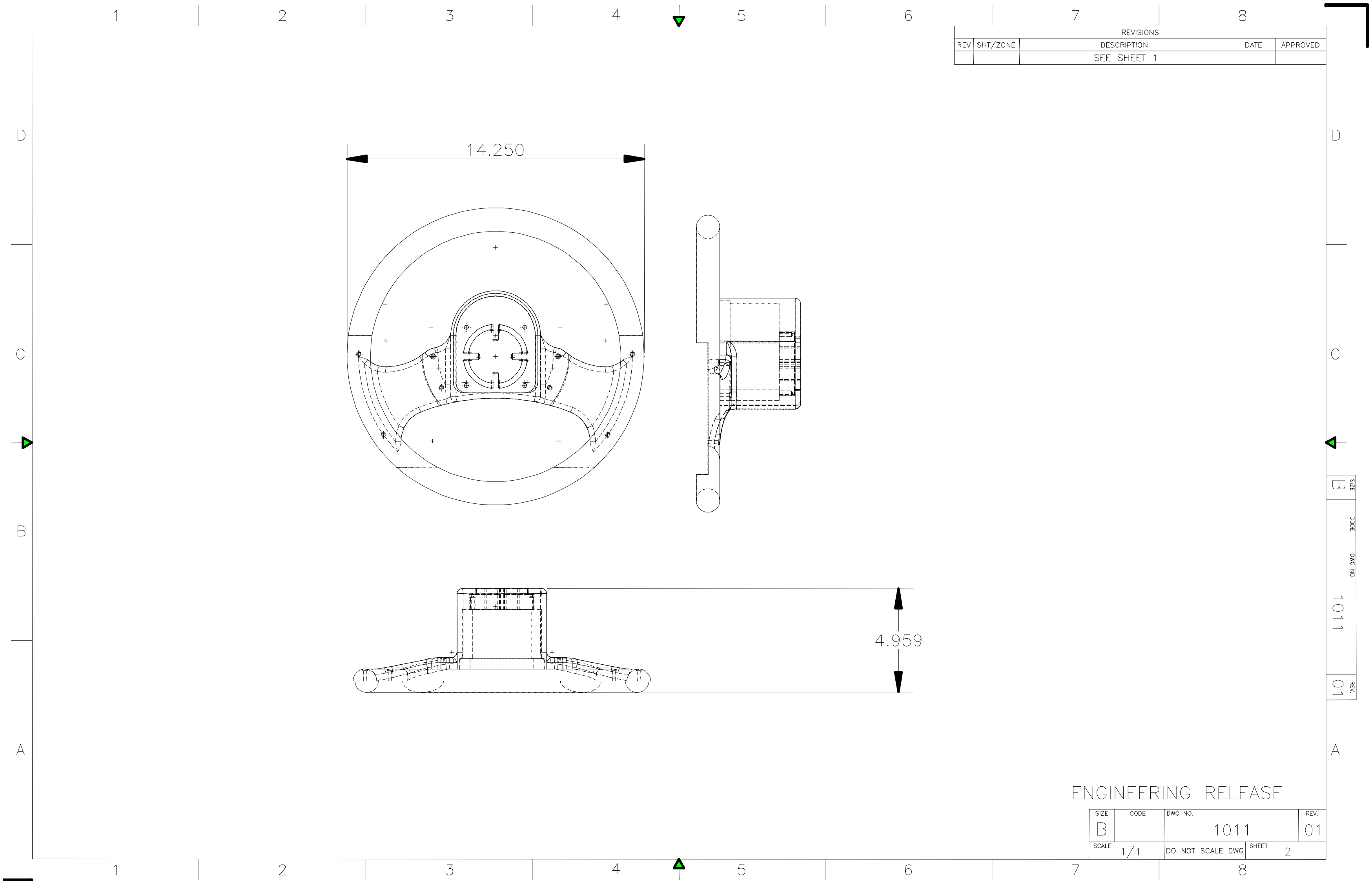
FINISH: SEE NOTE 4

YTPD Garage

TITLE: STEERING WHEEL

SIZE	CODE	DWG NO.	REV.
B		1011	01

SCALE 1/1 | DO NOT SCALE DWG | SHEET 1 OF 1

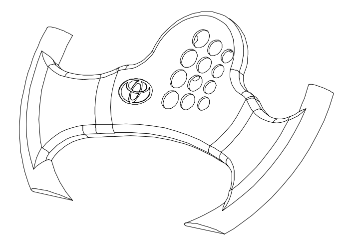

REVISIONS
REV
SHT/ZONE
DESCRIPTION
DATE
APPROVED
SEE SHEET 1
14.250
4.959
ENGINEERING RELEASE
SIZE
B
CODE
DWG NO.
1011
REV.
01
SCALE
1/1
DO NOT SCALE DWG
SHEET
2

9.7.3 Bezel

REVISIONS				
REV	SHT/ZONE	DESCRIPTION	DATE	APPROVED
01		ENGINEERING RELEASE		

NOTES: UNLESS OTHERWISE SPECIFIED

1. INTERPRET DRAWING PER ANSI STANDARD Y14.5.M–1994. ALL DIMENSIONS ARE IN INCHES.
2. THIS DRAWING (1012) DEFINES THE FABRICATION REQUIREMENTS FOR PART NUMBER 1012.
3. MATERIAL: 6061–T6 ALUMINUM ALLOY PER ASTM B–209.
4. FINISH: NONE.
5. PROPER PACKAGING MATERIAL AND PACKAGING METHODS SHALL BE USED TO PROTECT THE CLEANLINESS AND INTEGRITY OF THE FINISHED PART. PACKAGE SHALL BE MARKED WITH PART NUMBER, DASH NUMBER. REVISION LEVEL, AND DATE CODE (1012 XX WK/YY).
6. NO RESIDUAL CUTTING OILS, FINGERPRINTS, SILICONE, OR OTHER FLUIDS ALLOWED ON FINISHED PART.
7. ENGRAVE PART NUMBER, DASH NUMBER, REVISION LEVEL AND DATE CODE (1012 XX WK/YY) IN AREA INDICATED. TEXT HEIGHT TO BE AS REQUIRED TO FIT IN SPACE ALLOWED. ENGRAVING TO BE FLUSH OR BELOW FLUSH.
8. ALL SURFACES MUST BE FREE OF LOOSE PARTICLES, CHIPS, AND BURRS. DEBURR OUTER CORNERS .010 MAX PRIOR TO FINISH.
9. FEATURES ARE GOVERNED BY ELECTRONIC DATABASE, FILE 1011r01.STL. TOLERANCES ON .XXX DIMENSIONS AND UNDIMENSIONED FEATURES ARE ±.003.
10. ALL CORNER RADII .033 MAX. ALL BOTTOM RADII .015 MAX.
11. SURFACE FINISH TO BE 63 MICROINCH MAXIMUM.



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UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES

APPROVALS	DATE
DRN BY: D. FRIES	6/1/04
CHK:	DATE:
APPD:	DATE:
APPD:	DATE:
APPD:	DATE:
APPD:	DATE:

PROJECTION

TOLERANCES			
4 PLC	3 PLC	2 PLC	ANGLES
±.0005	±.003	±.01	±0°30'

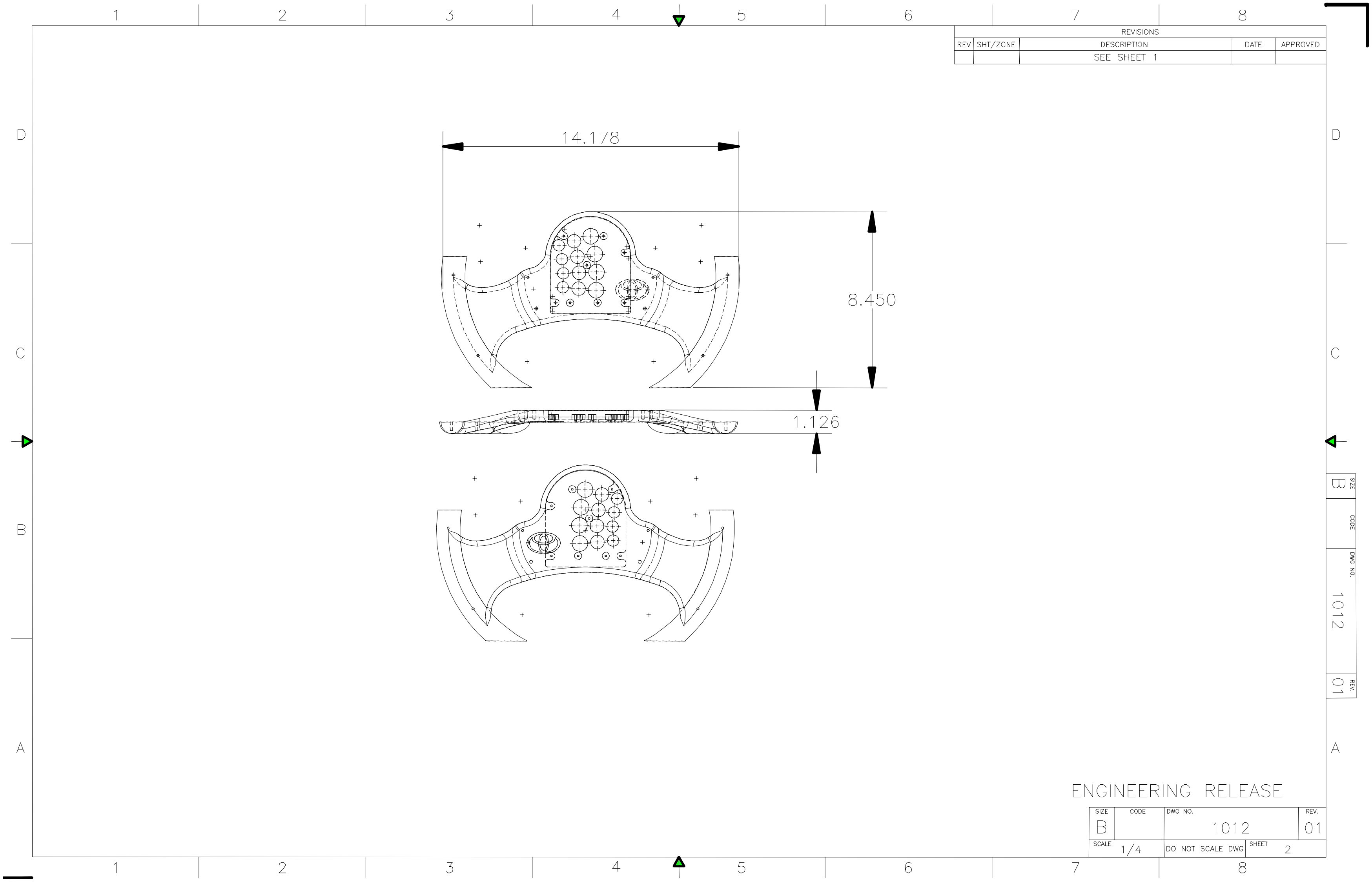
MATERIAL: SEE NOTE 3
FINISH: SEE NOTE 4

YTPD Garage

TITLE: BEZEL

SIZE	CODE	DWG NO.	REV.
B		1012	01

SCALE 1/1 | DO NOT SCALE DWG | SHEET 1 OF 1

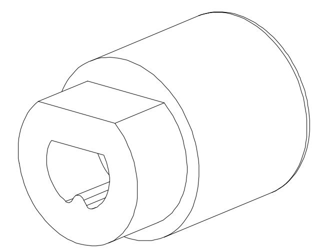

REVISIONS
REV
SHT/ZONE
DESCRIPTION
DATE
APPROVED
SEE SHEET 1
14.178
8.450
1.126
ENGINEERING RELEASE
SIZE
B
CODE
DWG NO.
1012
REV.
01
SCALE
1/4
DO NOT SCALE DWG
SHEET
2

9.7.4 Joystick Buttons

REVISIONS				
REV	SHT/ZONE	DESCRIPTION	DATE	APPROVED
01		ENGINEERING RELEASE		

NOTES: UNLESS OTHERWISE SPECIFIED

1. INTERPRET DRAWING PER ANSI STANDARD Y14.5.M–1994. ALL DIMENSIONS ARE IN INCHES.
2. THIS DRAWING (1015) DEFINES THE FABRICATION REQUIREMENTS FOR PART NUMBER 1015.
3. MATERIAL: FUSED DEPOSITION MODELING PLASTIC.
4. FINISH: NONE.
5. PROPER PACKAGING MATERIAL AND PACKAGING METHODS SHALL BE USED TO PROTECT THE CLEANLINESS AND INTEGRITY OF THE FINISHED PART. PACKAGE SHALL BE MARKED WITH PART NUMBER, DASH NUMBER. REVISION LEVEL, AND DATE CODE (1015 XX WK/YY).
6. NO RESIDUAL CUTTING OILS, FINGERPRINTS, SILICONE, OR OTHER FLUIDS ALLOWED ON FINISHED PART.
7. ENGRAVE PART NUMBER, DASH NUMBER, REVISION LEVEL AND DATE CODE (1015 XX WK/YY) IN AREA INDICATED. TEXT HEIGHT TO BE AS REQUIRED TO FIT IN SPACE ALLOWED. ENGRAVING TO BE FLUSH OR BELOW FLUSH.
8. ALL SURFACES MUST BE FREE OF LOOSE PARTICLES, CHIPS, AND BURRS. DEBURR OUTER CORNERS .010 MAX PRIOR TO FINISH.
9. FEATURES ARE GOVERNED BY ELECTRONIC DATABASE, FILE 1015r01.STL. TOLERANCES ON .XXX DIMENSIONS AND UNDIMENSIONED FEATURES ARE ±.003.
10. ALL CORNER RADII .033 MAX. ALL BOTTOM RADII .015 MAX.



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UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES

APPROVALS	DATE:
DRN BY: D. FRIES	6/1/04
CHK:	DATE:
APPD:	DATE:
APPD:	DATE:
APPD:	DATE:
APPD:	DATE:

PROJECTION

TOLERANCES			
4 PLC	3 PLC	2 PLC	ANGLES
±.0005	±.003	±.01	±0°30'

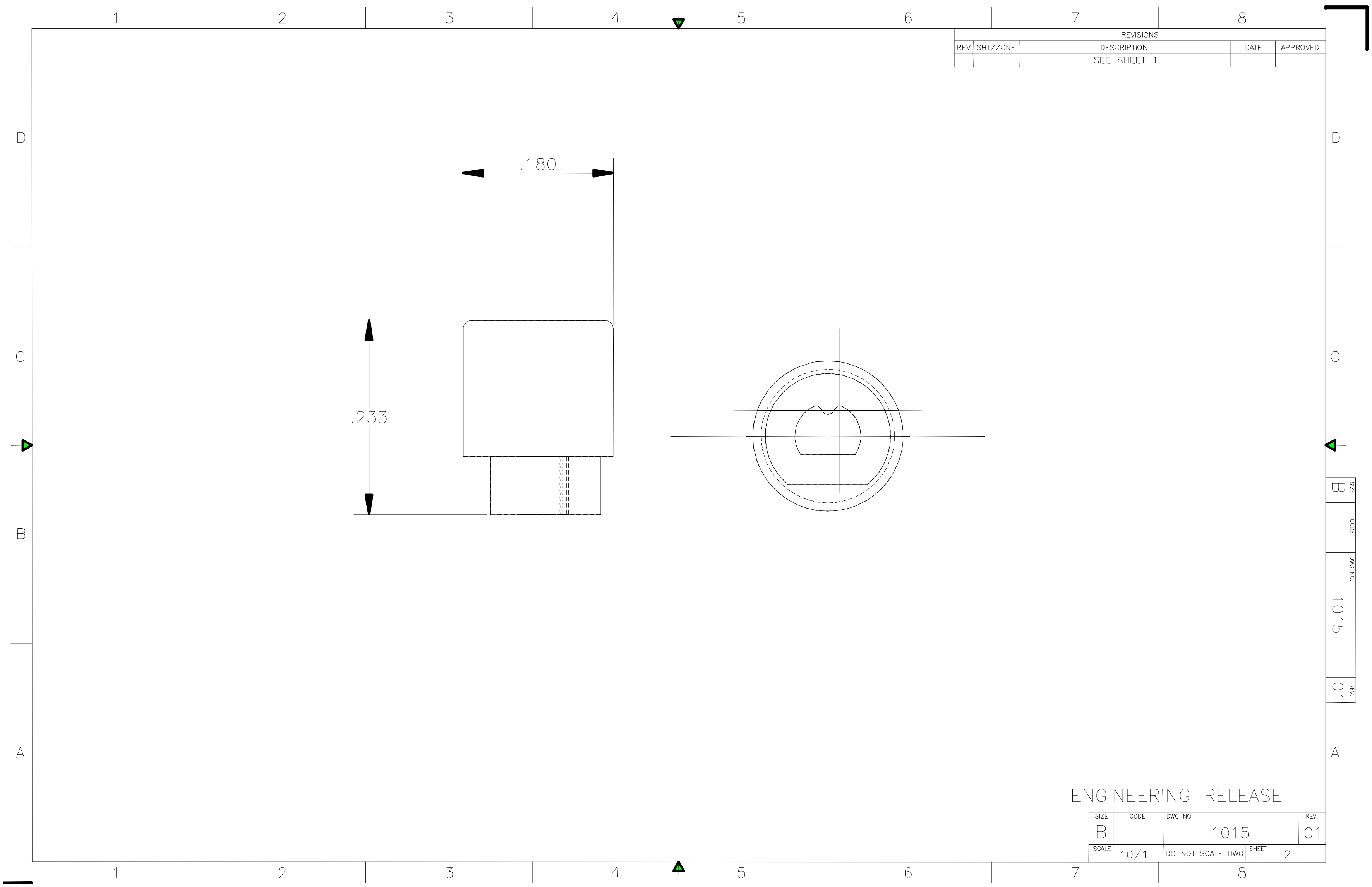
MATERIAL: SEE NOTE 3

FINISH: SEE NOTE 4

YTPD Garage

TITLE: SWITCH

SIZE	CODE	DWG NO.	REV.
B		1015	01
SCALE 1/1		DO NOT SCALE DWG	SHEET 1 OF 1


REVISIONS
REV
SHT/ZONE
DESCRIPTION
DATE
APPROVED
SEE SHEET 1
.180
.233
ENGINEERING RELEASE
SIZE
B
CODE
DWG NO.
1015
REV.
01
SCALE
10/1
DO NOT SCALE DWG
SHEET
2

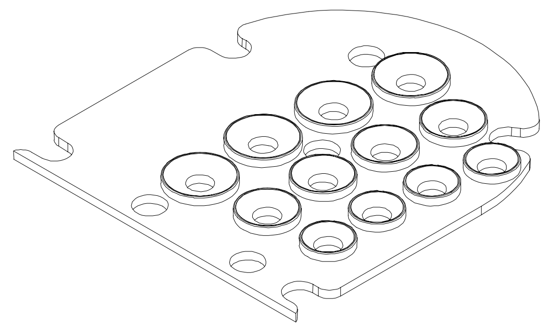
9.7.5 Button Enclosure

REV	SHT/ZONE	DESCRIPTION	DATE	APPROVED
01		ENGINEERING RELEASE		

REVISIONS

NOTES: UNLESS OTHERWISE SPECIFIED

1. INTERPRET DRAWING PER ANSI STANDARD Y14.5.M–1994. ALL DIMENSIONS ARE IN INCHES.
2. THIS DRAWING (1014) DEFINES THE FABRICATION REQUIREMENTS FOR PART NUMBER 1014.
3. MATERIAL: FUSED DEPOSITION MODELING PLASTIC.
4. FINISH: NONE.
5. PROPER PACKAGING MATERIAL AND PACKAGING METHODS SHALL BE USED TO PROTECT THE CLEANLINESS AND INTEGRITY OF THE FINISHED PART. PACKAGE SHALL BE MARKED WITH PART NUMBER, DASH NUMBER. REVISION LEVEL, AND DATE CODE (1012 XX WK/YY).
6. NO RESIDUAL CUTTING OILS, FINGERPRINTS, SILICONE, OR OTHER FLUIDS ALLOWED ON FINISHED PART.
7. ENGRAVE PART NUMBER, DASH NUMBER, REVISION LEVEL AND DATE CODE (1014 XX WK/YY) IN AREA INDICATED. TEXT HEIGHT TO BE AS REQUIRED TO FIT IN SPACE ALLOWED. ENGRAVING TO BE FLUSH OR BELOW FLUSH.
8. ALL SURFACES MUST BE FREE OF LOOSE PARTICLES, CHIPS, AND BURRS. DEBURR OUTER CORNERS .010 MAX PRIOR TO FINISH.
9. FEATURES ARE GOVERNED BY ELECTRONIC DATABASE, FILE 1014r01.STL. TOLERANCES ON .XXX DIMENSIONS AND UNDIMENSIONED FEATURES ARE ±.003.
10. ALL CORNER RADII .033 MAX. ALL BOTTOM RADII .015 MAX.



ENGINEERING RELEASE

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UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES

APPROVALS

	DATE:
DRN BY: D. FRIES	6/1/04
CHK:	DATE:
APPD:	DATE:
APPD:	DATE:
APPD:	DATE:
APPD:	DATE:

PROJECTION

TOLERANCES

4 PLC	3 PLC	2 PLC	ANGLES
±.0005	±.003	±.01	±0°30'

MATERIAL: SEE NOTE 3

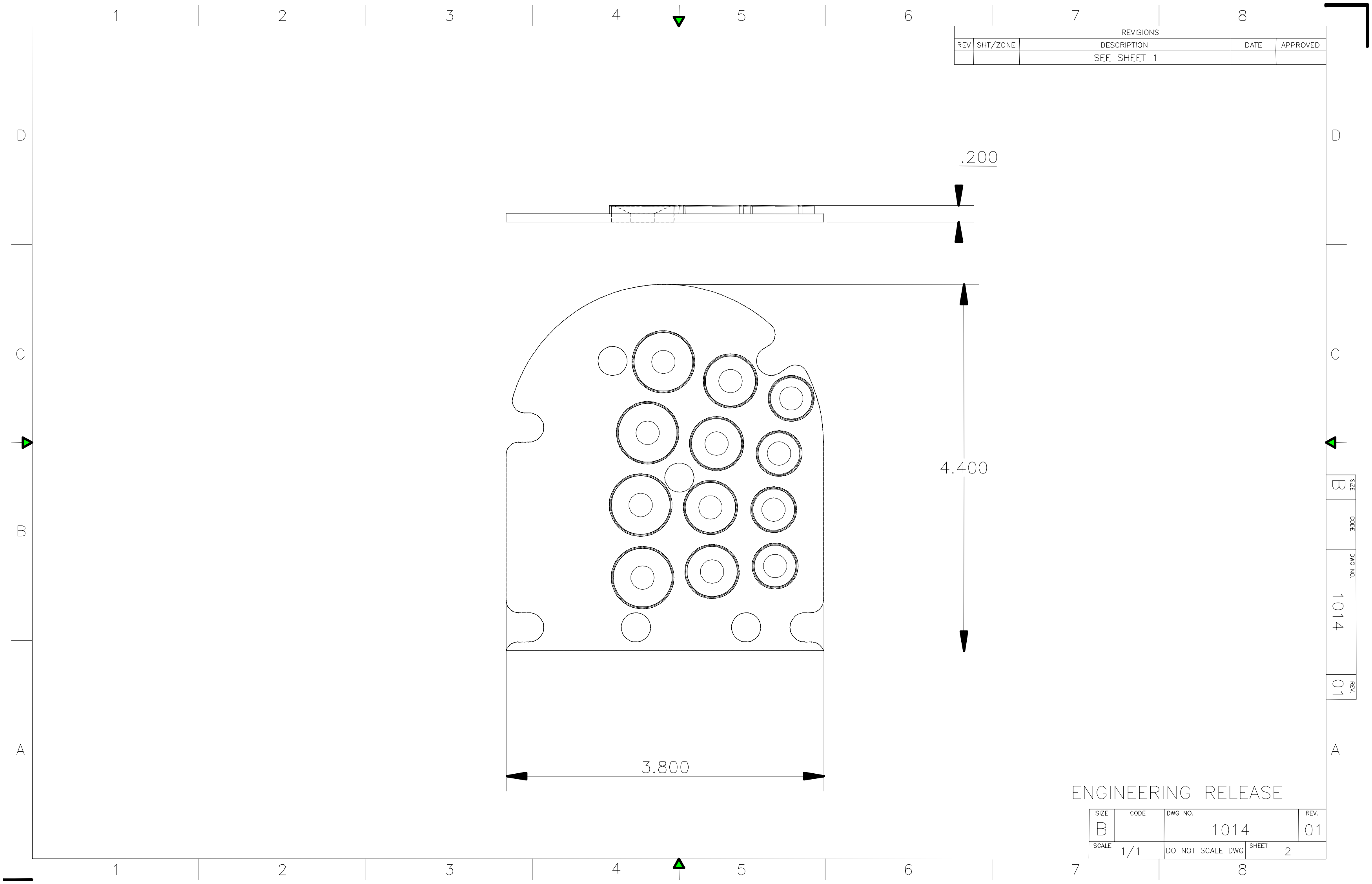
FINISH: SEE NOTE 4

YTPD Garage

TITLE: BUTTON PLATE

SIZE	CODE	DWG NO.	REV.
B		1014	01

SCALE 1/1 | DO NOT SCALE DWG | SHEET 1 OF 1

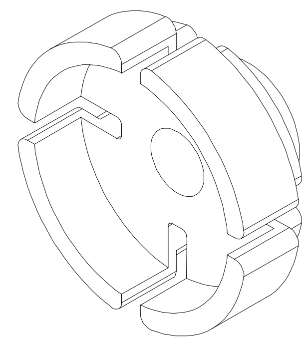

REVISIONS
REV
SHT/ZONE
DESCRIPTION
DATE
APPROVED
SEE SHEET 1
.200
4.400
3.800
ENGINEERING RELEASE
SIZE
B
CODE
DWG NO.
1014
REV.
01
SCALE 1/1
DO NOT SCALE DWG
SHEET 2

9.7.6 Volvo Adaptor

REV	SHT/ZONE	DESCRIPTION	DATE	APPROVED
01		ENGINEERING RELEASE		

NOTES: UNLESS OTHERWISE SPECIFIED

1. INTERPRET DRAWING PER ANSI STANDARD Y14.5.M–1994. ALL DIMENSIONS ARE IN INCHES.
2. THIS DRAWING (1013) DEFINES THE FABRICATION REQUIREMENTS FOR PART NUMBER 1013.
3. MATERIAL: MAKE FROM 1986 VOLVO STEERING WHEEL.
4. FINISH: NONE.
5. PROPER PACKAGING MATERIAL AND PACKAGING METHODS SHALL BE USED TO PROTECT THE CLEANLINESS AND INTEGRITY OF THE FINISHED PART. PACKAGE SHALL BE MARKED WITH PART NUMBER, DASH NUMBER. REVISION LEVEL, AND DATE CODE (1012 XX WK/YY).
6. NO RESIDUAL CUTTING OILS, FINGERPRINTS, SILICONE, OR OTHER FLUIDS ALLOWED ON FINISHED PART.
7. ENGRAVE PART NUMBER, DASH NUMBER, REVISION LEVEL AND DATE CODE (1012 XX WK/YY) IN AREA INDICATED. TEXT HEIGHT TO BE AS REQUIRED TO FIT IN SPACE ALLOWED. ENGRAVING TO BE FLUSH OR BELOW FLUSH.
8. ALL SURFACES MUST BE FREE OF LOOSE PARTICLES, CHIPS, AND BURRS. DEBURR OUTER CORNERS .010 MAX PRIOR TO FINISH.
9. FEATURES ARE GOVERNED BY ELECTRONIC DATABASE, FILE 1013r01.STL. TOLERANCES ON .XXX DIMENSIONS AND UNDIMENSIONED FEATURES ARE ±.003.
10. ALL CORNER RADII .033 MAX. ALL BOTTOM RADII .015 MAX.
11. SURFACE FINISH TO BE 63 MICROINCH MAXIMUM.



ENGINEERING RELEASE

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UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES

APPROVALS	DATE:
DRN BY: D. FRIES	6/1/04
CHK:	DATE:
APPD:	DATE:
APPD:	DATE:
APPD:	DATE:
APPD:	DATE:

PROJECTION

TOLERANCES

4 PLC	3 PLC	2 PLC	ANGLES
±.0005	±.003	±.01	±0°30'

MATERIAL: SEE NOTE 3

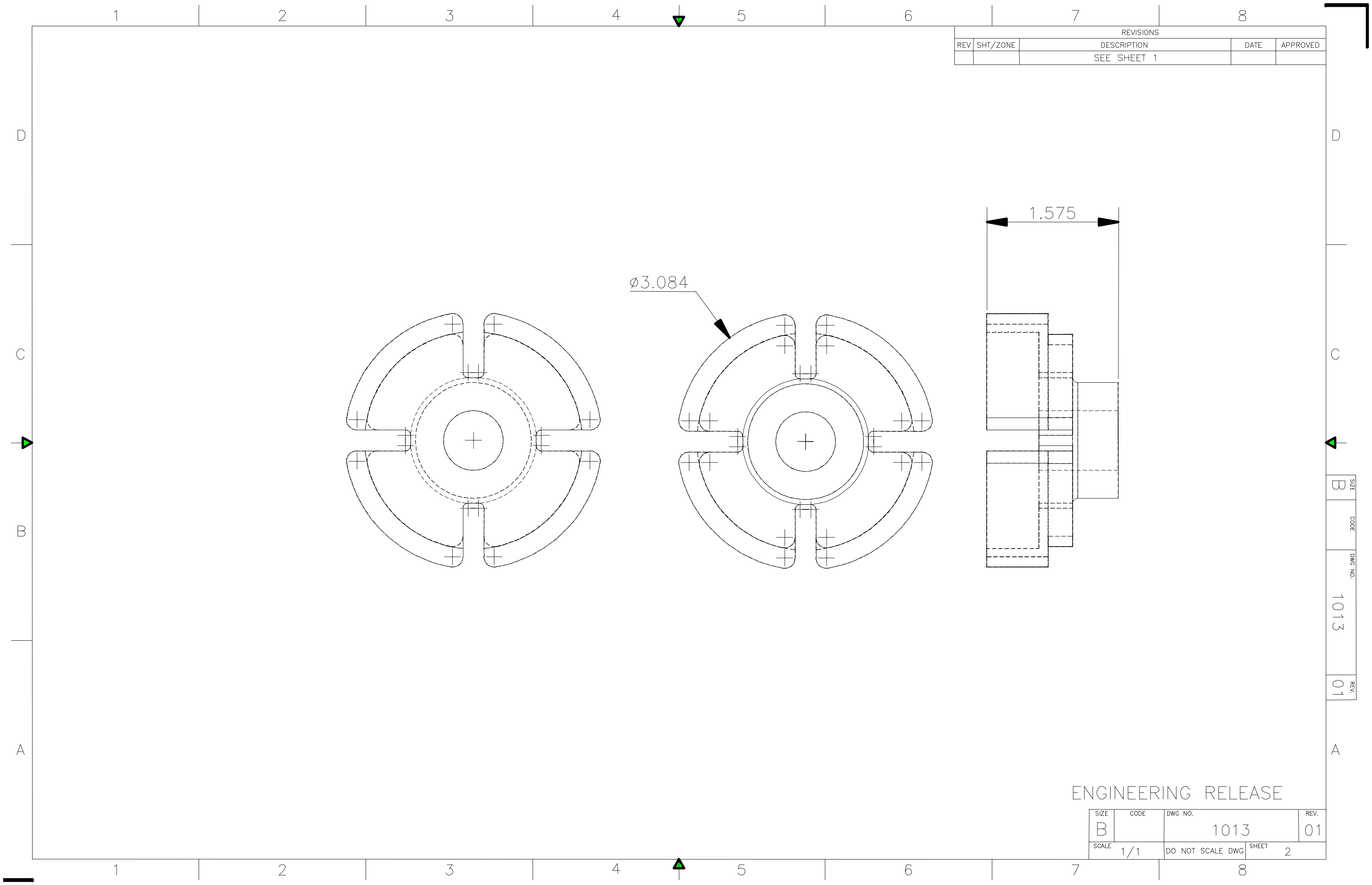
FINISH: SEE NOTE 4

YTPD Garage

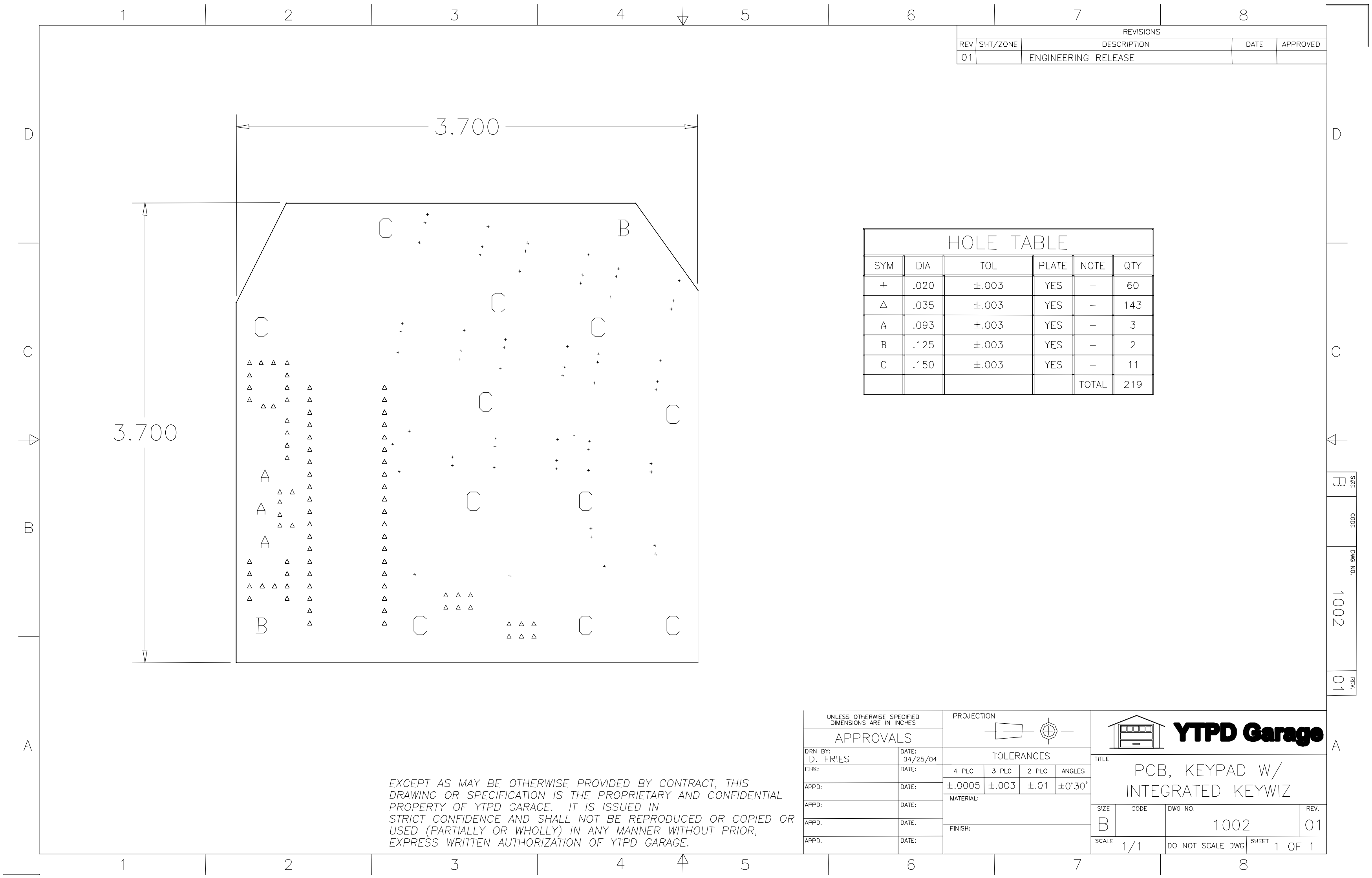
TITLE: VOLVO WHEEL ADAPTER

SIZE	CODE	DWG NO.	REV.
B		1013	01

SCALE 1/1 | DO NOT SCALE DWG | SHEET 1 OF 1


REVISIONS
REV
SHT/ZONE
DESCRIPTION
DATE
APPROVED
SEE SHEET 1
1.575
ø3.084
ENGINEERING RELEASE
SIZE
B
CODE
DWG NO.
1013
REV.
01
SCALE
1/1
DO NOT SCALE DWG
SHEET
2

9.7.7 PC Board



HOLE TABLE

SYM	DIA	TOL	PLATE	NOTE	QTY
+	.020	±.003	YES	–	60
Δ	.035	±.003	YES	–	143
A	.093	±.003	YES	–	3
B	.125	±.003	YES	–	2
C	.150	±.003	YES	–	11
				TOTAL	219

9.7.8 LCD Screen Mount

REV	SHT/ZONE	DESCRIPTION	DATE	APPROVED
01		ENGINEERING RELEASE		

NOTES: UNLESS OTHERWISE SPECIFIED

1. INTERPRET DRAWING PER ANSI STANDARD Y14.5.M–1994. ALL DIMENSIONS ARE IN INCHES.
2. THIS DRAWING (1016) DEFINES THE FABRICATION REQUIREMENTS FOR PART NUMBER 1016.
3. MATERIAL: CLEAR ACRYLIC.
4. FINISH: NONE.
5. PROPER PACKAGING MATERIAL AND PACKAGING METHODS SHALL BE USED TO PROTECT THE CLEANLINESS AND INTEGRITY OF THE FINISHED PART. PACKAGE SHALL BE MARKED WITH PART NUMBER, DASH NUMBER. REVISION LEVEL, AND DATE CODE (1016 XX WK/YY).
6. NO RESIDUAL CUTTING OILS, FINGERPRINTS, SILICONE, OR OTHER FLUIDS ALLOWED ON FINISHED PART.
7. ENGRAVE PART NUMBER, DASH NUMBER, REVISION LEVEL AND DATE CODE (1016 XX WK/YY) IN AREA INDICATED. TEXT HEIGHT TO BE AS REQUIRED TO FIT IN SPACE ALLOWED. ENGRAVING TO BE FLUSH OR BELOW FLUSH.
8. ALL SURFACES MUST BE FREE OF LOOSE PARTICLES, CHIPS, AND BURRS. DEBURR OUTER CORNERS .010 MAX PRIOR TO FINISH.
9. FEATURES ARE GOVERNED BY ELECTRONIC DATABASE, FILE 1016r01.DXF. TOLERANCES ON .XXX DIMENSIONS AND UNDIMENSIONED FEATURES ARE ±.003.
10. ALL CORNER RADII .033 MAX. ALL BOTTOM RADII .015 MAX.

ENGINEERING RELEASE

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES

APPROVALS	DATE
DRN BY: D. FRIES	6/1/04
CHK:	
APPD:	
APPD:	
APPD.	
APPD.	

PROJECTION

TOLERANCES

4 PLC	3 PLC	2 PLC	ANGLES
±.0005	±.003	±.01	±0°30'

MATERIAL: SEE NOTE 3

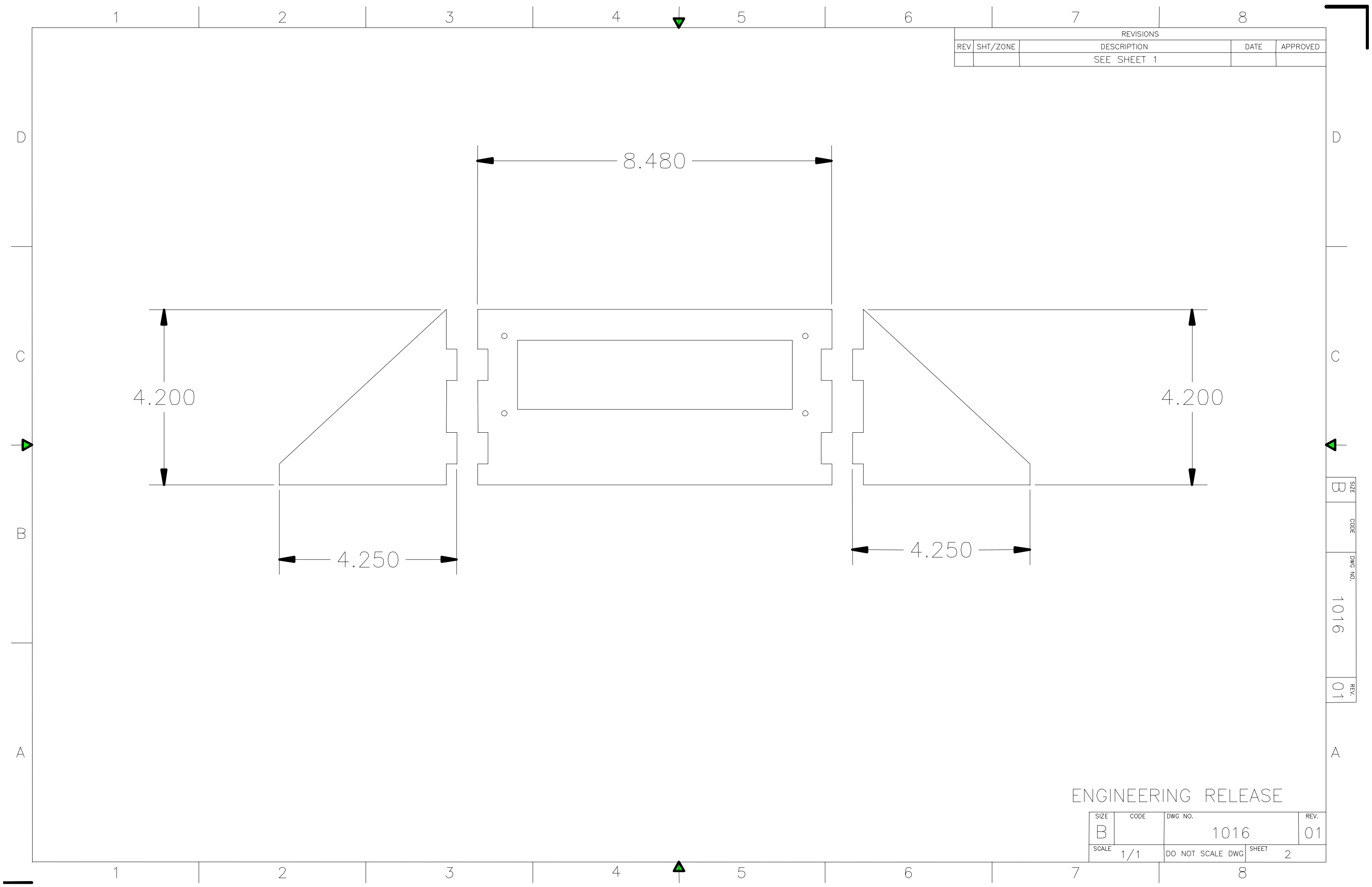
FINISH: SEE NOTE 4

YTPD Garage

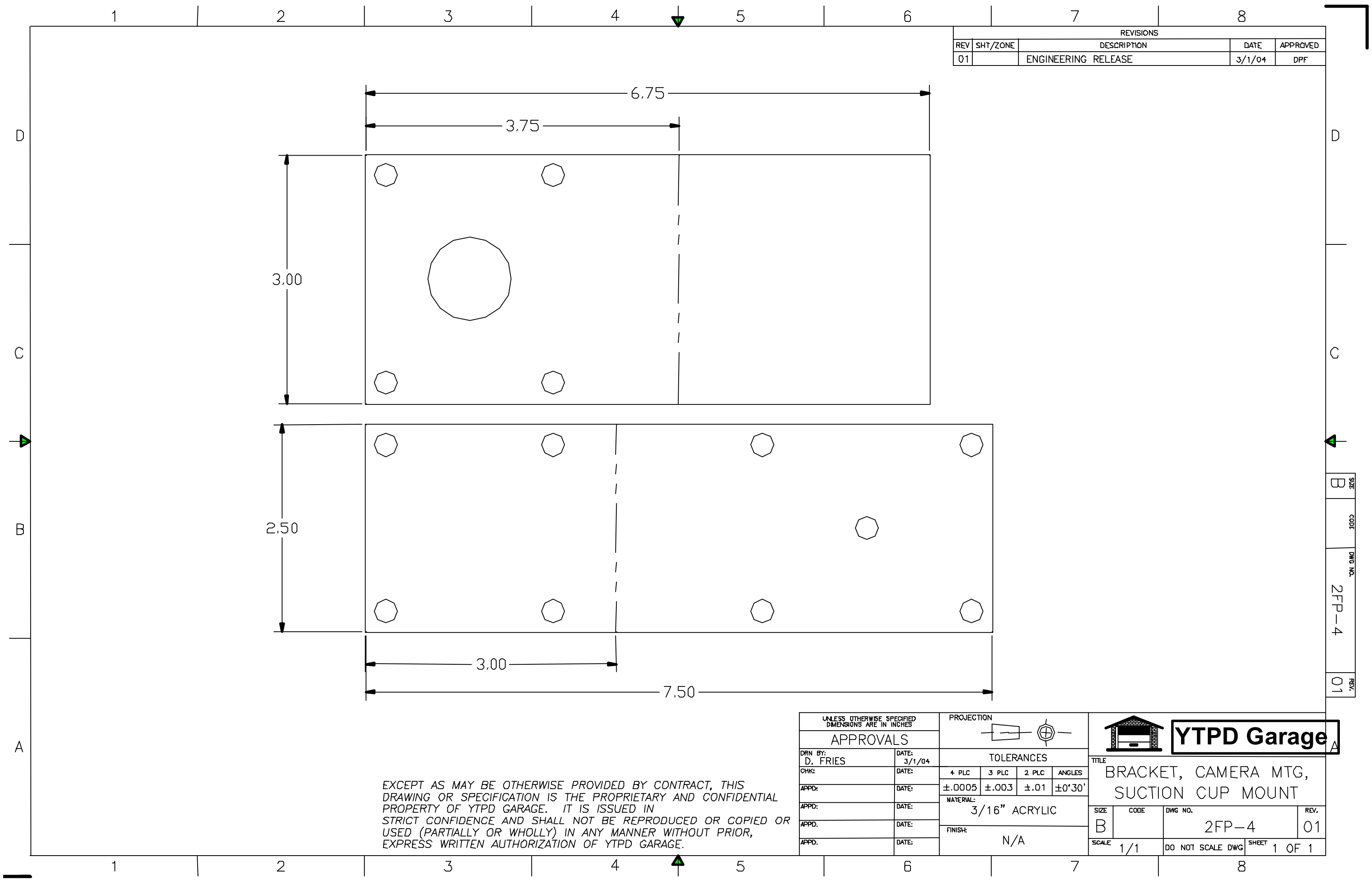
TITLE: LCD DISPLAY MOUNTING FRAME

SIZE	CODE	DWG NO.	REV.
B		1016	01

SCALE 1/1 | DO NOT SCALE DWG | SHEET 1 OF 1

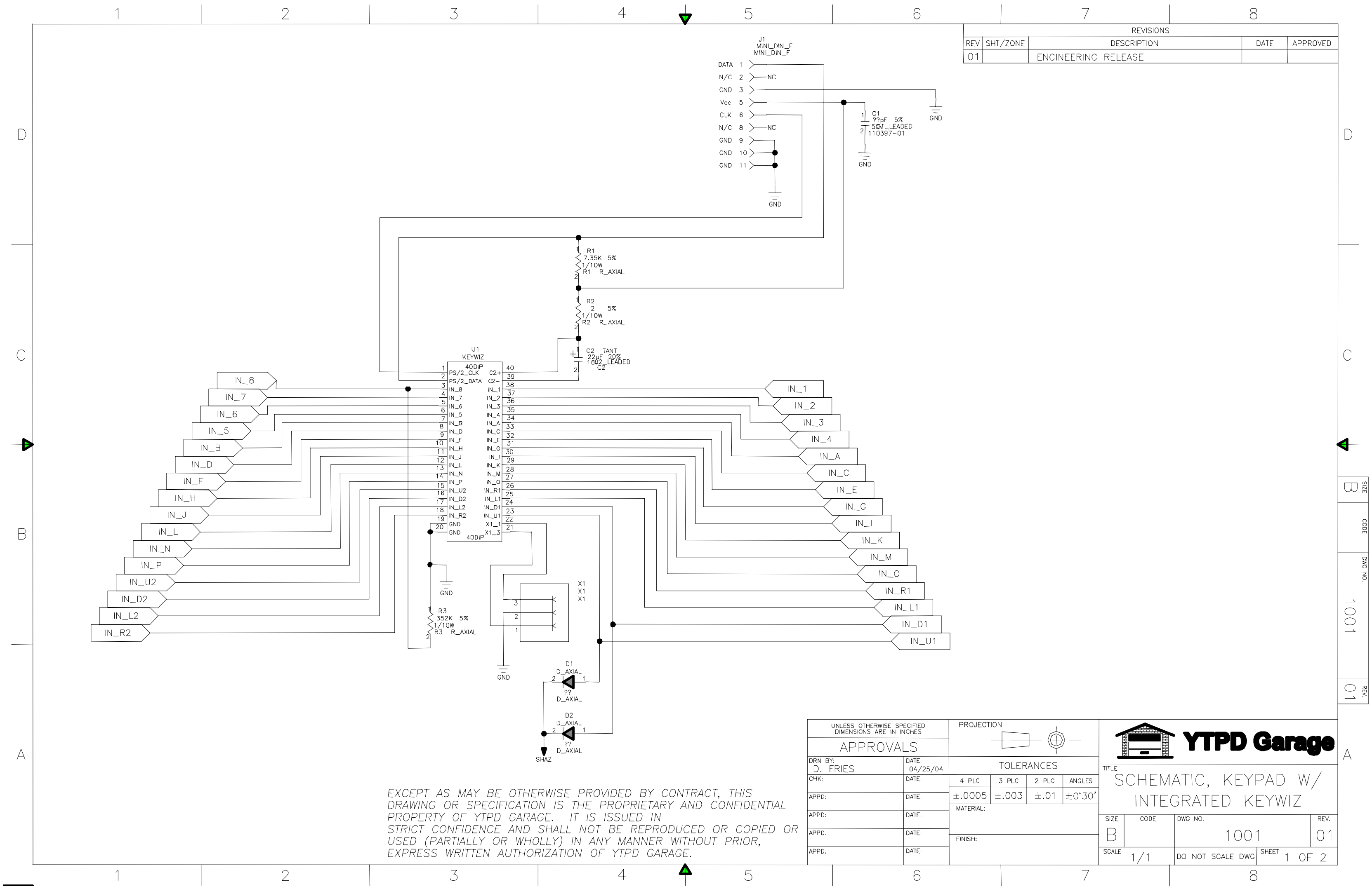

REVISIONS
REV
SHT/ZONE
DESCRIPTION
DATE
APPROVED
SEE SHEET 1
8.480
4.200
4.200
4.250
4.250
ENGINEERING RELEASE
SIZE
B
CODE
DWG NO.
1016
REV.
01
SCALE
1/1
DO NOT SCALE DWG
SHEET
2

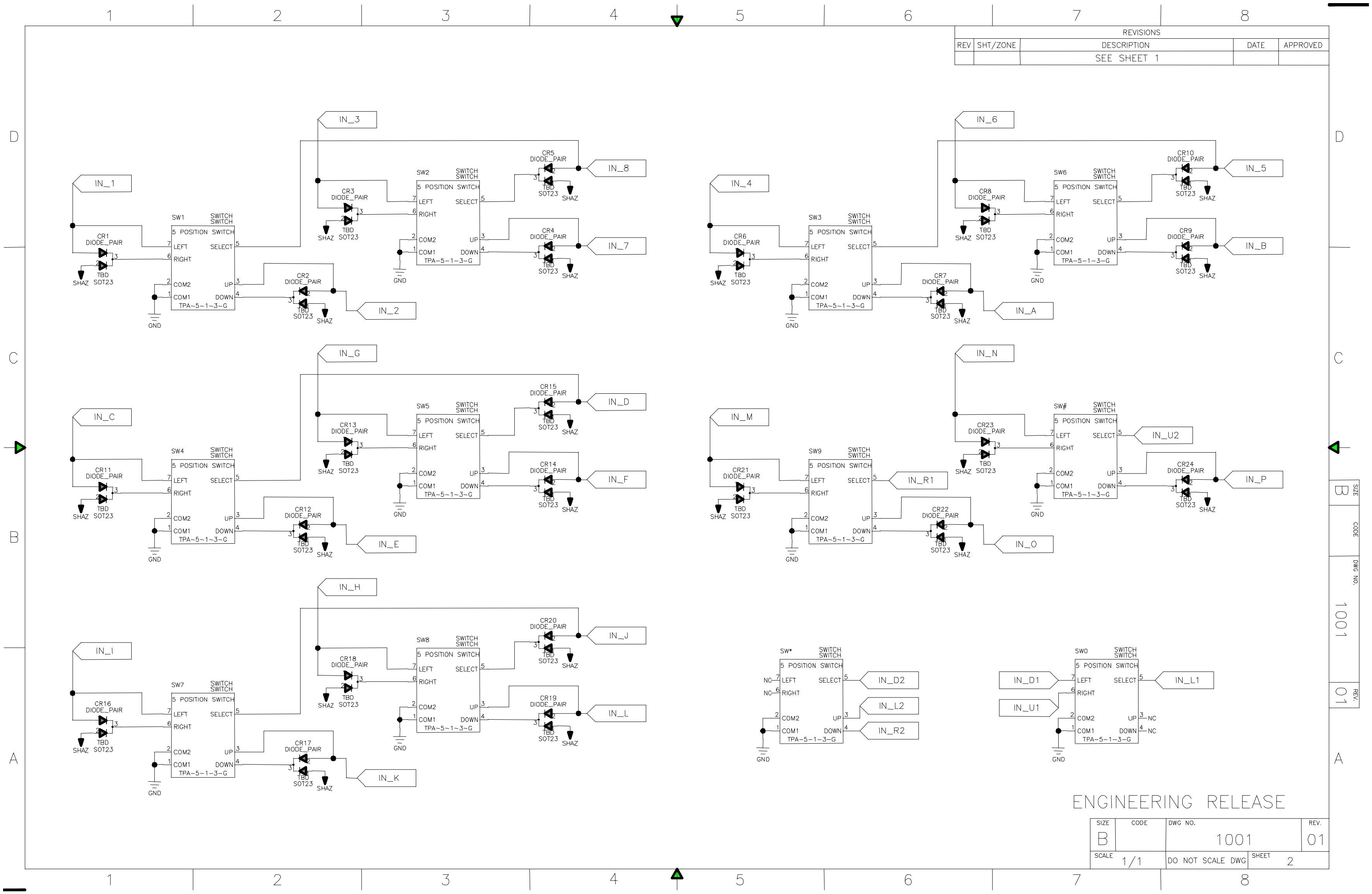
9.7.9 Lane Departure Camera Mounts



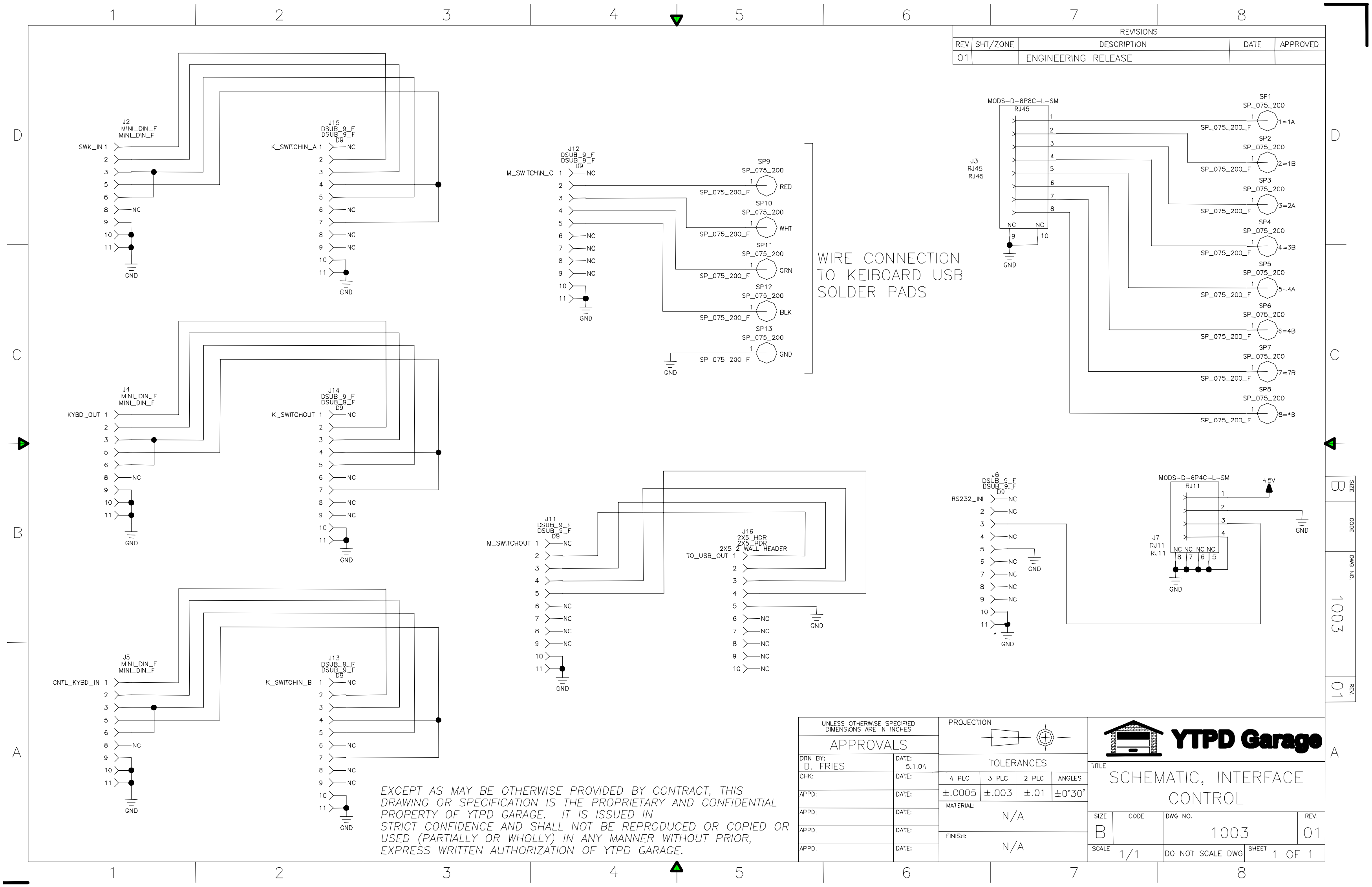
9.8 Wiring Schematics

9.8.1 PC Board




REVISIONS
REV SHT/ZONE DESCRIPTION DATE APPROVED
SEE SHEET 1
IN_1
IN_2
IN_3
IN_4
IN_5
IN_6
IN_7
IN_8
IN_A
IN_B
IN_C
IN_D
IN_E
IN_F
IN_G
IN_H
IN_I
IN_J
IN_K
IN_L
IN_M
IN_N
IN_O
IN_P
IN_R1
IN_U2
IN_D2
IN_L2
IN_R2
IN_D1
IN_U1
IN_L1
5 POSITION SWITCH
TPA-5-1-3-G
DIODE_PAIR
TBD SOT23
SHAZ
GND
ENGINEERING RELEASE
SIZE B CODE DWG NO. 1001 REV. 01
SCALE 1/1 DO NOT SCALE DWG SHEET 2

9.8.2 Interface Control Box



9.9 KeyWiz Keypad Layout Profiles

9.9.1 Multi-Tap Profile A

	1			2			3	
1	1	1	2	2	2	3	3	3
	1			2			3	
	4			5			6	
4	4	4	5	5	5	6	6	6
	4			5			6	
	7			8			9	
7	7	7	8	8	8	9	9	9
	7			8			9	
	*			0			-	
*	*	*	0	0	0	-	-	-
	*			0			-	

				B			E	
.	1	-	A	2	C	D	3	F
	H			K			N	
G	4	I	J	5	L	M	6	0
	Q			U			X	
P	7	R	T	8	V	W	9	Y
	S						Z	
	TAB							
NTEI	*		SPACI	0		DELET	-	

Keywiz	Keypad#	Direction	Normal
1	1	LEFT	1
2	1	UP	1
3	2	LEFT	2
4	3	LEFT	3
5	3	SELECT	3
6	6	LEFT	6
7	2	UP	2
8	1	SELECT	1
A	3	UP	3
B	6	UP	6
C	4	LEFT	4
D	4	SELECT	4
E	5	UP	5
F	8	UP	8
G	5	LEFT	5
H	8	LEFT	8
I	7	LEFT	7
J	7	SELECT	7
K	7	UP	7
L	8	UP	-
M	9	LEFT	9
N	#	LEFT	-
O	9	UP	9
P	#	UP	-
U1	0	UP	0
D1	0	DOWN	0
L1	0	SELECT	0
R1	9	SELECT	9
U2	#	SELECT	-
D2	*	SELECT	*
L2	*	UP	*
R2	*	DOWN	*

Keywiz	Keypad#	Direction	Shazam
1	1	RIGHT	1
2	1	DOWN	1
3	2	RIGHT	2
4	3	RIGHT	3
5	6	SELECT	6
6	6	RIGHT	6
7	2	DOWN	2
8	2	SELECT	2
A	3	DOWN	3
B	6	DOWN	6
C	4	RIGHT	4
D	5	SELECT	5
E	4	DOWN	4
F	5	DOWN	5
G	5	RIGHT	5
H	8	RIGHT	8
I	7	RIGHT	7
J	8	SELECT	8
K	7	DOWN	7
L	8	DOWN	8
M	9	RIGHT	9
N	#	RIGHT	-
O	9	DOWN	9
P	#	DOWN	-
U1	0	EMPTY	
D1	0	EMPTY	
L1	0	EMPTY	
R1	9	EMPTY	
U2	#	EMPTY	
D2	*	EMPTY	
L2	*	EMPTY	
R2	*	EMPTY	

9.9.2 Multi-Tap Profile B

	1			2			3	
~	1	~	~	2	~	~	3	~
	1			2			3	
	4			5			6	
~	4	~	~	5	~	~	6	~
	4			5			6	
	7			8			9	
~	7	~	~	8	~	~	9	~
	7			8			9	
	*			0			BS	
~	*	~	~	0	~	~	BS	~
	*			0			BS	

				B			E	
.	1	-	A	2	C	D	3	F
	H			K			N	
G	4	I	J	5	L	M	6	0
	Q			U			X	
P	7	R	T	8	V	W	9	Y
	S						Z	
	TAB						BS	
NTEI	*		SPACI	0			BS	
							BS	

Keywiz	Keypad#	Direction	Normal
1	1	LEFT	~
2	1	UP	1
3	2	LEFT	~
4	3	LEFT	~
5	3	SELECT	3
6	6	LEFT	~
7	2	UP	2
8	1	SELECT	1
A	3	UP	3
B	6	UP	6
C	4	LEFT	~
D	4	SELECT	4
E	5	UP	5
F	8	UP	8
G	5	LEFT	~
H	8	LEFT	~
I	7	LEFT	~
J	7	SELECT	7
K	7	UP	7
L	8	UP	BS
M	9	LEFT	~
N	#	LEFT	~
O	9	UP	9
P	#	UP	BS
U1	0	UP	0
D1	0	DOWN	0
L1	0	SELECT	0
R1	9	SELECT	9
U2	#	SELECT	BS
D2	*	SELECT	*
L2	*	UP	*
R2	*	DOWN	*

Keywiz	Keypad#	Direction	Shazam
1	1	RIGHT	~
2	1	DOWN	1
3	2	RIGHT	~
4	3	RIGHT	~
5	6	SELECT	6
6	6	RIGHT	~
7	2	DOWN	2
8	2	SELECT	2
A	3	DOWN	3
B	6	DOWN	6
C	4	RIGHT	~
D	5	SELECT	5
E	4	DOWN	4
F	5	DOWN	5
G	5	RIGHT	~
H	8	RIGHT	~
I	7	RIGHT	~
J	8	SELECT	8
K	7	DOWN	7
L	8	DOWN	8
M	9	RIGHT	~
N	#	RIGHT	~
O	9	DOWN	9
P	#	DOWN	BS
U1	0	EMPTY	
D1	0	EMPTY	
L1	0	EMPTY	
R1	9	EMPTY	
U2	#	EMPTY	
D2	*	EMPTY	
L2	*	EMPTY	
R2	*	EMPTY	

9.9.3 Multi-Switch Profile J

	.			A			D	
~	1	-	~	2	B	~	3	E
	1			C			F	
	G			J			M	
~	4	H	~	5	K	~	6	N
	I			L			O	
	P			T			W	
S	7	Q	~	8	U	Z	9	X
	R			V			Y	
	TAB			SPACE			~	
~	*	~	~	0	~	~	BS	~
	ENTER			~			~	

Keywiz	Keypad#	Direction	Normal
1	1	LEFT	~
2	1	UP	.
3	2	LEFT	~
4	3	LEFT	~
5	3	SELECT	3
6	6	LEFT	~
7	2	UP	A
8	1	SELECT	1
A	3	UP	D
B	6	UP	M
C	4	LEFT	~
D	4	SELECT	4
E	5	UP	J
F	8	UP	T
G	5	LEFT	~
H	8	LEFT	~
I	7	LEFT	S
J	7	SELECT	7
K	7	UP	P
L	8	UP	~
M	9	LEFT	Z
N	#	LEFT	~
O	9	UP	W
P	#	UP	~
U1	0	UP	SPACE
D1	0	DOWN	~
L1	0	SELECT	0
R1	9	SELECT	9
U2	#	SELECT	BS
D2	*	SELECT	*
L2	*	UP	TAB
R2	*	DOWN	ENTER

Keywiz	Keypad#	Direction	Shazam
1	1	RIGHT	-
2	1	DOWN	1
3	2	RIGHT	B
4	3	RIGHT	E
5	6	SELECT	6
6	6	RIGHT	N
7	2	DOWN	C
8	2	SELECT	2
A	3	DOWN	F
B	6	DOWN	O
C	4	RIGHT	H
D	5	SELECT	5
E	4	DOWN	I
F	5	DOWN	L
G	5	RIGHT	K
H	8	RIGHT	U
I	7	RIGHT	Q
J	8	SELECT	8
K	7	DOWN	R
L	8	DOWN	V
M	9	RIGHT	X
N	#	RIGHT	~
O	9	DOWN	Y
P	#	DOWN	~
U1	0	EMPTY	
D1	0	EMPTY	
L1	0	EMPTY	
R1	9	EMPTY	
U2	#	EMPTY	
D2	*	EMPTY	
L2	*	EMPTY	
R2	*	EMPTY	

9.9.4 Multi-Switch Profile K

	.			A			D	
~	1	-	~	2	B	~	3	E
	1			C			F	
	G			J			M	
~	4	H	~	5	K	~	6	N
	I			L			O	
	P			T			W	
S	7	Q	~	8	U	Z	9	X
	R			V			Y	
	TAB			SPACE			BS	
~	*	~	~	0	~	~	BS	~
	ENTER			~			~	

Keywiz	Keypad#	Direction	Normal
1	1	LEFT	~
2	1	UP	.
3	2	LEFT	~
4	3	LEFT	~
5	3	SELECT	3
6	6	LEFT	~
7	2	UP	A
8	1	SELECT	1
A	3	UP	D
B	6	UP	M
C	4	LEFT	~
D	4	SELECT	4
E	5	UP	J
F	8	UP	T
G	5	LEFT	~
H	8	LEFT	~
I	7	LEFT	S
J	7	SELECT	7
K	7	UP	P
L	8	UP	BS
M	9	LEFT	Z
N	#	LEFT	~
O	9	UP	W
P	#	UP	BS
U1	0	UP	SPACE
D1	0	DOWN	~
L1	0	SELECT	0
R1	9	SELECT	9
U2	#	SELECT	BS
D2	*	SELECT	*
L2	*	UP	TAB
R2	*	DOWN	ENTER

Keywiz	Keypad#	Direction	Shazam
1	1	RIGHT	-
2	1	DOWN	1
3	2	RIGHT	B
4	3	RIGHT	E
5	6	SELECT	6
6	6	RIGHT	N
7	2	DOWN	C
8	2	SELECT	2
A	3	DOWN	F
B	6	DOWN	O
C	4	RIGHT	H
D	5	SELECT	5
E	4	DOWN	I
F	5	DOWN	L
G	5	RIGHT	K
H	8	RIGHT	U
I	7	RIGHT	Q
J	8	SELECT	8
K	7	DOWN	R
L	8	DOWN	V
M	9	RIGHT	X
N	#	RIGHT	~
O	9	DOWN	Y
P	#	DOWN	~
U1	0	EMPTY	
D1	0	EMPTY	
L1	0	EMPTY	
R1	9	EMPTY	
U2	#	EMPTY	
D2	*	EMPTY	
L2	*	EMPTY	
R2	*	EMPTY	

9.9.5 Multi-Switch Profile M

	.			B			E	
~	1	-	A	2	C	D	3	F
	1			~			~	
	H			K			N	
G	4	I	J	5	L	M	6	O
	~			~			~	
	Q			U			X	
P	7	R	T	8	V	W	9	Y
	S			~			Z	
	TAB			SPACE			~	
~	*	~	~	0	~	~	BS	~
	ENTER			~			~	

Keywiz	Keypad#	Direction	Normal
1	1	LEFT	~
2	1	UP	.
3	2	LEFT	A
4	3	LEFT	D
5	3	SELECT	3
6	6	LEFT	M
7	2	UP	B
8	1	SELECT	1
A	3	UP	E
B	6	UP	N
C	4	LEFT	G
D	4	SELECT	4
E	5	UP	K
F	8	UP	U
G	5	LEFT	J
H	8	LEFT	T
I	7	LEFT	P
J	7	SELECT	7
K	7	UP	Q
L	8	UP	~
M	9	LEFT	W
N	#	LEFT	~
O	9	UP	X
P	#	UP	~
U1	0	UP	SPACE
D1	0	DOWN	~
L1	0	SELECT	0
R1	9	SELECT	9
U2	#	SELECT	BS
D2	*	SELECT	*
L2	*	UP	TAB
R2	*	DOWN	ENTER

Keywiz	Keypad#	Direction	Shazam
1	1	RIGHT	-
2	1	DOWN	1
3	2	RIGHT	C
4	3	RIGHT	F
5	6	SELECT	6
6	6	RIGHT	O
7	2	DOWN	~
8	2	SELECT	2
A	3	DOWN	~
B	6	DOWN	~
C	4	RIGHT	I
D	5	SELECT	5
E	4	DOWN	~
F	5	DOWN	~
G	5	RIGHT	L
H	8	RIGHT	V
I	7	RIGHT	R
J	8	SELECT	8
K	7	DOWN	S
L	8	DOWN	~
M	9	RIGHT	Y
N	#	RIGHT	~
O	9	DOWN	Z
P	#	DOWN	~
U1	0	EMPTY	
D1	0	EMPTY	
L1	0	EMPTY	
R1	9	EMPTY	
U2	#	EMPTY	
D2	*	EMPTY	
L2	*	EMPTY	
R2	*	EMPTY	

9.9.6 Multi-Switch Profile N

	.			B			E	
~	1	-	A	2	C	D	3	F
	1			~			~	
	H			K			N	
G	4	I	J	5	L	M	6	O
	~			~			~	
	Q			U			X	
P	7	R	T	8	V	W	9	Y
	S			~			Z	
	TAB			SPACE			BS	
~	*	~	~	0	~	~	BS	~
	ENTER			~			~	

Keywiz	Keypad#	Direction	Normal
1	1	LEFT	~
2	1	UP	.
3	2	LEFT	A
4	3	LEFT	D
5	3	SELECT	3
6	6	LEFT	M
7	2	UP	B
8	1	SELECT	1
A	3	UP	E
B	6	UP	N
C	4	LEFT	G
D	4	SELECT	4
E	5	UP	K
F	8	UP	U
G	5	LEFT	J
H	8	LEFT	T
I	7	LEFT	P
J	7	SELECT	7
K	7	UP	Q
L	8	UP	BS
M	9	LEFT	W
N	#	LEFT	~
O	9	UP	X
P	#	UP	BS
U1	0	UP	SPACE
D1	0	DOWN	~
L1	0	SELECT	0
R1	9	SELECT	9
U2	#	SELECT	BS
D2	*	SELECT	*
L2	*	UP	TAB
R2	*	DOWN	ENTER

Keywiz	Keypad#	Direction	Shazam
1	1	RIGHT	-
2	1	DOWN	1
3	2	RIGHT	C
4	3	RIGHT	F
5	6	SELECT	6
6	6	RIGHT	O
7	2	DOWN	~
8	2	SELECT	2
A	3	DOWN	~
B	6	DOWN	~
C	4	RIGHT	I
D	5	SELECT	5
E	4	DOWN	~
F	5	DOWN	~
G	5	RIGHT	L
H	8	RIGHT	V
I	7	RIGHT	R
J	8	SELECT	8
K	7	DOWN	S
L	8	DOWN	~
M	9	RIGHT	Y
N	#	RIGHT	~
O	9	DOWN	Z
P	#	DOWN	~
U1	0	EMPTY	
D1	0	EMPTY	
L1	0	EMPTY	
R1	9	EMPTY	
U2	#	EMPTY	
D2	*	EMPTY	
L2	*	EMPTY	
R2	*	EMPTY	

9.9.7 Multi-Switch Profile O

	B			E			H	
A	1	C	D	2	F	G	3	I
	~			~			~	
	K			N			Q	
J	4	L	M	5	O	P	6	R
	~			~			S	
	U			X			.	
T	7	V	W	8	Y	~	9	-
	~			Z			~	
	TAB			SPACE			BS	
~	*	~	~	0	~	~	BS	~
	ENTER			~			~	

Keywiz	Keypad#	Direction	Normal
1	1	LEFT	A
2	1	UP	B
3	2	LEFT	D
4	3	LEFT	G
5	3	SELECT	3
6	6	LEFT	P
7	2	UP	E
8	1	SELECT	1
A	3	UP	H
B	6	UP	Q
C	4	LEFT	J
D	4	SELECT	4
E	5	UP	N
F	8	UP	X
G	5	LEFT	M
H	8	LEFT	W
I	7	LEFT	T
J	7	SELECT	7
K	7	UP	U
L	8	UP	BS
M	9	LEFT	~
N	#	LEFT	~
O	9	UP	.
P	#	UP	BS
U1	0	UP	SPACE
D1	0	DOWN	~
L1	0	SELECT	0
R1	9	SELECT	9
U2	#	SELECT	BS
D2	*	SELECT	*
L2	*	UP	TAB
R2	*	DOWN	ENTER

Keywiz	Keypad#	Direction	Shazam
1	1	RIGHT	C
2	1	DOWN	~
3	2	RIGHT	F
4	3	RIGHT	I
5	6	SELECT	6
6	6	RIGHT	R
7	2	DOWN	~
8	2	SELECT	2
A	3	DOWN	~
B	6	DOWN	S
C	4	RIGHT	L
D	5	SELECT	5
E	4	DOWN	~
F	5	DOWN	~
G	5	RIGHT	O
H	8	RIGHT	Y
I	7	RIGHT	V
J	8	SELECT	8
K	7	DOWN	~
L	8	DOWN	Z
M	9	RIGHT	-
N	#	RIGHT	~
O	9	DOWN	~
P	#	DOWN	~
U1	0	EMPTY	
D1	0	EMPTY	
L1	0	EMPTY	
R1	9	EMPTY	
U2	#	EMPTY	
D2	*	EMPTY	
L2	*	EMPTY	
R2	*	EMPTY	

9.9.8 Multi-Switch Profile P

	B			E			H	
A	1	C	D	2	F	G	3	I
	~			~			~	
	K			N			Q	
J	4	L	M	5	O	P	6	R
	~			~			S	
	U			X			.	
T	7	V	W	8	Y	~	9	-
	~			Z			~	
	TAB			SPACE			~	
~	*	~	~	0	~	~	BS	~
	ENTER			~			~	

Keywiz	Keypad#	Direction	Normal
1	1	LEFT	A
2	1	UP	B
3	2	LEFT	D
4	3	LEFT	G
5	3	SELECT	3
6	6	LEFT	P
7	2	UP	E
8	1	SELECT	1
A	3	UP	H
B	6	UP	Q
C	4	LEFT	J
D	4	SELECT	4
E	5	UP	N
F	8	UP	X
G	5	LEFT	M
H	8	LEFT	W
I	7	LEFT	T
J	7	SELECT	7
K	7	UP	U
L	8	UP	~
M	9	LEFT	~
N	#	LEFT	~
O	9	UP	.
P	#	UP	~
U1	0	UP	SPACE
D1	0	DOWN	~
L1	0	SELECT	0
R1	9	SELECT	9
U2	#	SELECT	BS
D2	*	SELECT	*
L2	*	UP	TAB
R2	*	DOWN	ENTER

Keywiz	Keypad#	Direction	Shazam
1	1	RIGHT	C
2	1	DOWN	~
3	2	RIGHT	F
4	3	RIGHT	I
5	6	SELECT	6
6	6	RIGHT	R
7	2	DOWN	~
8	2	SELECT	2
A	3	DOWN	~
B	6	DOWN	S
C	4	RIGHT	L
D	5	SELECT	5
E	4	DOWN	~
F	5	DOWN	~
G	5	RIGHT	O
H	8	RIGHT	Y
I	7	RIGHT	V
J	8	SELECT	8
K	7	DOWN	~
L	8	DOWN	Z
M	9	RIGHT	-
N	#	RIGHT	~
O	9	DOWN	~
P	#	DOWN	~
U1	0	EMPTY	
D1	0	EMPTY	
L1	0	EMPTY	
R1	9	EMPTY	
U2	#	EMPTY	
D2	*	EMPTY	
L2	*	EMPTY	
R2	*	EMPTY	

9.10 Text Messaging Abbreviations

Abbreviation	**Meaning**
AAP	Always a pleasure
AAR	At any rate
AAS	Alive and smiling
ADN	Any day now
AEAP	As early as possible
AFAIK	As far as I know
AFK	Away from keyboard
AKA	Also known as
AISB	As it should be
AOTA	All of the above
ASAP	As soon as possible
A/S/L	Age/sex/location
AT	At your terminal
ATM	At the moment
AYEC	At your earliest convenience
B/F	Boyfriend
B4	Before
B4N	Bye for now
BAK	Back at keyboard
BAU	Business as usual
BBIAF	Be back in a few
BBIAM	Be back in a minute
BBL	Be back later
BBS	Be back soon
BC	Because
BCNU	Be seein' you
BF	Best friend
BFN	Bye for now
BLNT	Better luck next time
BM&Y	Between me and you

Abbreviation	**Meaning**
BOL	Best of luck
BRB	Be right back
BRT	Be right there
BTA	But then again
BTDT	Been there, done that
BTW	By the way
CMIIW	Correct me if I'm wrong
CMON	Come on
COB	Close of business
CU	See you
CUA	See you around
CUL	See you later
CUL8R	See you later
CWYL	Chat with you later
CYA	See ya
CYO	See you online
D/L	Download
DEGT	Don't even go there
DIKU	Do I know you?
DQMOT	Don't quote me on this
DTS	Don't think so
EBKAC	Error between keyboard and chair
EMA	E-mail address
EOD	End of day
EOM	End of message
F2F	Face to face
FBM	Fine by me
FISH	First in, still here
FOMCL	Falling off my chair laughing
FITB	Fill in the blank
FRT	For real though

Abbreviation	**Meaning**
FWIW	For what it's worth
FYEO	For your eyes only
FYI	For your information
G/F	Girlfriend
G2G	Got to go
G2R	Got to run
GA	Go ahead
GAL	Get a life
GB	Goodbye
GBU	God bless you
GFI	Go for it
GG	Gotta Go or Good Game
GIAR	Give it a rest
GIGO	Garbage in, garbage out
GL	Good luck
GL/HF	Good luck, have fun
GLNG	Good luck next game
GMTA	Great minds think alike
GOI	Get over it
GOL	Giggling out loud
GR8	Great
GR&D	Grinning, running and ducking
GTG	Got to go
GTRM	Going to read mail
HAGN	Have a good night
HAGO	Have a good one
HAND	Have a nice day
HF	Have fun
HHIS	Head hanging in shame
HOAS	Hold on a second
HRU	How are you?

Abbreviation	**Meaning**
HTH	Hope this helps
IAC	In any case
IANAL	I am not a lawyer
IB	I'm back
IC	I see
ICBW	It could be worse
IDK	I don't know
IDTS	I don't think so
IG2R	I got to run
IIRC	If I remember correctly
ILBL8	I'll be late
ILU	I love you
ILY	I love you
IM	Instant message
IMHO	In my humble opinion
IMNSHO	In my not so humble opinion
IMO	In my opinion
INAL	I'm not a lawyer
IOW	In other words
IRL	In real life
IRMC	I rest my case
IUSS	If you say so
IYKWIM	If you know what I mean
IYO	In your opinion
IYSS	If you say so
JAC	Just a sec
JIK	Just in case
JJA	Just joking around
JK	Just kidding
JMO	Just my opinion
JP	Just playing

Abbreviation	Meaning
KISS	Keep it simple, stupid
KIT	Keep in touch
KOTC	Kiss on the cheek
KNIM	Know what I mean?
L8R	Later
LD	Later, dude / Long distance
LMAO	Laughing my a** off
LOL	Laughing out loud
LTM	Laugh to myself
LTNS	Long time no see
LYLAS	Love you like a sis
M8	Mate
MorF	Male or female?
MoS	Mother over shoulder
MUSM	Miss you so much
MYOB	Mind your own business
n00b	Newbie
NBD	No big deal
NFM	None for me / Not for me
NIMBY	Not in my back yard
NLT	No later than
NM	Nothing much / Never mind
NMH	Not much here
NOYB	None of your business
NP	No problem
NRN	No response/reply necessary
NW	No way
OIC	Oh, I see
OMG	Oh my God
OMW	On my way
OO	Over and out

Abbreviation	**Meaning**
OOH	Out of here
OOTD	One of these days
OP	On phone
OTB	Off to bed
OTL	Out to lunch
OTOH	On the other hand
OTTOMH	Off the top of my head
OTW	Off to work
PDQ	Pretty darn quick
PLMK	Please let me know
PLZ	Please
PMFI	Pardon me for interrupting
PMFJI	Pardon me for jumping in
POAHF	Put on a happy face
POS	Parent over shoulder
PPL	People
PRW	People/parents are watching
PTL	Praise the Lord
PXT	Please explain that
PU	That stinks!
QIK	Quick
RL	Real life
RME	Rolling my eyes
ROTFL	Rolling on the floor laughing
RSN	Real soon now
RTFM	Read the f***ing manual
SICNR	Sorry, I could not resist
SIG2R	Sorry, I got to run
SLAP	Sounds like a plan
SMHID	Scratching my head in disbelief
SIS	Snickering in silence

Abbreviation	**Meaning**
SOMY	Sick of me yet?
SOTMG	Short of time, must go
SPK	Speak
SPST	Same place, same time
SRY	Sorry
SS	So sorry
SSDD	Same stuff, different day
SSINF	So stupid it's not funny
STR8	Straight
STW	Search the Web
SUITM	See you in the morning
SUL	See you later
SUP	What's up?
SYL	See you later
TA	Thanks a lot
TAFN	That's all for now
TAM	Tomorrow a.m.
TBD	To be determined
TBH	To be honest
TC	Take care
TGIF	Thank God it's Friday
THX	Thanks
TIA	Thanks in advance
TIAD	Tomorrow is another day
TLK2UL8R	Talk to you later
TMI	Too much information
TMWFI	Take my word for it
TNSTAAFL	There's no such thing as a free lunch
TPM	Tomorrow p.m.
TPTB	The powers that be
TSTB	The sooner, the better

Abbreviation	**Meaning**
TTFN	Ta ta for now
TTTT	These things take time
TTYL	Talk to you later
TTYS	Talk to you soon
TU	Thank you
TY	Thank you
TYT	Take your time
TYVM	Thank you very much
UGTBK	You've got to be kidding
UKTR	You know that's right
UL	Upload
UR	Your / You're
UV	Unpleasant visual
UW	You're welcome
WAM	Wait a minute
WAN2TLK	Want to talk
WAYF	Where are you from?
W/B	Write back
WB	Welcome back
WIIFM	What's in it for me?
WK	Week
WKD	Weekend
WOMBAT	Waste of money, brains and time
WRUD	What are you doing?
WTF	What the f*ck
WTG	Way to go
WTH	What the heck?
WU?	What's up?
WUCIWUG	What you see is what you get
WUF?	Where are you from?
WWJD	What would Jesus do?

Abbreviation	**Meaning**
WWYC	Write when you can
WYLEI	When you least expect it
WYSIWYG	What you see is what you get
YBS	You'll be sorry
YGBKM	You gotta be kidding me
YMMV	Your mileage may vary
YW	You're welcome

http://www.webopedia.com/quick_ref/textmessageabbreviations.asp

9.11 Itemized Expenditures

Date Purchas	Vendor Name	Description of Materials	Expense	Category	For
01/13/04	Fry's	Force Feedback steering wheel and driving simulation games	$ 108.17	Supplies	CFP
01/13/04	Halted Specialties	Microswitches, push buttons for CFP	$ 39.18	Supplies	CFP
01/15/04	The Home Depot	Tubing, pvc pipe, pvc fittings, and foam prototype steering wheels	$ 14.29	Supplies	CFP
01/17/04	Halted Specialties	Additional microswitches for CFP	$ 11.37	Supplies	CFP
01/30/04	Amazon.Com	Frogpad one handed keyboard	$ 187.47	Supplies	FFP
01/31/04	MegaSharp.com	Cykey Plus one handed keyboard	$ 165.95	Supplies	FFP
02/05/04	Fry's	Mini USB Keyboard, steering wheel (returned 2/11/04), gamepad (returned 3/3/04)	$ 21.64	Supplies	FFP
02/07/04	Fry's	Game steering wheel and typing game	$ 43.28	Supplies	FFP
02/07/04	The Home Depot	Wood, hinges, and screws for FFP prototypes	$ 72.70	Supplies	FFP
02/10/04	Fry's	CD scratch kit (returned mini keypads 3/3/04)	$ 10.81	Supplies	FFP
02/11/04	Fry's	Soldering iron, solder iron tip, solder (returned steering wheel on 3/3/04)	$ 17.04	Supplies	FFP
02/12/04	Fry's	PS/2 - USB adapter, mini USB port	$ 25.96	Supplies	2FP
02/25/04	Jameco	LCD Serial Display and USB Serial Converter	$ 205.56	Supplies	2FP
02/27/04	Jameco	Bread Boards, IC components, power inverter, LEDs, cable ties, wire jumper kit, USB extension cables, grab bag of capacitors, resistors, diodes, switches	$ 327.29	Supplies	2FP
02/29/04	Fry's	PS2-USB connector (Security Camera System returned 3/5/03)	$ 16.23	Supplies	2FP
03/01/04	Fry's	Video Tapes (returned power adapters)	$ 10.81	Supplies	2FP
03/01/04	Halted Specialties	LED 7 Segment displays and soldering hands	$ 15.01	Supplies	2FP
03/01/04	Fry's	Geko GPS Unit, Cigarette Lighter Apater	$ 194.79	Supplies	2FP
03/01/04	The Home Depot	Friction tape, safety glasses, plugs,copies of Volvo test car keys,	$ 20.01	Supplies	2FP
03/01/04	Tap Plastics	30x8 clear acrylic sheet, 26x21 clear acrylic sheet	$ 59.99	Supplies	2FP
03/01/04	Fry's	Maglite rechargeable flashlight assembly	$ 108.24	Supplies	2FP
03/01/04	Target	VCR for video monitoring system, painter's tape, velcro	$ 67.63	Supplies	2FP
03/02/04	Napa Auto Parts	Screws, (returned radar detector mount, bracket)	$ 36.96	Supplies	2FP
03/02/04	Orchard Suplly Hardware	Velcro, bolt washers, cable ties, and cable mounting	$ 43.06	Supplies	2FP
03/02/04	Sommer & Maca	6" vacuum cups for camera mounts	$ 106.96	Supplies	2FP
03/03/04	Halted Specialties	Multimeter, LEDs, molex connectors, switches, wire cutters, battery pack, battery connectors	$ 74.90	Supplies	2FP
03/03/04	Target	Tire valves, windshield wipers, tool kit	$ 40.40	Supplies	2FP
03/03/04	Kmart	Power strip (returned mechanic strip)	$ 11.88	Supplies	2FP
03/03/04	Napa Auto Parts	Voltmeter gauge, lights for camera mounts (credit applied from returned radar dector mount, bracket)	$ 29.20	Supplies	2FP
03/03/04	Fry's	3 foot coaxial cables, rip-ties, clipboard	$ 18.75	Supplies	2FP
03/03/04	Walgreens	Small tv for video monitoring system	$ 27.05	Supplies	2FP
03/04/04	Fry's	Video monitoring system, batteries, RCA cables, and Y connector for power supply	$ 333.26	Supplies	2FP
03/04/04	Sharon Heights Shell	Gas for test vehicle	$ 27.20	Supplies	OH
03/26/04	Systems Technologies	STISIM Drive Simulator Software	$ 250.00	Supplies	OH
03/26/04	Costco	Car Cover and Tie Downs	$ 68.18	Supplies	OH
03/18/04	Stanford Bookstore	Stanford Seal Glasses	$ 12.83	Supplies-Gifts	OH
03/13/04	Costco	See's Gift Certificates/Chocolates	$ 63.29	Supplies-Gifts	OH
03/01/04	Stanford Transportation	Parking Permit	$ 188.00	Supplies	OH
02/23/04	FedEx	Shipping: Non Disclosure Agreements to Japan	$ 22.42	Supplies	OH
01/23/04	FedEx	Shipping: Autumn Quarter Reports to Toyota	$ 22.31	Supplies	OH
12/12/03	FedEx	Shipping: Video Conference Equipment for Professor Ito	$ 86.60	Supplies	OH
02/23/04	Mevael Corp	Second Functional Prototype: 3 Keiboards	$ 85.61	Supplies	2FP
02/27/04	Orchard Supply Hardware	Second Functional Prototypes: Horseshoe magnets for monitoring camera mounts	$ 37.31	Supplies	2FP
03/01/04	Pep Boys	Second Functional Prototype: Holders and Clipboard for LCD Display mount	$ 43.22	Supplies	2FP
03/06/04	Halted Specialties	Second Functional Prototype: Switches for Attention Module	$ 13.37	Supplies	2FP
03/08/04	Fry's	Second Functional Prototype: Powerstrip and AC Adapters	$ 10.78	Supplies	2FP
03/16/04	Kinko's	Printing: Binding for Winter Quarter Final Reports	$ 19.27	Supplies	OH
03/26/04	Halted Specialties	Final Prototypes: Basic Stamp Board of Education Kit	$ 109.12	Supplies	FP
03/31/04	Scott Edwards Electronics	Final Prototypes: Display Cables for LCD Display	$ 38.00	Supplies	FP
03/31/04	Jameco	Final Prototypes: LCD Display	$ 156.95	Supplies	FP
04/02/04	Halted Specialties	Final Prototypes: Power supplies and IC componets for control box	$ 31.23	Supplies	FP
04/03/04	Walmart	Final Prototypes: Sculpting Clay and Dough	$ 11.81	Supplies	FP
04/03/04	Fry's	Final Prototypes: Touch Screen from Refurbished Palm Pilot	$ 43.29	Supplies	FP

04/04/04	Radio Shack	Final Prototypes: PC Boards	$ 7.32	Supplies	FP
04/05/04	Halted Specialties	Final Prototypes: Switches for Control Box	$ 12.73	Supplies	FP
04/06/04	Meveal Corp	Final Prototypes: 2 Keiboards	$ 58.73	Supplies	FP
04/07/04	Walmart	Final Prototypes: Dremel tool accessories and calculator buttons for keypad prototype	$ 34.41	Supplies	FP
04/08/04	Halted Specialties	Final Prototypes: Amber LEDs for Attention Module	$ 20.20	Supplies	FP
04/09/04	Jameco	Final Prototypes: Basic Stamp 2P24 Microcontroller IC	$ 85.46	Supplies	FP
04/14/04	Fry's	Final Prototypes: Connectors, Switches, Adapters, and Power Strip for Control Box	$ 56.20	Supplies	FP
04/14/04	Digi-Key.com	Final Prototypes: Tactile Navigation Switches for Final Prototype	$ 49.90	Supplies	FP
04/15/04	Fry's	Final Prototypes: Wireles Keyboards, Electronics Fans, and Bearings	$ 45.23	Supplies	FP
04/18/04	Fry's	Final Prototypes: Serial Connecters for Control Box	$ 18.10	Supplies	FP
04/18/04	Fry's	Final Prototypes: Thumbscrews and KVM Switch for Control Box	$ 31.51	Supplies	FP
04/19/04	Jameco	Final Prototypes: Connectors, Sockets, Jacks and PS/2 Adapters for Keypad Prototypes	$ 47.95	Supplies	FP
04/19/04	Tap Plastics	Final Prototypes: Black Acrylic Sheets for Control Box	$ 24.05	Supplies	FP
04/19/04	Tap Plastics	Final Prototypes: Black Acrylic Sheets for Attention Module	$ 5.41	Supplies	FP
04/19/04	Stanford Bookstore	Final Prototypes: Battery for Basic Stamp, protractor, compass	$ 11.44	Supplies	FP
04/20/04	Halted Specialties	Final Prototypes: Additional connectors for control box	$ 4.68	Supplies	FP
04/21/04	The Oleander Company	Final Prototypes: nuts, screws and bolts for control box	$ 111.74	Supplies	FP
04/21/04	The Oleander Company	Final Prototypes: nuts, screws and bolts for control box	$ 26.90	Supplies	FP
04/21/04	Halted Specialties	Final Prototypes: Connectors for control box	$ 3.51	Supplies	FP
04/21/04	Fry's	Final Prototypes: Thumbscrews for Control Box	$ 6.47	Supplies	FP
04/21/04	Digi-Key.com	Final Prototypes: Tactile Navigation Switches and Button Tops for Final Prototypes	$ 229.35	Supplies	FP
04/21/04	Sweden Auto Warehouse	Final Prototypes: Steering wheel for Volvo test vehicle	$ 60.87	Supplies	FP
04/23/04	Radio Shack	Final Prototypes: PC Board	$ 1.83	Supplies	FP
04/24/04	University Art Center	Final Prototypes: Foam Core Sheets for Steering Wheel Mockups	$ 42.00	Supplies	FP
04/25/04	Orchard Supply Hardware	Final Prototypes: Black Super Glue, Plastic Gloves, and Xacto Knife Blades	$ 9.70	Supplies	FP
04/26/04	Jameco	Final Prototypes: IC Sockets, Header Plugs, Diodes, and USB Cables	$ 43.63	Supplies	FP
05/03/04	PCBexpress	Final Prototypes: 8 PCB Boards - Aligned Layout	$ 167.23	Supplies	FP
05/03/04	PCBexpress	Final Prototypes: 8 PCB Boards - Rotated Layout	$ 167.23	Supplies	FP
05/03/04	Jameco	Final Prototypes: Diodes for Keypads	$ 11.69	Supplies	FP
05/05/04	Tap Plastics	Final Prototypes: Acrylic Cement and Dispenser	$ 7.42	Supplies	FP
05/05/04	Tap Plastics	Final Prototypes: Acrylic Sheets for Final Steering Wheel	$ 5.41	Supplies	FP
05/08/04	FedEx	Shipping: Keypad prototype for TMIT	$ 63.35	Supplies	OH
05/22/04	Sage Hill Engineering	Final Product: Manufacturing of Alumninum Steering Wheel	$ 3,963.25	Supplies	FP
05/25/04	Tangible Designs	Final Product: Manufacturing of Aluminum Steering Wheel Bezel	$ 1,975.56	Supplies	FP
05/19/04	Stanford University	One Quarter Pass for Stanford Product Realization Lab	$ 120.00	Supplies	OH
05/12/04	Stanford University	Final Prototypes: Product Realization Lab Manufacturing of Steering Wheel Bezel Keypad Prototype	$ 123.00	Supplies	FP
05/18/04	Stanford University	Final Prototypes: Product Realization Lab Manufacturing of Steering Wheel Bezel Prototype	$ 81.30	Supplies	FP
11/17/03	Japan Airlines	Railpass for David Cannon	$ 260.75	Travel	Trav
01/07/04	City of San Jose Market 2	Parking for San Jose Auto Show	$ 4.00	Parking/Transportation	Trav
01/17/04	San Francisco Intl Airport	Parking fee for picking up Kaz and Kohei	$ 1.00	Parking/Transportation	Trav
01/17/04	San Francisco Intl Airport	Parking fee for picking up Kaz and Kohei	$ 3.00	Parking/Transportation	Trav
01/19/04	Ampco Systems Parking	Parking fee for San Francisco tour	$ 6.00	Parking/Transportation	Trav
01/19/04	Golden Gate Bridge	Bridge toll for San Francisco tour	$ 5.00	Parking/Transportation	Trav
1/17 - 1/21/2004	Driving Mileage (266 miles)	Mileage Summary: 2 Round Trips to SFO, San Francisco, Cambpell for Kaz and Kohei Visit	$ 93.10	Parking/Transportation	Trav
02/01/04	United Airlines	3 Roundtrip Tickets SFO-Japan ($566.99) March 18 -24	$ 1,700.97	Travel	Trav
02/29/04	Parking and	Service Vehicle Permit	$ 188.00	Parking/Transportation	Trav
03/24/04	San Francisco Intl Airport	Parking fee for trip to Japan (5 days, 23 hours, 35 min)	$ 78.00	Parking/Transportation	Trav
03/17/04	Travel Cuts	7 day Japan Rail Passes (3 passes $252 plus $20 processing fee)	$ 816.00	Parking/Transportation	Trav
03/22/04	Hotel Pine Hill Ueno	(3 days - 8500 yen + 425 tax) * 3 Check in 3/19 - Check out 3/22	$ 763.29	Travel	Trav
03/22/04	Sun Hotel Kyoto	(1 day - 7000 yen + 350 tax) *3 Check in 3/22 - Check out 3/23	$ 209.52	Travel	Trav
03/23/04	Hotel Pine Hill Ueno	(1 day - 8500 yen +425 tax) *3	$ 255.60	Travel	Trav
03/20/04	Japan Railways Subway	Subway Yurikamome Shimbashi - Yurikamome Odaiba-Kaihin Koen; 310 yen * 3	$ 8.82	Travel/Transportation	Trav

03/20/04	Japan Railways Subway	Subway Yurikamome Odaiba-Kaihin Koen - Yurikamome Shiodome; 310 yen * 3	$ 8.82	Travel/Transportation	Trav
03/20/04	Tokyo Water Bus	Water Bus Hinode Pier - WaterBus Asakusa; 660Yen *3	$ 18.77	Travel/Transportation	Trav
03/20/04	Japan Railways Subway	Subway Ginza Line Asakusa - Subway Ginza Line Ueno; 160Yen *3	$ 4.55	Travel/Transportation	Trav
03/22/04	Japan Railways Subway	Subway Meitetsu Shinnagoya - Meitetsu Tuchihashi; 650Yen *3	$ 18.49	Travel/Transportation	Trav
03/22/04	Japan Railways Subway	Subway Meitetsu Toyotashi - Meitetsu Nagoya 790Yen *3	$ 22.47	Travel/Transportation	Trav
03/23/04	Japan Railways Subway	Subway Ginza - Subway Asakusa; 190Yen * 3	$ 5.40	Travel/Transportation	Trav
03/23/04	Japan Railways Subway	Subway Asakusa - Subway Ueno; 160Yen * 3	$ 4.55	Travel/Transportation	Trav
03/19/04	Hotel Pine Hill Ueno Vending Machine	Snack: Softdrinks from vending machine; 120 Yen	$ 3.41	Travel/PerDiem	Trav
03/20/04	Mu-Lan	Lunch: Lunch Special 1200 Yen * 3	$ 34.13	Travel/PerDiem	Trav
03/20/04	Very Very	Snack: Italian Ice (250 yen) and Strawberry Crepe (450 yen)	$ 6.64	Travel/PerDiem	Trav
03/20/04	JR Train Station Vending Machine	Snack: Softdrinks and Hot Coffe from Vending Machine; 120 Yen and 150 Yen	$ 3.70	Travel/PerDiem	Trav
03/21/04	Ueno Zoo Concessions	Breakfast: Pizza, softdrink (820 yen) and coffee (150yen)	$ 9.20	Travel/PerDiem	Trav
03/21/04	Restaurant in Akihabara	Lunch: Noodle Lunch Special 1200 Yen * 3	$ 34.13	Travel/PerDiem	Trav
03/21/04	JR Train Station Vending Machine	Snack: Water (110yen), Hot Chocolate (120yen), and Coke (120 yen)	$ 3.32	Travel/PerDiem	Trav
03/21/04	Circle K	Dinner/Snack: Sandwhich (500 yen), Ice Cream Bar, Soft Drink (300 yen) Crackers, M&Ms (300 yen)	$ 10.43	Travel/PerDiem	Trav
03/22/04	Sun Hotel Kyoto Vending Machine	Snack: Hot Coffee, Green Tea, Large Soft Drink 150 yen	$ 4.27	Travel/PerDiem	Trav
03/22/04	Restaurant in Kyoto	Lunch: Curried Rice and Pork Cutlet (2) and Tempura Lunch Specials; 1200 yen	$ 34.13	Travel/PerDiem	Trav
03/22/04	Pronto Café - Kyoto	Snack: 2 Coffees (250 yen *2), Cappacino(300 yen), Tea Cake (200 yen), Hot Chocolate (200 yen)	$ 12.80	Travel/PerDiem	Trav
03/22/04	Kobashi Restaurant - Kyoto	Japan Trip Food Per Diem: Kaz Kayashi, Kohei Hiwaki, Tori Bailey, Dave Fries and Philipp Skogstad (8975 ¥)	$ 84.10	Travel/PerDiem	Trav
03/23/04	JR Train Station Vending Machine	Snack: Softdrinks and Hot Coffee from Vending Machine; 120 Yen and 150 Yen	$ 3.70	Travel/PerDiem	Trav
03/24/04	Restaurant in Asakusa	Lunch: Tempura Lunch Special 1200 yen * 3	$ 34.13	Travel/PerDiem	Trav
03/24/04	JR Train Station Vending Machine	Snack: Green Tea, Large Soft Drinks (150 yen)	$ 4.27	Travel/PerDiem	Trav
03/24/04	Travel Per Diem		$ 17.24		
01/17/04	Armadillo Willy's	Working meal with Kaz, Kohei, Philipp and Tori	$ 83.76	Working Meal	OH
01/18/04	Hobee's	Working meal with Kaz, Kohei, and Tori	$ 33.04	Working Meal	OH
01/19/04	In-N-Out Burger	Working meal with Kaz, Kohei, Philipp, Tori and Dave	$ 23.86	Working Meal	OH
01/19/04	Jamba Juice	Working meal with Kaz, Kohei, Philipp and Tori	$ 15.00	Working Meal	OH
01/19/04	Bubba Gump	Working meal with Kaz, Kohei, Philipp and Tori	$ 91.89	Working Meal	OH
01/20/04	Chevy's	Working meal with Dave C., Kaz, Kohei, Philipp, Tori and Dave	$ 113.29	Working Meal	OH
01/20/04	Pollo Rey - Treehouse	Working meal with Kaz, Kohei and Philipp	$ 15.62	Working Meal	OH
	tbd	Printing and Binding for Final Report (est)	$ 500.00		OH
		Total	**$ 17,194**		

9.12 Handouts

9.12.1 Critical Functional Prototype (CFP)

Please see next page.

Team YTPD Garage and TMIT

TOYOTA

Critical Function Prototype Review
January 20, 2004

Introduction:

Toyota's problem statement for the project asks for the "optimum human-machine interface for the IT generation". Team YTPD Garage found that those who are born after the introduction of the personal computer in 1985 are considered as the IT generation. The oldest members of the IT generation are currently entering college, grew up with windows based computer systems and do not remember a time without email or instant messaging. This prompted YTPD Garage to conclude that the main difference between the IT generation and older generations is their "connectedness".

Need Statement:

YTPD Garage determined that the IT generation is connected to email and instant messaging at all times using cell phones. Currently, members of the IT generation are starting to drive vehicles and but do not stop communicating with others when they drive. While this at first may appear normal, the problem is that the IT generation does not only use their cell phone to talk but also to type. One can observe teenagers driving in dense traffic while typing short messages (SMS) on their phones and having difficulty to stay in lanes. YTPD Garage found that it is not possible to stop these people from using their cell phones while driving even if prohibited by law. This prompts the need for a "safer" way to communicate written text while driving.

Design Development:

The need for a "safer" way to communicate written text leads to a broad range of requirements and solutions on both the input and output side of the interface. YTPD garage decided to focus on the text input method since there is already a great deal of research being done on information output and display in vehicles and any attempt to compete with these efforts is outside the scope of the ME 310 course given the time and deliverable constraints. The input side, on the other hand, appears to be less thoroughly researched. Therefore it was decided that all effort would be put into the development of an intuitive input interface that allows the user to enter text characters safely while driving.

Various ways to input text were researched and it was concluded that the two best input methods are either voice recognition or a button based input system. Voice recognition is not only researched by thousands of researchers worldwide but also disturbing to other passengers in the vehicle. Therefore, the design space for this project was limited to the development of an input method that would allow the text input using buttons.

The team decided that buttons mounted to the steering wheel would be the safest and follow Toyota's paradigm of "eyes on the road and hands on the wheel". Physical implementations of this idea could involve any number of buttons on the right or left and front or back of the steering wheel. The buttons could be activated using any number of fingers. Any of these ideas, however, assume the driver is able to move individual fingers independently and in no connection to the arm movement required to turn the steering wheel.

The following test was done to test this assumption: One shall sit down and start to rotate the right leg in a clockwise direction while at the same time drawing a large "6" into the air with the right hand (see illustration).

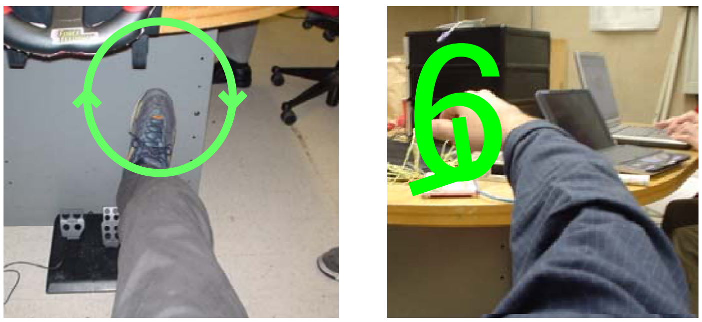


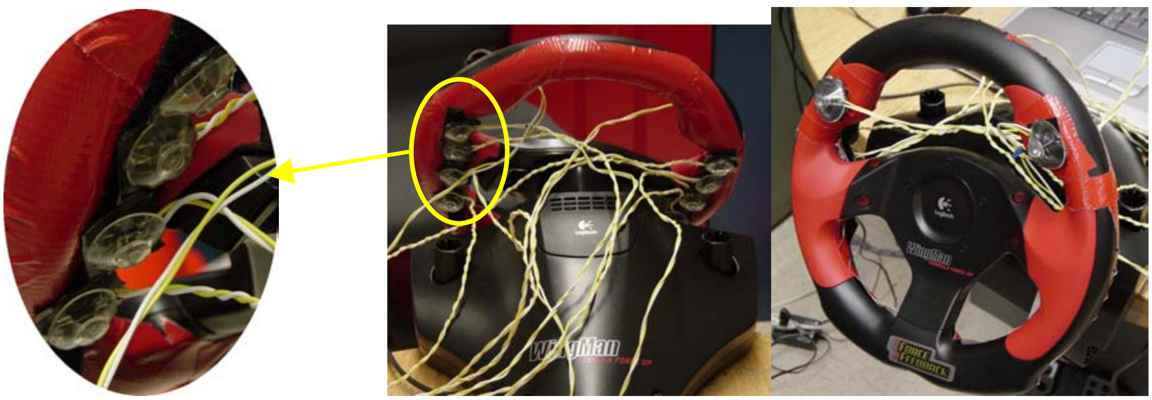
Diagram of quick test, which showed that an assumed fact must be tested prior to further development

The test quickly revealed that this ability cannot be assumed and therefore YTPD Garage decided that the average driver's ability to do this "stereo" motion should be further investigated since it would be the underlying basis for all future development. A simple prototype was produced to test this critical function.

Critical Function Prototype:

The critical function prototype was built using two laptop computers, a simulator steering wheel with pedals and ten micro switches. The micro switches were attached to the steering wheel with one on the front and four on the back of the steering wheel on each side so that when the steering wheel is held in a quarter to three position, every finger would rest on one button. These buttons were wired to the number keys of a standard keyboard, which was connected to the first laptop so that the button activation could be observed. The steering wheel and pedals were connected to the other laptop, on which a driving video game was run as shown in the pictures below:

Pictures of hardware setup used as CFP



Buttons on front and back of steering wheel used as CFP

Every test candidate was then asked to “drive” the video game while entering numbers using the buttons on the steering wheel.

Lessons Learned:

Testing of the CFP revealed that it is not possible to move all fingers independently while driving at the same time. It was observed that moving individual fingers requires so much attention, that it is not possible to concentrate on the main task of driving. In addition to the counter-intuitive motion, it was found that the unusual setup is counter-intuitive too. The number setup (1, 2, 3, 4, 5 and 6, 7, 8, 9, 0 on the right and left starting with the thumb to the pinky finger respectively) requires a tremendous amount of training since every user is used to the standard 9+1 key setup found on phones and full-size keyboards for number input.

Additionally, a health or comfort issue was found. After typing and steering at the same time for about five minutes, all users were greatly fatigued and felt a pain either in their shoulders or forearms, which could lead to the CARpul tunnel syndrome.

The team also made the following observations, which will be important for consideration in the following designs:

- The layout and size of the buttons must accommodate hands of various sizes.
- All users admitted that it took them a long time (sometimes years) to become familiar with the standard QWERTY keyboard but they were questioning their

and the final users' willingness to learn a new keyboard for use in their car only. Therefore, a standard layout, which the operator is familiar with is desirable.

- Other keys such as a backspace and function keys must be easily accessible too.
- Moving individual fingers is very difficult. It is hard to wiggle the ring finger without moving any other fingers if one is not used to this motion from playing piano or performing similar tasks.
- The simulation should be more realistic rather than based on a difficult to use computer game.

The team concluded that the two-thumb operation on the steering wheel should be further investigated but that any additional motion on the steering wheel would require too much attention to be safe while driving.

Future Development:

YTPD Garage meet with the Toyota liaisons to discuss the design idea and CFP results. It was agreed that this idea constitutes an acceptable and useful design project (whether as final success or failure). In addition, Toyota limited the paradigm of "eyes on the road, hands on the wheel" to a single hand on the wheel thus allowing one hand to be used for typing exclusively. This greatly opens the design space for solutions scenarios such as a one-handed keyboard on the center console.

The design process will be continued by researching more standardized input methods. These will extend from one-handed input keyboards to keyboards made for visually impaired people. When the team has produced a variety of ideas for inputs on the center console or steering wheel, the most promising ideas will be assembled as crude prototypes and compared with each other to determine the best location and input method.

The following figures show some initial ideas for where this development may lead:

Various ideas for character input to be investigated in during future development

9.12.2 First Functional Prototype (FFP)

Please see next page.

Team YTPD Garage and TMIT

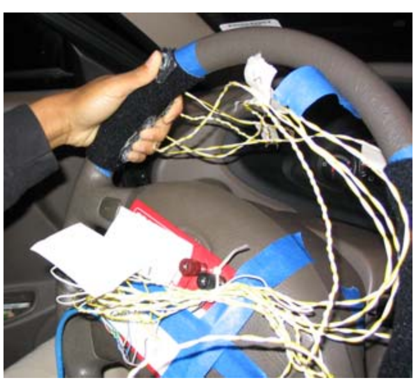
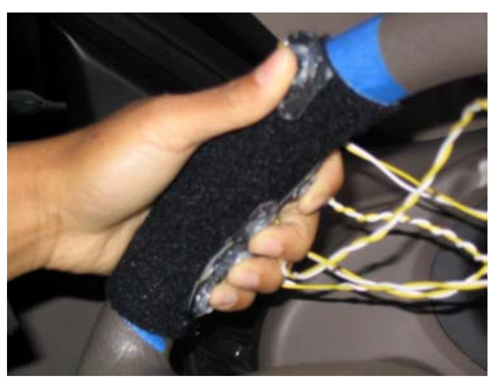
First Functional Prototype Review
February 12, 2004

Introduction:

Toyota's problem statement for the project asks for the "optimum human-machine interface for the IT generation". Team YTPD Garage determined that the IT generation is much more connected than any other generation. Members of the IT generation are used to SMS (Short-Messaging Service), Instant Messaging and email at all times even while driving a car. Given that the current inputs for use in cars are either very tedious (multi tab or dials) or obtrusive (voice recognition) the design goal was stated as follows: To design an interface that allows efficient character and data input while driving safely.

Design Development:

Team YTPD tested the possibility of placing buttons on the front and back of the steering wheel that would allow the user to type and steer with both hands at the same time. This test was done on a simulator and in an actual car as the Critical Functional Prototype. Various users tested the system and found that the average human person is not used to or not even able to perform the two unrelated motions required to steer and type with the same hands at the same time. This was especially the case when the buttons were placed on the front and back of the steering wheel since the fingers had to move against each other.

Steering wheel with buttons on front and back as used for CFP.

Another test was done by placing five buttons on the center console and typing with one hand only. This approach was much more intuitive and easy to use since the workload was split up between the two hands and whenever the right hand was removed from the buttons, the user was able to relocate on the "keyboard" easily and quickly since the keyboard remained in the same place. The steering wheel, on the other hand was constantly moving and thus it was difficult to correctly relocate the hands on the buttons.

Buttons on center console for one-handed input.

The one handed method worked well when using five buttons (one for each finger) but quickly reached its limits when the user wanted to enter all characters of the alphabet and numbers. Therefore, other methods had to be considered as well. Ideas included various keyboards such as the frog-pad, chorded or QWERTY (standard) keyboard, or a brand new method. Testing of the different input methods showed that the frog-pad's efficiency can approach that of using QWERTY after a considerable amount of training. Given Toyota's requirement of having similar interfaces at home and in the car and the amount of training that everybody put into the QWERTY keyboard, it was concluded that the QWERTY keyboard would be the most desirable input method.

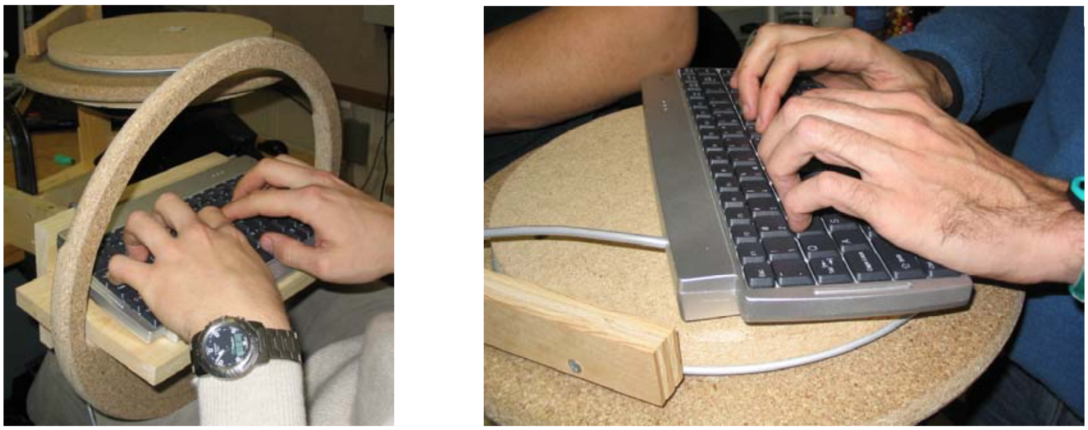
Various keyboards: Frog-Pad, chorded and QWERTY

One major drawback of the QWERTY keyboard is that is requires two hands for efficient input. There are many users who "hunt and peck", often with only one hand, however these methods require a significant visual effort at concentrating on the keyboard. Touch typists are not only faster at input, but can type while looking (and concentrating) on other tasks. A major challenge of using the QWERTY keyboard as the entry device is continuing to control the vehicle if both hands are on the keyboard.

YTPD Garage has focused on two implementations of typing with two hands while steering. The first approach uses both hands to steer and type at the same time, by integrating the keyboard into the steering wheel. Two modified steering wheel/keyboard combinations have been built and tested. The second approach allows the hands to type by using the driver's feet to steer. A custom interface for steering/accelerating/braking with your feet has been built and tested.

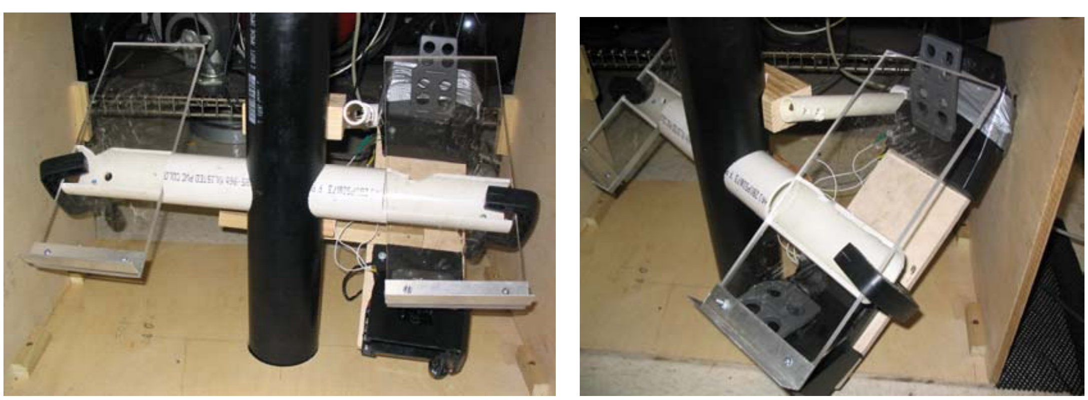
First Functional Prototype:

Two variations of the keyboard integrated steering wheel were built and tested for the First functional prototype effort. The first design incorporates a keyboard into an alcove in the center hub of the steering wheel. The keyboard rotates with the wheel, but can be adjusted for tilt and depth. This approach adapts the keyboard to the typical steering wheel position.



Prototype of steering wheel with integrated keyboard.

The second design adapts the steering wheel to the typical keyboard position. The steering wheel is tilted up to a flat position, much like the steering configuration of a bus or large truck. The keyboard is mounted to the center of the steering wheel. The keyboard is affixed to the wheel through a rotary joint, while a strut keeps the keyboard from spinning. This configuration allows the keyboard to remain in a fixed position to the driver while the steering wheel is free to rotate independently.



Prototype of foot driving system.

Lessons Learned:

The testing and comparison between the two methods has not been concluded yet. It will not only be necessary to test the character input efficiency of the two methods but also the negative impact they have on driving safety. The team determined during the first stages of the project, that any interaction is a distraction to a greater or lesser extend.

The detailed tests planned are outlined in the next section but it can already be concluded that both, the drive by palm and drive by foot method are viable solutions scenarios.

The major lesson learned so far, is that it is very difficult to find a reasonably priced driving simulator. Most driving games are designed as action games and therefore do not include many straights or regular traffic conditions. In addition, the team encountered major problems when attempting to make the simulations games work with the input hardware due to differences in software versions.

Future Development:

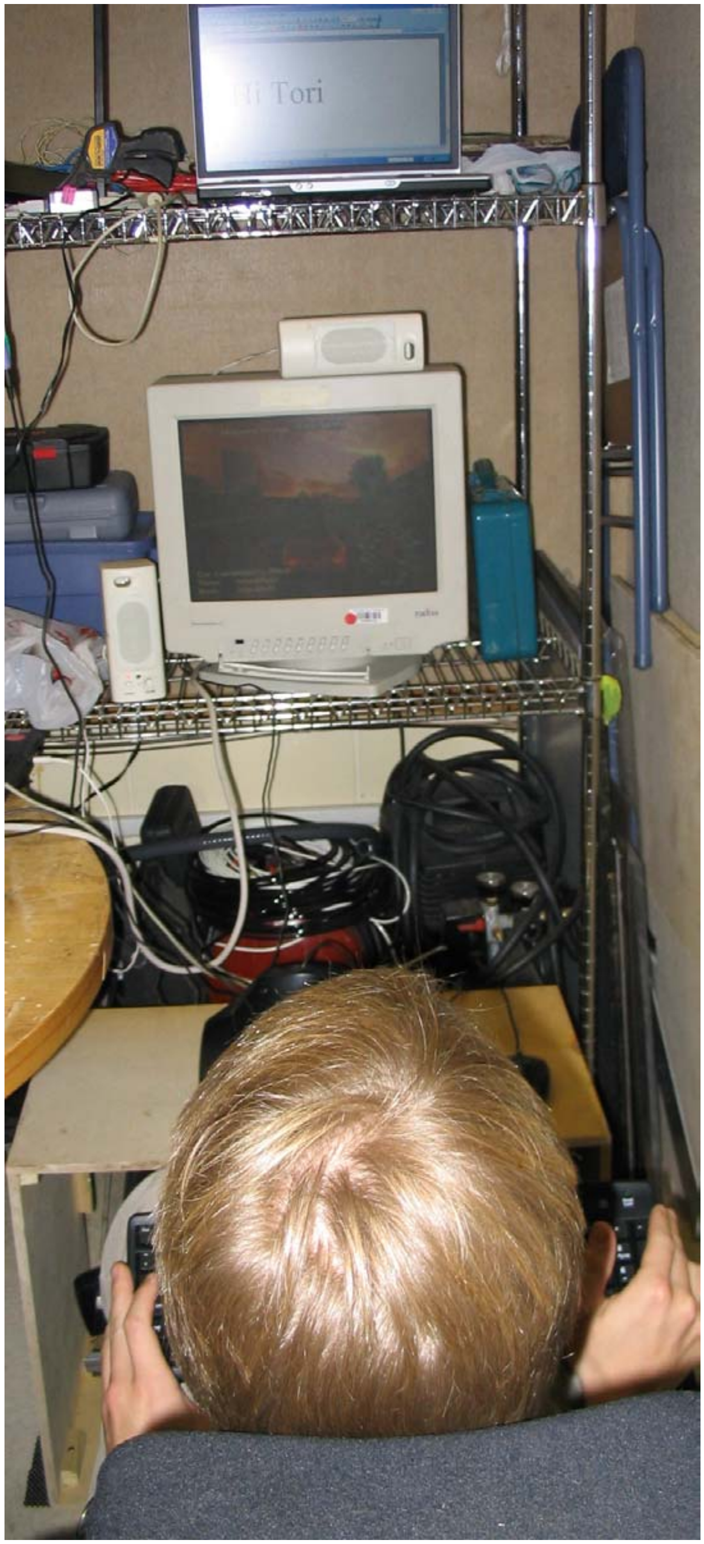
The next steps in the design and testing cycle will be an extensive test of the two functional prototypes. The team will use various computer driving games (Driver's Education 99, Autobahn Racing and Hot Pursuit) to test different users under different driving conditions. These games all keep scores about accidents and thus allow and easy interpretation of the results. The different users, while driving will be asked to complete a typing game simultaneously on a separate screen. For each user, the driving game score will be divided by the typing game score on each session to allow a statistical analysis of the various input methods. Every user will also be asked to complete the simulation without typing to allow a comparison with current driving conditions.

In addition, another set of tests will be performed to test the viability of the foot steering system. To do this, the team plans to recruit a group of 14 or 15-year-old teenagers who have now driving experience so far. They will be asked to drive the simulators using the traditional and the drive-by-foot steering interface.

Once these tests are performed and the project direction has been reviewed with Toyota, the team plans to integrate a typing interface into a vehicle or vehicle simulator for the purpose of this project. This should then demonstrate how a driver can drive safely while entering data efficiently in an unobtrusive fashion.

Picture of system used to test steering and typing with hands at the same time.

Picture of keyboard and foot steering system used in test.



Picture of system used to test foot steering concept.

9.12.3 Second Functional Prototype (SFP)

Please see next page.

Team YTPD Garage and TMIT

Second Functional Prototype Review
March 4, 2004

Introduction:

Toyota's problem statement for the project asks for the "optimum human-machine interface for the IT generation". Team YTPD Garage determined that the IT generation is much more connected than any other generation. Members of the IT generation are used to SMS (Short-Messaging Service), Instant Messaging and email at all times even while driving a car. Given that the current inputs for use in cars are either very tedious (multi tab or dials) or obtrusive (voice recognition) the design goal was stated as follows: To design an interface that allows efficient character and data input while driving safely.

Design Development:

Team YTPD Garage expanded its scope using the lessons learned from the critical functional prototype, the first functional prototype (see pictures below), and a meeting with the client, Toyota. Until now the team focused primarily on the input portion of the interface. Now, the team in collaboration with TMIT plans to develop an entire interface system. In addition, the team will greatly emphasize on user testing using a simulator and an actual vehicle in traffic.

Critical (Buttons on Steering Wheel) and First Functional (QWERTY and Foot-Steering) Prototypes

The design will therefore consist of the following blocks:

INPUT
- CyKey
- Keiboard

→

PROCESS
- E-mail
- Instant Message

→

OUTPUT
- Heads-Up-Display
- LCD Display

Using the testing and benchmarking data gathered on various input devices, the team concluded that for the vehicle applications the design must allow for at least one hand to be on the steering wheel at all times. Therefore, a one-handed input method must be used in the design. The input devices selected are the chorded CyKey or the Keiboard, which are both shown in the picture below.

Keiboard and Chorded CyKey, which are considered as Input Devices

The process will be performed by a CPU, which is integrated into the vehicle's backbone and also used for all other interface operations. This CPU would have to run the various software programs required to email, instant message or a word processor. For the purpose of this design, the CPU will be a separate Windows based PC, which is connected to the input and output devices.

Finally, the user would receive feedback and information through a visual display. This display could be a combination of various technologies such as a heads-up display complemented with a small LCD screen to show a few characters only. The details of this part of the system will be designed in collaboration with the team at TMIT.

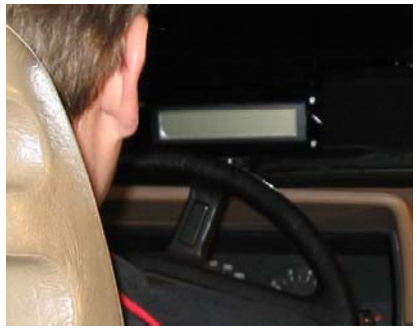
Toyota requires that the driver will still be able to drive safely without the aid of any autopilot system. Therefore it is critical for the design to keep the driver's distraction to a minimum and within reasonable boundaries. This requires the various concepts to be tested and verified using a set of predetermined metrics.

The team found that this is difficult given the number of variables involved in the task of driving and the tremendous amount of technology required to simulate these realistically. Therefore, it was decided to focus on a test procedure and test bed for the second functional prototype as described below.

Second Functional Prototype:

The team obtained and equipped a car with a preliminary interface system and test equipment. The interface system consists of an interchangeable Keiboard and CyKey input device, a Windows PC and an LCD display. The test equipment includes four cameras with monitor and a VCR, a GPS system and switchable LEDs used to measure reaction time.

The input devices were mounted on an adjustable center console, which the team fabricated and the LCD display mounted to the windshield as shown below:



LCD Display on Windshield

The test equipment is explained in detail in the following section and will be used to test the following parameters, which the team judges to be good indications of the driver's distraction:

- Lane departure on right and left side.
- Variation in driving speed.
- Steady state deviation from the posted speed limit.
- Reaction time to emergencies ahead.
- Awareness of the vehicle's environment.

The lane departures to either side will be tested using cameras mounted on either side of the vehicle as shown below. These cameras record the position of the tires relative to the lane markings.

Cameras used to track lane departures

Two other cameras are positioned inside the vehicle to record the driver's movement on the steering wheel and his or her use of the interface. The cameras are positioned so that they track the driver from behind with the same view as the driver and sideways from the front as shown in the picture. All cameras are connected to a VCR to record all four views simultaneously to allow later analysis of the data collected.

Camera to track driver, recording setup and GPS used to measure speed

The speed measurements are performed using a GPS receiver, which is attached to a computer, which logs the vehicle speed and time stamps it. In addition, the driver's reaction time is measured using an LED cluster. This cluster is mounted in the line of vision, along with an OFF button on the steering wheel. The LED cluster will be illuminated at random and the time until the driver activates the OFF button will be recorded. This time can be considered equivalent to the reaction time in case of an emergency. The driver's awareness of the vehicle's environment is measured similarly but using smaller LEDs placed at the four corners of the windshield and on either side of the rear window. One of these LEDs will be illuminated at random and the time until the driver reacts will be measured as well to test how much the driver "scans" the environment.

The team plans to overlay all the collected data and compare it to the recorded data input efficiency. This should allow for a quantitative comparison between the individual interface systems and components. Comparisons will also be done with baseline data collected on test-drives with no interface interaction to evaluate the overall impact of the interface system on the user's ability to drive.

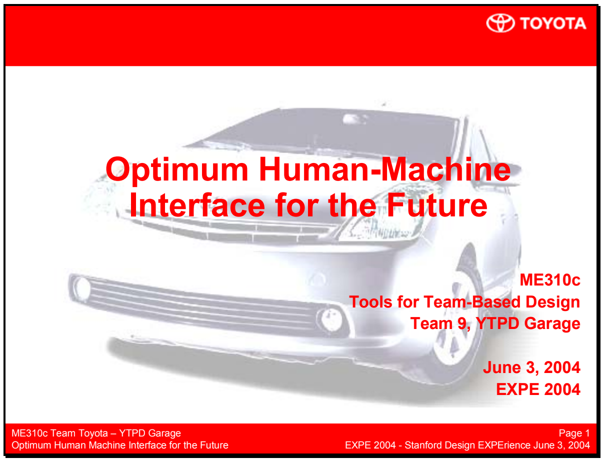
In addition to the quantitative analysis, questionnaires for the drivers and passengers will be used for qualitative comparisons. Questions will address issues such as perceived safety and comfort.

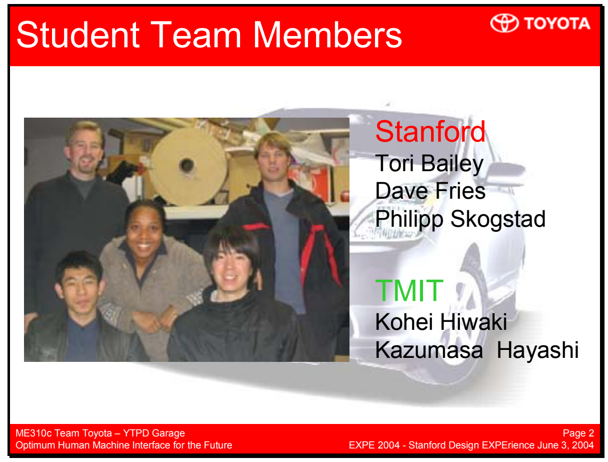
Future Development:

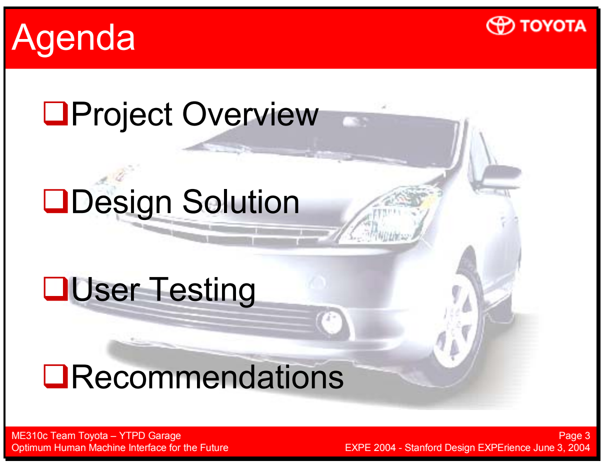
In the immediate future, the team plans to collect some data to allow for an initial starting point. This data will be included in the winter quarter report and presented to the partners in Japan during the trip between March 18 and 24.

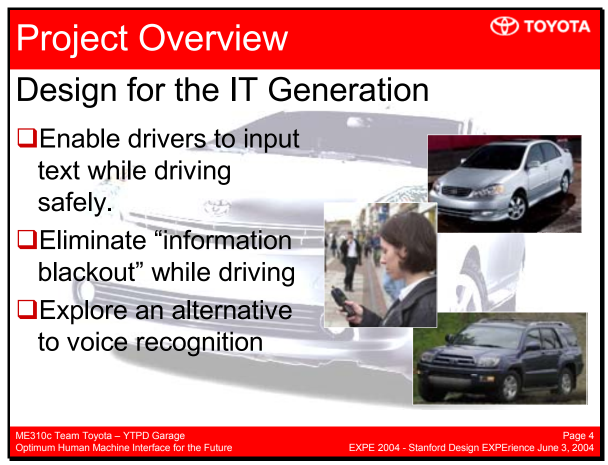
Upon return from Japan, the team will fix various technical issues and perform additional detailed testing. At the same time, various alterations to the system including the installation of the output portion designed by the TMIT students will be tested. Once the system has been completed, a final and through test should allow for a good comparison between driving as we do today and driving while being connected through the interface.

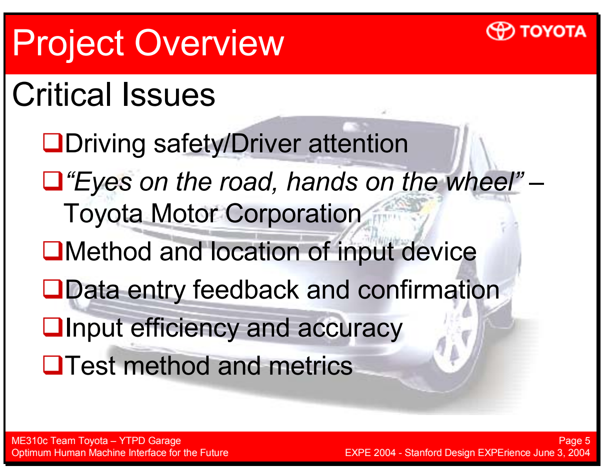
9.13 Slides from Final Presentation on June 3, 2004

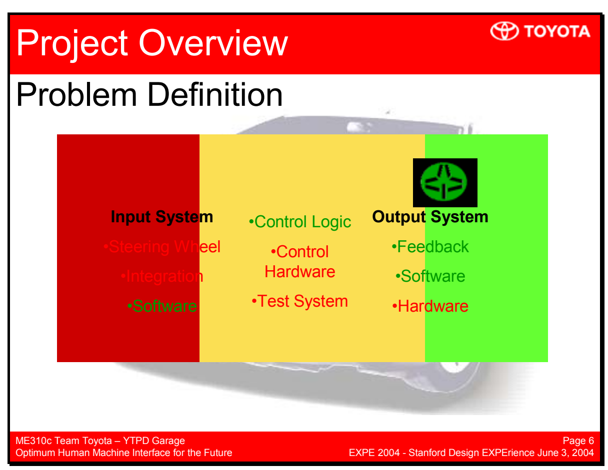













Design Solution
TOYOTA
Lessons Learned From Prototypes
•Activating buttons on steering wheel with all 10 fingers is difficult
•Ergonomics issues depend on size of steering wheel
•"Home" position required
•Decouple steering and typing motions as much as possible
•Confirmation of WYTIWYG
•Typing on a moving QWERTY keyboard is difficult
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Design Solution
TOYOTA
Lessons Learned From Prototypes
•Combined accelerating, braking and steering is difficult
•Need a complete system to evaluate the input device
•Display
•Evaluate speed and accuracy of text entry
•Evaluate the effect of the text input system on the driver's performance
•One hand steering full-time is better than two hands steering part-time
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Design Solution
TOYOTA
The Textura 310 Steering Wheel
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Design Solution
TOYOTA
Steering and "Texting" Regions
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Design Solution
TOYOTA
Steering and "Texting" Regions
Housing for electronics
"Texting" only region
Contoured shape for home positioning and hand size accommodations
Rim of steering wheel – For steering only
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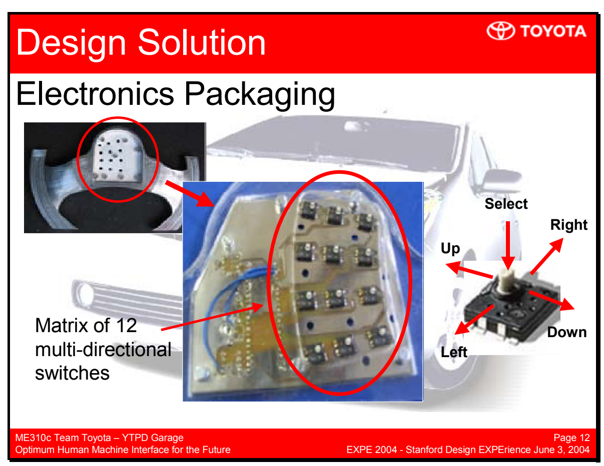
Design Solution
TOYOTA
Electronics Packaging
Select
Right
Up
Down
Left
Matrix of 12 multi-directional switches
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Design Solution

TOYOTA

Thumb Operated Keypad

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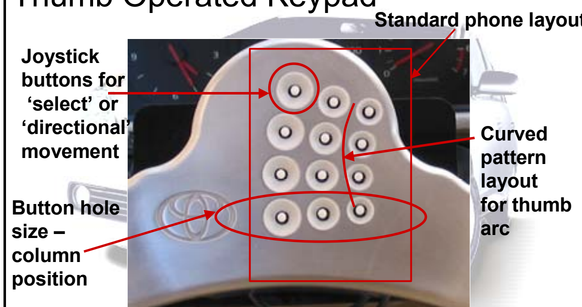
Design Solution

TOYOTA

Thumb Operated Keypad



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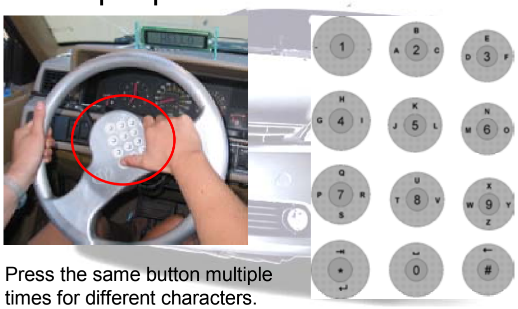
Design Solution

TOYOTA

Multi-Tap Input Method



Press the same button multiple times for different characters.

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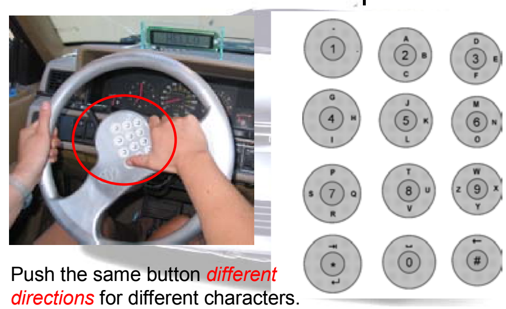
Design Solution

TOYOTA

Multi-Directional Switch Input Method



Push the same button *different directions* for different characters.

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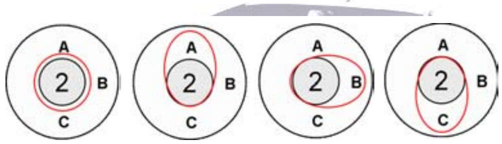
Design Solution

TOYOTA

Multi-Directional Switch Input Method



	Select	Up	Down	Right	Left
Button	2	2	2	2	2
Result	2	A	B	C	

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Design Solution

TOYOTA

TMIT Work

- ❑Brainstorm new car functions
- ❑Research input methods
- ❑Research feedback methods
- ❑Design feedback method - combine Head Up Display with text to speech feedback
- ❑Design of feedback algorithm – unrestricted/regular/hurry modes change method of feedback and ability to correct text

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User Testing

Original Test Methodology

What	Why	How
Erratic Driving	Is the driver overloaded due to interface?	Count lane departures using cameras Measure speed variations using GPS Compare driving speed to speed limit using GPS
Reaction Time	Is there a change in emergency situation reaction time?	LED cluster and timer
Awareness of surroundings	Can a driver pay attention to two things at once?	Distributed LEDs and timer
Text Input Performance	What interface is better for text input?	Record and count key strokes Spell check written text

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User Testing

Test Methodology

What	Why	How
Erratic Driving	Is the driver overloaded due to interface?	Count lane departures using cameras Measure speed variations using GPS Compare driving speed to speed limit using GPS
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User Testing

Test Bed Overview

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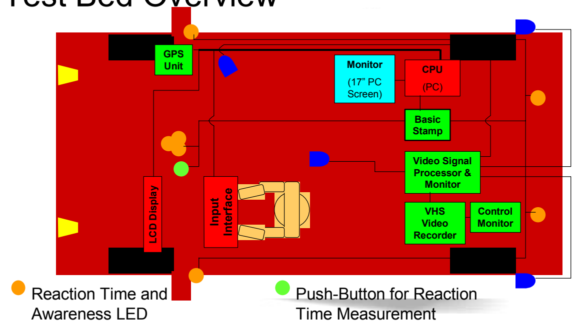
User Testing

Test Bed Overview



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User Testing

Driver Feedback

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User Testing

Driver Reaction & Awareness

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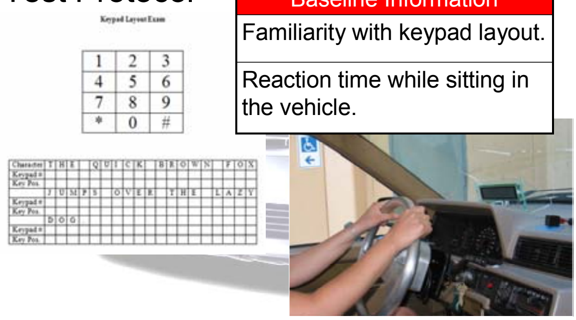
User Testing

TOYOTA

Test Protocol

Baseline Information
Familiarity with keypad layout.
Reaction time while sitting in the vehicle.



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User Testing

TOYOTA

Test Protocol

THE QUICK BROWN FOX JUMPS OVER THE LAZY DOG

Method #1: Multi-tap	Method #2: Multi-switch
Type sentence 2 to 3 times.	Type sentence 2 to 3 times.
Type sentence 2 to 3 times with reaction LEDs.	Type sentence 2 to 3 times with reaction LEDs.

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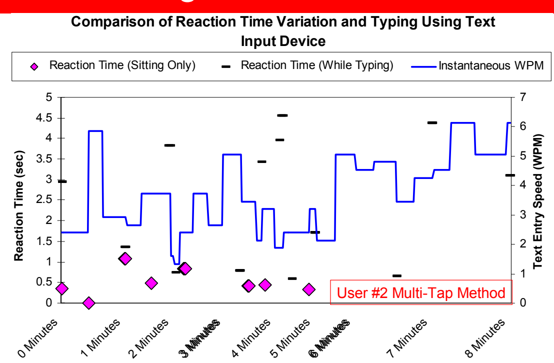
User Testing

TOYOTA



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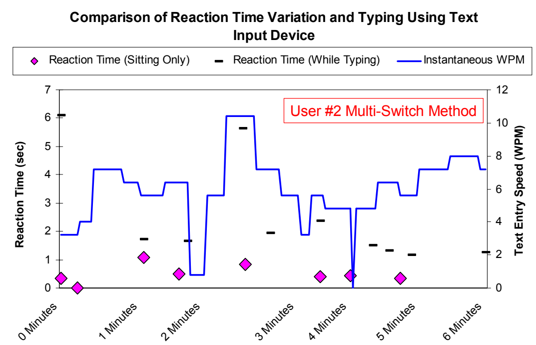
User Testing

TOYOTA



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User Testing

TOYOTA

Lessons Learned

- Multi-switch method enables fastest input
  - 30% faster input speeds
  - 5-6 WPM typical for Multi-switch
- Small amounts of training provide large input increases
  - 100% faster input speed with 3 hours training
  - 9-10 WPM
- Typing adds ~2 seconds to average reaction time
  - Independent of method
  - Baseline value overly optimistic

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Product Performance

TOYOTA

Design Requirements	Design Specifications
Must be safe to use and cause minimal distraction	Typically adds 2 seconds to reaction time
Must be easy to use	Cell phone input speeds immediately (3-5 WPM) 100% improvement with 3 hours training time
Must be accurate to use	Input speeds are with user corrections

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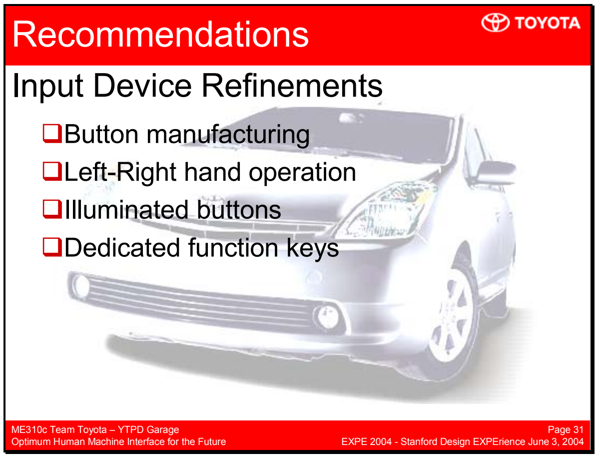

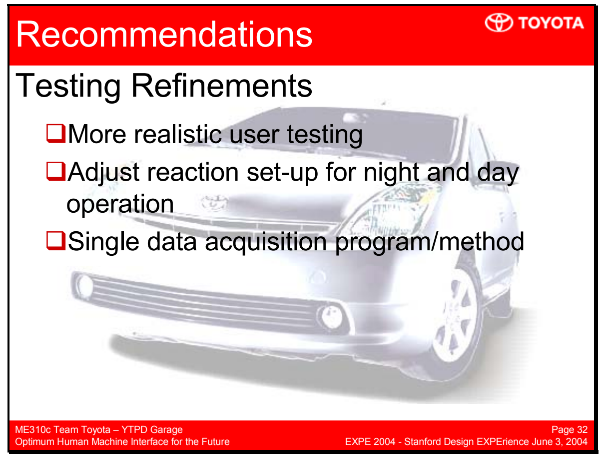

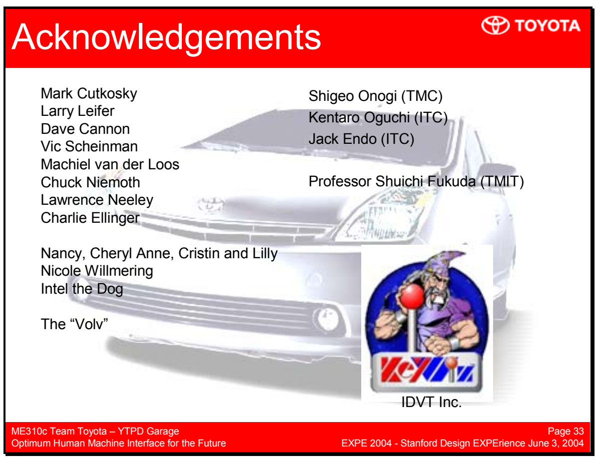

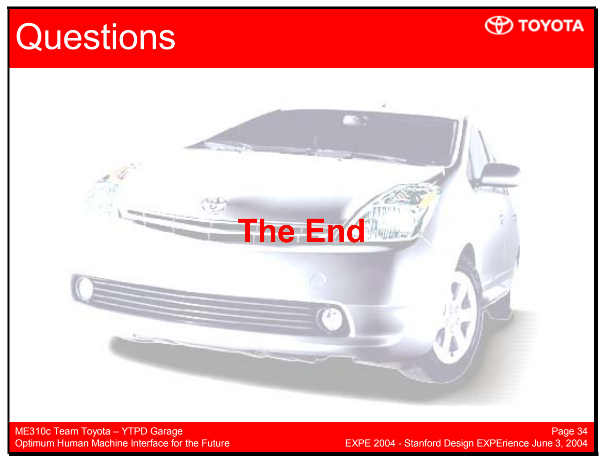

9.14 Deliverables Contract

Please see following pages.

Deliverables Contract

for

YTPD Garage – Team Toyota

1. Disclaimer

This document is a course assignment, not a legal document.

2. Parties Involved

This document outlines an agreement between the 2004 Toyota Design Team, the Toyota corporate liaison, and the Stanford teaching team.

3. Deliverables

The design team will deliver the following:

1. An interface to enter text while driving.
2. A hardware prototype consisting of an input, logic, and output system that satisfies the Design Specifications listed below.
3. A test protocol for repeating the user testing procedures.
4. Summary of test data collected.
5. CAD drawings, documentation, and original data collected during the development.
6. Software, including the source code, used in the system.
7. A final report documenting the development effort.

4. Validation Criteria

The validation of the interface functionality will be based upon user testing. Both quantitative data and user acceptance comments will be collected and compiled. User reaction times will be measured with an external stimulus. Normative baselines will be compared to the same test protocol when the user is using the text entry interface. User acceptance comments will be collected using a survey.

The design team anticipates collecting data from 5 users of the final system. Each subject will be given training on any proprietary input protocols prior to testing.

Design Specifications

Description	Required value	Anticipated value
The interface must be safe to use in a car.	<1.2 second look-away time <3 lane departures	<1.0 second look-away time <2 lane departures
The interface must cause minimal distraction.	<20% increase in reaction time	<10% increase in reaction time
The interface must be easy to use.	User is able to use immediately User can meet accuracy	User is able to use immediately User can meet accuracy

	requirements within <4 hours training time	requirements within <3 hours training time
The interface must be accurate to use.	>80% accuracy after training	>90% accuracy after training
The interface should not require significant movement to operate.	one-handed operation	one-handed operation

5. Documentation

Full documentation of the project will be provided by the design team to the corporate liaison and the teaching team. This documentation will include the following items:

1. Spring quarter design document containing
    a. Problem description and design criteria
    b. Brainstorming leading to concept generation
    c. Design rationale and design analysis supporting the exploration strategy and decisions.
    d. A description of the final interface design.
    e. Description of how the final interface design would be integrated with the larger system.
    f. Validation testing description and results.
    g. Description of testing protocol.
    h. Labeled design sketches, schematics and drawings.
2. Summary of data collected, with test protocols.
3. Source code for software used in the system.

6. Terms

Completion date for all hardware and testing is: May 31, 2004.
Final design presentation to the liaison and teaching team will be on June 1, 2004.
Delivery date for all hardware and software: June 10, 2004.
Delivery date for all documentation: June 7, 2004.
Method of delivery of hardware, software and documentation will be hand carry to the Toyota ITC office in Palo Alto, CA.

7. Signatures

Signed: ______________________ Date: ______________________
Design Team Member
Tori Bailey

Signed: ______________________ Date: ______________________
Design Team Member
David P. Fries

Signed: ______________________ Date: ______________________
Design Team Member
Philipp Skogstad

Stanford University ME310 Design Team
Mechanical Engineering Design Division
Terman 501
Stanford, CA 94304-4021

Signed: ______________________ Date: May 26, 2004
Toyota Motor Corporation, Japan
Shigeo Onogi

Signed: ______________________ Date: May 26, 2004
Toyota Info Technology Center U.S.A.
Kentaro Oguchi

Toyota Info Technology Center U.S.A.
4009 Miranda Avenue
Palo Alto, CA 94304-1218

Signed: ______________________ Date: ______________________
Mark R. Cutkosky

ME310 Course Instructor
Mechanical Engineering Design Division
Terman 501
Stanford, CA 94304-4021

9.15 Important emails

9.15.1 Email from a Chording Expert on February 23, 2004

From: Doug Platt [mailto:dplatt@aptalaska.net]
Sent: Monday, February 23, 2004 3:35 PM
To: Tori Bailey
Cc: hewdo@starband.net
Subject: Re: CyKey Assistant Software

Hi Tori,

I have been driving and chording on a regular basis since 1984, when I bought the original Microwriter.

Since it is inherently a touch-typing system, it is a very easy thing to do.

I have also been handling objections about safety, whenever I mention this, since day 1.

The first point I make is that while reading and driving are not safe, chording and driving can be safe as long as there is no interaction, i.e., you aren't text chatting. A recent study showed that talking on the cell phone while driving is dangerous, even if you are using a headset or speakerphone, because the user's attention is divided.

Chording while driving, on the other hand, can keep you awake (and productive) on long highway drives. Even with the chording device not built in or attached to the steering wheel, there is really no problem. If the driving gets "hairy", both hands go back to the wheel immediately. With other one-handed driving activities, such as eating, or talking on a handset cell phone, you are delayed by needing to either say something, like, "excuse me but I'm merging now and have to stop talking for a bit", or to find a place to put your food down.

Our current designs for car control/text input feature "thumb-free" chording (both CyKey compatible and QWERTY partially compatible devices). We have designs with footprints smaller than 3.5" x 1.25".

(…) is doomed but they don't know it yet. We have designs that are smaller, as fast or faster, scalable to 2 handed versions, thumb-free, and much easier to learn (though no learning is required). Also, our designs can be made to work on the numeric keypad of existing keyboards, or external ones, through software. There are some very compact external usb keypads on the market that just need our software to become powerful, serious, ergonomic, portable/wearable (even pocketable) input devices.

You probably also want to look at vibratory tactile feedback.

I would be happy to talk with you over the phone about this as well. We may need to implement an NDA.

Doug

9.15.2 New Idea for Accuracy of Input on March 15, 2004

From: owner-me310-team9@lists.Stanford.EDU
[mailto:owner-me310-team9@lists.Stanford.EDU]On Behalf Of Philipp L. Skogstad
Sent: Monday, March 15, 2004 11:18
To: Tori Bailey; 'Mark C'; 'Dave Fries'
Cc: me310-team9@lists.Stanford.EDU
Subject: RE: proactive error checking??

Audi has the same thing in the MMI. A picture and description is included in the benchmarking section of last fall and in this quarter's appendix.
The problem for regular input, I think is that you cannot restrict yourself to a database of words unlike in navigation systems. If the navigation system does not know the place you are trying to enter, then there is no point entering it.
Also, T9 often finds many words with the same keys in one way. Now, if you go the other way, all keys will most often be allowable if you are working with a cell phone keypad. On a QWERTY, on the other hand it would be more feasible because there is only one key per character. So lets design a new QWERTY....

PLS

From: owner-me310-team9@lists.Stanford.EDU
[mailto:owner-me310-team9@lists.Stanford.EDU]On Behalf Of Tori Bailey
Sent: Monday, March 15, 2004 11:13
To: 'Mark C'; 'Dave Fries'
Cc: me310-team9@lists.Stanford.EDU
Subject: RE: proactive error checking??

Toyota has implemented something similar to this idea with their Lexus touch screen navigation systems. Once you enter the city, state of your destination, as you begin to enter the street address, only the letters of the possible street names are illuminated.
I don't see an example on the Lexus website, but these are the pictures I took at the SJ Auto Show when I asked the Lexus rep to enter my old address in Palo Alto, CA on Alma St. They are just using a database of all the streets in each city....we could do something similar with frequently used words... I like it! We can call it 6T!
http://wikibox.stanford.edu:8080/docushare/dsweb/Get/Document-5102/lexus_nav.ppt

tori

From: owner-me310-team9@lists.Stanford.EDU
[mailto:owner-me310-team9@lists.Stanford.EDU] On Behalf Of Mark C
Sent: Monday, March 15, 2004 9:41 AM
To: Dave Fries
Cc: me310-team9@lists.Stanford.EDU

Subject: Re: proactive error checking??

Dave - This is a really cool idea. Could be patentable. It should be something that increases resistance rather than absolute lockout or (as T9 sometimes does) it could get pretty annoying if you want to type something unusual. Actually, it should be user-controlled on/off like a Shift or Function key setting. So, when typing something unusual (like a password for instance) the feature is turned off. Otherwise, for 'normal' text it locks out very unlikely keys. Of course, this might not prevent errors like the one in the cartoon I taped to the door of your cubicle in the loft :-)

On Sunday, March 14, 2004, at 08:33 PM, Dave Fries wrote:

> Mark/Tori/Philipp -- an interesting comment on trading speed for accuracy to reduce distraction while driving. Feedback is certainly the key to increasing accuracy, since I don't think we can significantly alter the human operator (maybe a project for next year :-)). Auditory and visual feedback are reactive methods for error
checking -- I hear/see the wrong letter so then I backspace to fix it.
OK -- here is where too many hours at the compute may have sparked my creativity ---
What if the interface was PROACTIVE in error checking -- effectively preventing the user from entering the wrong letters? I am thinking specifically of T9 in reverse. T9 looks at what you enter and tries to predict the word. Alternatively, the system could look at what you have entered, try to predict the word, and then lock out all of the keys that don't fit. If the keys had variable resistance, the user would feel that the key would not go down, and realize they were pushing the wrong key. Definitely slower, but all of the feedback is through the hand, eliminating added distractions of sight and sound feedback.
Probably something to talk about on the plane after the beverage cart has passed by a few times.

Dave

From: Mark C [mailto:cutkosky@stanford.edu]
Sent: Sun 3/14/2004 11:42 AM
To: Dave Fries
Cc: me310-ytpd@lists.stanford.edu
Subject: Re: taking you up on your offer....

> An aside:
> I was also thinking... maybe if I really need to avoid visual distraction then I would like my absolute touch typing accuracy to be *better* than it presently is with a QWERTY keyboard. That is, I would be willing to trade speed for accuracy. With my laptop, I can touch type pretty well, but I can't go more than about seven or eight words without having to look at the screen to make sure I have not screwed something up. And I'm not driving. I guess if my laptop spoke the words as I typed them I could go longer (or at least catch errors and backtrack). I have seen blind people use this technique... just a thought.

....

9.15.3 Dave Fries announcing the Completion of Another Project

From: owner-me310-class@lists.Stanford.EDU
[mailto:owner-me310-class@lists.Stanford.EDU]On Behalf Of Dave Fries
Sent: Wednesday, April 28, 2004 22:29
To: me310-class@lists.Stanford.EDU; me310-toyota@lists.Stanford.EDU; me310-staff@lists.Stanford.EDU
Subject: the newest addition to ME310.....

While many of our ME310 projects are really starting to come together, I thought I would share the results of another project I have been working on for the last 38 1/2 weeks. After much hard work (mostly from my other team member), the final product is ready to be revealed!

Lillian (Lily) Catherine Fries was born on Monday. In an effort to "document as you go", please find attached the DocuShare links.
http://wikibox.stanford.edu:8080/docushare/dsweb/Get/Document-5689/Lillian+Catherine+Fries.jpeg
http://wikibox.stanford.edu:8080/docushare/dsweb/Get/Document-5690/Proud+Parents.jpeg

I have also compiled a summary table to capture the important aspects of the final product configuration:

Design Requirements	Product Specifications
A healthy baby	7 lbs. even, 20 inches long (3.175 kg, 51 cm long)
A happy baby	She slept 5 hours the first night! (well, at least it made Dad happy)
Project completed on time	She was born at 5:27pm on 4/26/04 (1 1/2 weeks early)
A pain free delivery	Dad did not feel a thing

Mom, Dad, and her two sisters are all excited to have her home from the hospital today.

Best regards,
Dave

9.15.4 Oguchi-san after Final Presentation on June 4, 2004

From: owner-me310-team9@lists.Stanford.EDU
[mailto:owner-me310-team9@lists.Stanford.EDU]On Behalf Of Ken Oguchi
Sent: Friday, June 04, 2004 21:03
To: me310-team9@lists.Stanford.EDU
Cc: Mark Cutkosky; Shigeo Onogi; yamaguti@takayuki.tec.toyota.co.jp; Jack (Norikazu) Endo
Subject: Thank you

Dear Team Toyota,

Thank you very much for great work for the final prototype and presentation. Prof. Saito praised, "Toyota team was most sophisticated."
Mr. Onogi gave some comments after seeing the presentation slides. He wanted following items to be included in final documentation.
1) Please clearly mention about what aspect of IT generation did you focus to design. And, what is the good way to evaluate and confirm that the prototype is fit to that aspect?
2) The evaluation did not emulate the driving task. What did you think would be the good way to emulate the driving task?
3) As a total system, what task or function needs yet to be done? Such as confirmation,...
4) Please analyze the data statistically. Select the appropriate parameter to show your point. Between young and old, before learning and after, which value changed?
5) If possible, please evaluate the reaction time for some other task, such as talking with cell phone, selecting the channel of the radio,...

Even though he requires the above items, Mr. Onogi was very impressed with your work.

Thank you,
--
Ken Oguchi
TOYOTA InfoTechnology Center, USA
(650) 251-0517

9.16 Important Meeting Minutes

9.16.1 SGM on January 8, 2004

Larry's suggestions:

- Consider critical events that occur in car (not just driving)
- Make something move – what invites movement?
- How do you predict/measure distraction?
- How many things do you bookmark/customize things in your environment, on your computer - they are volatile

Vic's suggestions:

- Don't use voice recognition – its been done
- Stay away from additional visual distractions
- Optimum Human Machine Interface for In Vehicle Function = We define optimum people interacting with cars

9.16.2 Team Meeting on January 12, 2004: Project Refinement and Brainstorming

Attendees: Tori, Dave and Phil
Task: Come up with a project idea

Revised Problem Statement

- Since most of the functionality of a "smart car" including communication between subsystems has been addressed in most high-end luxury vehicles, reorient the project in a direction that addresses a specific need for the IT generation, performing secondary tasks.
- Assume driver follows the "eyes on road/hands on wheel" paradigm and is responsible for controlling the vehicle while interacting with the secondary tasks.
    - The function and interface should be designed to be safely integrated within the automobile cockpit
    - The operation of this task while driving should not significantly increase the frequency of unsafe driving incidents such as lane wandering.

Design Concept

- Function is to provide and maintain a means for drivers safely perform the secondary task of data entry while "connected" (engaged in internet based communications such as email composition, text messaging, and web browsing,) in the vehicle.
- The physical interface should enable the driver to interact with current and future control systems in the automobile cockpit environment.
- The physical interface should provide efficient and intuitive data entry method suitable for text based programs such as email composition, text messaging, and web browsing.
    - Input method should be tactile (interaction with combination of buttons/T9 method/Chord method, gestures, or tracking physical movements)
    - Output method should include some combination of tactile (buttons), audio (data entry confirmation, playback) and visual (LCD display, HUD) feedback

Design Development

- Design questions
    - Why do we need the ability to do data entry in the cockpit?
    - How can we improve existing data entry methods used in vehicle control systems?
- Input/output method design questions
    - What are the methods/devices for doing data input?
    - How do these different methods/devices compare?
    - What are the current methods/devices for data entry in vehicles? What are there limitations? strengths? weaknesses?
    - What feedback methods/devices are required?
    - What interaction protocols should be used?
- Interaction and safety questions
    - How much attention does data entry require?
    - How much attention does data entry require while driving?
    - How efficient is the data entry interaction?
    - How intuitive/repeatable/easy is the data entry task to perform?
    - How much attention do the feedback methods require?
- Human factors questions
    - Where in the cockpit should the interface be physically located? Within an arm's reach?

- How should the interface be positioned/oriented to the driver?

Critical Functional Prototype – Input Methods

- Design prototype using a driving simulator to evaluate whether a physical method for data entry while driving makes sense.
- Evaluate attention required:
  - How often does the driver wander out of lane or steer incorrectly.
  - How often do the driver's eyes leave the road?
- Compare different interface locations:
  - Steering wheel (spokes/hub, hidden/full view)
  - By the gear shift
  - Buttons on the vehicle door
  - Other locations?
- Compare different text based interaction methods:
  - T9
  - Chord keys
  - Graffiti
  - Multitap

9.16.3 Videoconference with TMIT on January 18, 2004

Attendees: Tori, Dave, Kaz, Kohei and Phil
Agenda:

- Introductions
- Review TMIT and 310 course expectations
- Review ME310bc deliverables
- Review project ideas
- Work on Critical Functional Prototype

Introductions

- Tori: BS in Mechanical Engineering/MS in Mechanical Engineering
- Dave: BS in Mechanical Engineering/working on MS in Mechanical Engineering
- Kaz: Mechanical Engineering in High School/BS in Computer Science/MS in Educational Technology - Design Engineering
- Kohei: BS in Mechanical Engineering/working on MS in Design Engineering

TMIT Course Expectations

- Submit a final report (in June) to Professor Fukuda of several ideas for new functions for Toyota
  - Class ends in June (no Spring Break)
  - Short reports submitted to Professor Fukuda every two weeks
- Collaborate with Stanford team to develop an idea into a final prototype (with hardware and software)

Stanford (ME310) Course Expectations

- Autumn Quarter: Brainstorm several ideas for new functions for Toyota (Autumn Qtr report)
- Winter, Spring Quarters: Collaborate with TMIT to develop an idea into a prototype (with hardware and software)

Critical Functional Prototype

- Critical functions:
  - Drive and enter data at the same time
  - Receive feedback that WYTIWYG (What You Typed Is What You Get)
  - Enter discrete characters

- Critical test: Is it possible to perform 2 unrelated motions in space? (6 with your hand, clockwise with your foot experiment)

- Critical Prototype
  - 10 push buttons 'Velcro'-ed to a force feedback gaming steering wheel
    - Buttons (mini push button switch covered with suction cups) attached to 0 to 9 of keyboard
    - Button for the thumbs, on front of steering wheel, buttons for the other fingers on the back
  - Hot Pursuit video game on laptop #1
  - Keyboard attached laptop #2 using Microsoft word to record data entry

- Critical Experiment
  - Randomly press buttons while 'driving' in video game
  - Press buttons in any desired while 'driving' in video game
- Lessons learned:
  - Carpal tunnel syndrome: after trying to type and steer for 5 minutes or so, your arms got tired (Tori's shoulders and Dave's forearms)
  - The layout of the buttons must accommodate hands of various size (Phil's layout did not work for Tori)
  - Turn on the number lock key! (Duh)
  - Crude prototypes are useful! (A little Velcro goes a long way….)
  - Remember how long it took you to learn how to touch type on a regular QWERTY keyboard…equate that time to how long it will take you to learn how to type on a steering wheel)
  - 0 – 9 is cool, but where's the backspace key!
  - Remembering 0 to 4 pm your left hand and 5 – 9 on your right takes TIME
  - The simulation should be more realistic (Hot Pursuit required a lot of attention BEFORE we added buttons to the steering wheel)
  - Moving your individual fingers is difficult…try wiggling your ring finger without moving any other fingers, especially pinky and middle finger…we aren't all concert pianist!
  - Opposing thumbs are useful!!! …but not when you are trying to press 6 – 9 with your other fingers…

9.16.4 SGM on January 15, 2004

Attendees: Tori, Dave, Phil and 310 Teaching Team
Agenda:

- Announcements/Logistics
- Project Ideas/Direction
- Critical Functional Prototype (CFP)

Project Idea

- Since most of the functionality of a "smart car" including communication between subsystems has been addressed in most high-end luxury vehicles, reorient the project in a direction that addresses a specific need for the IT generation, performing secondary tasks.
- Assume driver follows the "eyes on road/hands on wheel" paradigm and is responsible for controlling the vehicle while interacting with the secondary tasks.
  - The function and interface should be designed to be safely integrated within the automobile cockpit
  - The operation of this task while driving should not significantly increase the frequency of unsafe driving incidents such as lane wandering.
    - Input method should be tactile (interaction with combination of buttons/T9 method/Chord method, gestures, or tracking physical movements)
    - Output method should include some combination of tactile (buttons), audio (data entry confirmation, playback) and visual (LCD display, HUD) feedback

Critical Function Prototype (Summary of Teaching Team suggestions)

- Larry
  - consider safety in the eyes of ubiquitous temptations
  - if goal of "device" to replace other input methods by guaranteeing reduced attention demands, demonstrate reduced attention demand (safety)
    - demonstrate measurement of attention/distraction
    - develop a critical test to evaluate final prototype
- Vic
  - assume physical text entry is safer, then test different wheel mounted layouts – ask the question, will a crude prototype give me a good answer?
  - make some hypotheses and test
  - make engineering assumptions to narrow input options (don't waste time or money on things you can make assumptions about)
  - decide on a key component that is an issue for the device – the display? feedback that WYTIWYG (What You Typed Is What You Got)
  - start thinking about the depth of the project, what do you want to deliver to Toyota – what is critical about the final prototype
- Lawrence
  - test 3 layout ideas against the usual method, but not in a car, some basic nominal testing
  - attention seems to be a big issue

- check out the Peter Skilling, designer of original handspring, discusses the pitfalls of using graffiti as an input method
- strike a balance between the hardware you build, and the questions it will answer (unfair to test a crude ,crude prototype against a piece of refined hardware)

- Dave C.
  - consider safety in different scenarios, i.e. driving on an open road vs. driving on a congested road
  - how are your hands positioned on the wheel? are they always in the same position? are the buttons always present?
- Mark
  - consider the desire to "pause" input (i.e. conversations in Italian)
  - don't have to respond immediately with text based communications

9.16.5 Team Meeting on January 15, 2004

Attendees: Tori, Dave and Phil
Agenda:

- What do we want to deliver to Toyota?
- Brainstorm assumptions, functions, requirements, questions, opportunities for final prototype
- What is our critical function?

Final deliverables to Toyota

- Hardware – physical interface for textual data entry and a 'display' to test interface
- Software – translates 'input' into usable text
- Evaluation criteria – a means to compare our prototype to alternative data entry methods

Assumptions

- People want to do text entry while driving
- It is better to your hand(s) on the wheel than not
- Novice/"casual" users will be faster with a standard interface (something they are familiar with)
- Users are expert text messaging/SMS ers
- Designed for IT (internet) generation in the U.S.
- The IT generation is willing to try new interfaces
- Standard vehicles of the 'future' will come with smart/adaptive features of current high-end, luxury cars

Requirements

- For the average driver, the time saved using the input device should be greater than the time required to train to use the device.

Function Decomposition (Good Ideas)

Task: Text Data Entry and Graphical Control				
Interface w/ Person	**Provide Feedback**	**Drive and enter data simultaneously**	**Allow Entry of Discrete Characters**	**Accept graphical control inputs**
Hands/Fingers	Beep	Require 1 hand	26 discrete keys	Move a lever
	Resistance/push back	Change steering wheel design	Multiple characters for a single key	Track position in space
	Vibrate	Not look at?	Multiple keys for a single character	Grid
	No sound/always sound sequence	Finds your hand	Draw/outline a shape	Relative motion – indirect mapping
	Visual display	Adapt to 'no hand' on steering wheel	Interpret representative drawing	Indirect contact with interface
	Light/no light/change in light	Pause 'hold state'	Binary	Direct contact with interface
	Change shape/deform		Hex	Scrolling (1 axis)
	Shape		Morse Code	2 axis
	Layout			3 axis (how many distinct potions detect on the slope of sphere)
	Texture			
	Edges			

What are our critical functions?

- Provide feedback, drive and type simultaneously, and entering discrete characters
- Can you move you draw a '6' in the air and move your foot clockwise at the same time? Its difficult!
- Goal – keep two hands on the wheel
- Critical question: Can you perform 2 unrelated motions in space?
  - Type with 2 hands OR
  - Type with 1 hand on wheel typing/1 hand steering
  - Type with 1 hand on wheel steering/1 hand on the 'console' typing

9.16.6 Videoconference with TMIT on January 29, 2004

Kaz and Kohei passed along the comments from their meeting with Mr. Onogi on 1/28/04

* Mr. Onogi would like to have some additional rationale for why we chose to focus on text input. Felt the idea came out of the blue.
* His impression was that we jumped to the idea too soon. Perhaps we could focus on something else in the car (such as the air conditioner controls), redesign them, and use that knowledge to move forward to a more complex interface.
* If the project is focused on 10 years from now, perhaps people will not have keyboards then.
* Mr. Sekiama is new to the Team Toyota project (within the past month). His comment was that Toyota has a mountain of people who are familiar with current technology and interfaces. Is there any way we can focus on more imaginative interfaces.
* Some valuable things to consider:
    * What about the issue of speed? Consider how the interface will work at varying conditions.
    * Can you demonstrate different conditions and applicability? Situational based inputs.
    * Test data that determines where the product works, and also where it does not work is valuable to Toyota. What is the best way to interface with the product under each condition.

Team Stanford has two actions:
* Try to elaborate on the rationale and process that lead to the selection of text input for the project. Include some of the ME310 requirements.
* Send an email proposing 2/19/04 for the Toyota USA/Toyota Japan/TMIT/Stanford video conference.

9.16.7 Team Meeting on February 12, 2004

Observations/Questions from SGM

- Reverse foot steering difficult
- Feet/legs tired during foot steering b/c of angle and height
- Trouble finding the home position of the keyboard in the “bus driver” configuration
- Finger spelling camera/glove capture for data entry
- Is data entry also for communication with other cars/car functions
- WE ARE NOT DOING VOICE RECOGNITION…ADD TO ALL HANDOUTS AND PUT IN THE EXECUTIVE SUMMARY THAT OUR SPONSORS DON’T WANT US TO GO IN THAT DIRECTION
- Have tried writing/graffiti while driving
- Vic’s gimbled keyboard idea from email…like a see saw with a limited range
- Distraction/Attention metrics – meet with Ben Reeves…papers
- Simulations in a real vehicle?
- How can we make steering by foot more realistic than a video game
- Vic – doing a real task in a virtual world … do real tasks in the real world…ask him for his camry
- Collaborate more with TMIT! Ala Intel, Wheelchair, Games global teams
- Create a system flavor/framework and present that with prototypes

    - Outline all of our existing 'smart' technologies that we are assuming will be in place
    - Larry – its obvious from your set-up that you need a system for your project
- Establish weekly communication channels with Toyota
    - Accomplishments for the week
    - Future work and direction
    - Opinions from Toyota
- Pick a metric/standard for evaluating the project and know why
- What "improvements/refinements" can be made to the first prototypes
- What have we learned from the first prototypes
- How can we do more work in parallel at Stanford and with TMIT
- What tests do we need to run on the first prototypes in order to move forward
- Map out the milestones, with real description of the deliverables
- Morphological analysis and PMI charts!!!

9.16.8 Videoconference with Toyota and TMIT on February 25, 2004

Clarifications from Meeting

- Toyota wants to consider existing car functions as well as future car functions for project
- Clarification on purpose of project progression flowchart – chart thought process and work from Fall quarter
- Customization, smart car, driver distraction3 separate ideas not necessarily separate categories (thought process)
- Toyota does not want us to change anything for this quarter, want to get a consensus for Spring quarter
- How did we make the decision to choose one of the particular ideas to move forward with during Winter and Spring quarters?
    - Decided that the Smart Car design area was the best area to move forward
    - Decision driven by course and hardware requirements
        - Build hardware
        - Manageable design project for Winter and Spring quarters
        - Time constraints
    - In final winter report, design development section – make sure to talk about the smart car, etc. decision paths
    - Modifications to progression chart:
        - Expand the list of brainstormed ideas from Autumn Quarter
        - Add some text to the progression chart to indicate/explain flow from one level of the chart to the next

9.16.9 Videoconference with Toyota and TMIT on March 9, 2004

Attendees: Philipp, Kaz, Tori, Mr. Onogi, Mr. Oguchi, and Dave Cannon

Project Discussion

- Kaz and Kohei – software design
  - Need the hardware to make sure the software to work (purchase duplicate sets – 1 for TMIT / 1 for Stanford)
  - Possible head-up display design
  - Standard interface for input device (USB)
  - Re-engineered input device from Keiboard, CyKey and standard QWERTY Keyboard
  - Receive standard characters as if from standard QWERTY keyboard or Keiboard (USB)
  - Research on head-up display in Japan
    - Investigate after market HUD technology
    - Limited number of HUD systems available in Japan
    - Toyota Crown in Japan – Head-Up Display off the line of site of the driver
- Onogi-san and Oguchi-san
  - Feedback is very important
  - The concentration of the driver should not settle on the feedback…visual or non-visual
  - Goal: combination of feedback should inform the driver without distracting the driver
  - Size of letters not as important as location of the display wrt the driver's line of vision
  - Variety of options for displays and communication with displays (do not narrow thinking to notebook display only)
  - Dave Cannon: Investigate how far off the driver's line of sight can the display be located, based on the height of the text
  - Homework: Bring ideas, sketches to meeting on March 23rd with Onogi-san's boss

9.17 Teaching Team Feedback

9.17.1 CFP Presentation on January 22, 2004

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Initial thoughts based on reading the handout:
  Is problem only typing or also talking while driving?

Presumably computer generated voice would be OK for display?
But input is an unsolved problem (OK - good motivation.)

Steering wheel buttons - so is this last year's Toyota
project,
properly implemented?

Is there maybe some whole better way of doing text input?
Beyond
buttons.... ?
```

The CFP Review:

Carpal tunnel - steering wheel is not the right ergonomic posture for typing.

So what is the right solution?

Will buttons cut it? Or do we need something like combination of voice + buttons (synergistic combination)?
Or something else + buttons.
Dave Cannon's point about how limited vocabulary voice recognition is easy to add.

Other motions (twist, squeeze,) etc.
Maybe the steering wheel needs to be redesigned to facilitate steering + typing. What if I had a keyboard (special keyboard) that was rotatable for steering a car? (Turn the problem backwards -- make the keyboard be in a good position and orientation for text input and also make it guide the car.)
"steering wheel is a keyboard" or "keyboard is a steering wheel"

Or is it better to decouple typing from steering? So have a one handed keyboard - steer with one hand for a while and type with the other. Is this better for how the human brain works? (A useful question to get a firm answer on).

Dave - thinking in future steering will require less continuous input.
OK - so that may help.

I think you have learned some useful things. There are clearly more questions to answer. I hope you are now trying to separate some of the factors that, in combination, lead to difficulty

and understand which of them are most important, and when and why. Then
you will really feel like
you understand the problem well.

Questions from audience:

Jaime - how wedded are you the steering wheel as primary interface?
(Ans: we're not).
Safety issue & when in use. When rolling, when at stoplight?
(Good questions from Jaime!)

Interesting point by Vic. When you talk you get instant confirmation
what you said. (But not what computer thinks you said.) Conversely,
with typing you soon get what computer thinks it got, but not such
immediate feedback on what you actually input.

This was a good CFP I think.
Score: 4.5

9.17.2 SGM on February 5, 2004

Poor Dave is playing lasertag with his boss :-)

Flow Diagram of functions and the path leading to where the team is
looking at present.

Concepts of alternative steering. For example steering with the feet.
Does this take outside the main scope of project the design team
wonders?

Doing a foot steer system could be a project in itself...

Larry suggests idea of "deferred steering" or steering interrupted:
  moments of high quality data input and moments of high quality
steering control.
If riding a horse, this is sort of what you get.

If I was flying an airplane (not a helicopter) or piloting a boat I
could do this... Take my hands off the wheel for long enough to compose
a short email.

Taxi drivers. Police officers. Truckers have to enter lots of data
while trucking (learned this at Peterbuilt/Kenworth Inc.)

Larry: Could the challenge of data entry be somewhat separate from the
(design) challenge of steering.
Is it hard to switch back and forth? Are there distinct problems to
solve for each?

--> Team says that foot steering while typing on keyboard in lap gave
less sense of conflict.

Dave Cannon recommends to go to lab and really test this if you want to
go with it.
Foot steering -- does one get tired more quickly? What about needing to
go around multiple turns (or not, in which case the amplification must
be higher -- in which case stability is a concern).
Is it more constraining to body posture and comfort if you need to
steer with feet?

Lots of feedback from your tech. advisory board that this is
interesting but high-risk. If you go with it, need to be sure it won't
have a hidden stability or leg fatigue or sensitivity problem.

Vic: as a consultant I'd advise to look around more at steer + text
entry solutions before abandoning that route. Today with cruise
control you can do most anything with your feet while driving.

Accordion - keying on a moving keyboard...

Larry you have 2 arguments:
1. "We have a better idea what to do with hands." -- I like this idea.
2. "We want to steer with feet" -- this is more dubious... does it necessarily follow from 1?

Dave Cannon - importance of haptic feedback, fine control that can be harder with feet.

What about parallel parking with the feet. (Even Toyota only semi-automates it, sometimes.)

A thought:
In near future, things like lane control etc. might make steering easier, or more intermittent, whether steering with feet, hands, or whatever.

9.17.3 First Functional Prototype Review on February 16, 2004

Bus wheel with keyboard versus foot steering. Hard to type OK on the bus wheel while playing the driving education game. In fact, nearly impossible to concentrate on both...

On the other hand we can type pretty well while steering with the feet.
But steering with the feet was a bit tough. Super tough with the steering reversed (!) and with the pedals raised an uncomfortable distance above the ground.

Some conclusions - it's hard to overcome the built-in familiarity with how we type, how we steer, how we accelerate and brake.

Audience wondered about why not just use voice? (indeed!)
Ans:
1. Some cultures (German, Japanese) don't like it so much.
2. Toyota would like team to explore non-vocal solution.

Ozgur - measures of distraction? What is the point at which you've got
a problem?
(Indeed it seems like highway driving is a lot easier than city driving
while doing stuff.)

Idea that the remote person on phone doesn't have cues (either from
context or from the listener) of need to pause or suspend the conversation.
Also, conversation is real time. Worse in that regard than video.
Remember also the data from VW team that a driver's heart rate soars
when cell phone rings.

Typing is less realtime. More suspendable.

Could provide cues to remote person to help them know when the
conversation is being paused (for good reason) briefly.

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A nagging question: Are these prototypes too rough to draw true
conclusions about the merits of each approach? Will it matter too much
that ergonomics, etc. are satisfied -- in either case?

Timing in the real world is not same as game.

Vic - thinks you need to try to get into a real car because real
driving will be different (maybe easier, in fact),

I guess you'd like one of those dual-steering wheel driving school cars
to experiment with. Maybe you can find an old one on EBay ;-)

Laurie - idea of one hand could stay on a wheel for security.
Non-qwerty keyboard.
Could people learn finger spelling? Might make sense...

Vic - what about idea of having keyboard on gimbal and you can push it
around to impart steering while typing?

Larry - I concluded from my brief experience that one would need to
redeisgn the keyboard as well. The standard keyboard doesn't give me
enough tactile feedback to center myself.

What about a sort of cellphone like gizmo on a cord. A pod floating in
space
that you can type one handed while driving one handed? Something that
is like a 50/50 morph between a one-handed keyboard and cellphone?
Ans: TMIT team found a Japanese keyboard for cell phone SMS fanatics.

Larry - We like that you set up a bunch of physical systems stuff. And
seems like another lesson learned is that we need to deal with a fairly
complete system to know what's going to work. The total framework.
==========

Summary:
Good prototypes. Still, more like deluxe CFPs than a system (i.e. more
exploratory than indicative of a systems perspective). Evidently the
YTPD team felt that this was a necessary step before going further.
Looking ahead, it may be harder to progress much further with this kind
of prototyping and with video games. What will work best when driving a
real car?
Score: 4

9.17.4 Second Functional Prototype on March 4, 2004

Well, I'm impressed!
You've put a pretty interesting system together.

I like your point that part of your deliverable to Toyota will probably

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be the testing procedure or metrics -- as well as the
specifications of
any particular system.

The written comments from peers are also quite positive.

I'd say it's about a 4.5 on the scoring...
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9.18 Electronic Appendix

The enclosed CD ROM contains the following information:

- Source code and executable files for interface for use on a MS Windows PC including instructions.
- CAD parts and drawings of steering wheel components as Pro-E, Solidworks and Step files.
- Wiring Schematics of electronics.
- Final report and presentation as Acrobat Reader files.