Enhanced Visibility Project

Team LED Zeppelin

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Abstract

We worked with a personal mobility device company, WHILL Inc., to develop an enhanced lighting system for their wheelchair to provide greater safety measures and achieve 360° visibility for WHILL users at night. This system will be built into WHILL’s high-tech mobility devices and will further empower users to confidently navigate their surroundings. Our current design incorporates LEDs onto the front arm panels and around the side panels of the WHILL model. Over the course of the past term, we constructed a full prototype of our control electronics and LED circuitry and also manufactured custom housings to mount these LEDs onto the WHILL. We integrated our hardware and electronic components into a current WHILL model, after which we evaluated the effectiveness of our system through extensive user testing.

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Introduction

In 2012, 4,743 pedestrians were killed in traffic accidents in the United States, and another 76,000 pedestrians were injured\(^1\). While awareness is growing about the need to better protect pedestrians, change has been slow to improve infrastructure and roads to protect citizens. This is an especially big problem for wheelchair users in particular as they are especially at risk of injury every time they traverse the streets. With low profiles and insufficient lighting systems available to them, users of manual chairs and power chairs alike can easily be caught in a driver’s blind spots. This is what happened to Kenneth “Bryan” Goodwin, a popular wheelchair safety advocate in the Bay Area community, who was hit and killed by a car one night in San Francisco \(^2\). Rather than this being an isolated case however, tragedies like Bryan’s sadly remain commonplace and outside of public awareness.

Wheelchair users need greater visibility at night in order to not only see and navigate their surroundings but also be seen by drivers and other pedestrians. To address this need, we are working with WHILL, a Japanese startup company that develops next-generation mobility devices that fuse functionality and aesthetics. WHILL aims to change the negative perception of personal mobility devices and wheelchairs by empowering users to go out confidently in public by using their sleek, all-wheel drive devices. However, none of their devices have adequate built-in visibility aids such as headlights or sidelights. We along with WHILL recognized the unmet needs associated with wheelchair visibility and to that end worked together to design a new integrated lighting system that enhanced the visibility of WHILL users.

Objectives

The objective of this project was to design a prototype system that enhances the night time visibility and safety of the WHILL product (Fig. 1). Our solution, LED lighting integrated into the body of the WHILL model, is comprised of three main components: illumination, visibility, and aesthetic design.

The first component, illumination, addresses the concern of wheelchair users being able to see their surroundings in the dark. Forward illumination is necessary for the wheelchair user to see his or her path ahead and be aware of any obstacles. We planned to incorporate bright headlights in our design to allow users to see their immediate foreground as well as several feet ahead. The second component of our design solution is visibility – allowing the wheelchair user to be seen by others. This problem of nighttime visibility not only applies to

\(^1\)http://www-nrd.nhtsa.dot.gov/Pubs/811888.pdf
wheelchair users, but to all other pedestrians as well. Being clearly visible from all angles will greatly reduce a wheelchair user’s risk of being hit by a car or bicyclist when roaming around at night. In order to achieve 360° visibility, our design incorporates a set of LEDs mounted on the front, side, and back of the wheel covers. The third component, aesthetic design and appearance, is also a very important consideration in our design solution. The shape and form outline of our lighting design must be prominent and visible, but not distracting, so that it can be well-integrated with WHILL’s sleek exterior.

By addressing these three components, we aimed to design and create a simple, non-intrusive, yet effective lighting system to enhance the safety and visibility of WHILL users at night.
Methods

Ideating

We began our design process by speaking with Fernanda Castelo: a wheelchair user, current WHILL tester, and a valuable resource for us throughout our project. Fernanda provided us with key insights about what wheelchair users need, and are currently lacking, in terms of nighttime visibility. We also got the opportunity to visit WHILL’s office and speak with the engineering team. We were able to see previous models of the WHILL and even test out the models ourselves - this gave us valuable insight into WHILL’s unique design and functionality, and helped steer us further along our path to a final design.

Our brainstorming process resulted in lots of ideas for the lighting system. After many sketches (Fig. 2) and discussions, we decided on the shape and form of our final design solution. We also decided that the best way to achieve our design goals would be through the use of flexible LED strips mounted on the arm and wheel covers and thermoformed plastic covers to protect the LEDs and diffuse their light.
Prototyping

Hardware
The hardware for our lighting system consisted of light-diffusing plastic panels, which we thermoformed to take the shape of WHILL’s arm and wheel covers. Our first stages of prototyping involved finding ways to thermoform our plastic. Vacuum forming was our first choice, since it is a quick process that provides accurate results. Unfortunately, the vacuum former in the PRL was not working for most of the quarter. We then turned to another method of thermoforming: using a heat gun and clamps to shape our plastic to the arm and wheel covers. This process proved to be very simple and allowed us to make plastic covers that could be easily mounted onto the wheel and arm covers, as shown in Fig. 3.

![Photo of heat-formed plastic covers](image1.jpg)

*Fig. 3 Heat-formed plastic covers for headlights (top) and side lighting (bottom)*

We also experimented with different types of plastic: the plastic for our panels needed to be thin, semi-opaque, and easily thermoformable. We experimented with clear PETG and acrylic,
which we later bead-blasted to create a “frosted” look. While these plastics were good options, we eventually chose to use 0.020” white matte acrylic as our final material. The white matte acrylic sheet was an easy material to cut and thermoform, and had sufficient light diffusivity to serve as a good cover for the LED strips.

For our final prototype, we placed the LED strips on both wheel covers and arm covers and mounted our plastic panels directly on top of the LED strips. We then secured the plastic panels with black electrical tape and mounted our modified wheel and arm covers onto the wheelchair model. As shown in Fig. 4, the simple shape and form of our hardware integrates well into the existing model and preserves WHILL’s minimalistic design.

![Fig. 4 Hardware mounted onto the WHILL model for final prototype](image)

Electronics
For the light source itself, we decided on using thin, flexible LED strips which were low profile and could be easily shaped to fit the contours of the existing WHILL model. For prototyping purposes, we purchased both RGB LEDs and pure white LEDs with the hopes that either one of them or a combination would allow us to create an effective illumination scheme. Through many iterations, we found that the RGB strips were well suited for the side panel lighting due to their vibrant and customizable array of colors, and the pure white LED strips were best used in the headlight modules due to their exceptional brightness. We attached these LED strips with velcro backing to some sample body panels from the WHILL so we could fine tune the aesthetic layout of the lights (Fig. 5). Close up images in Fig. 6 show the separate RGB side lights and white headlights in more detail and how they consisted of multiple, parallel strips.
We developed a simple control circuit for testing the light strips which consisted of an Arduino microcontroller and some discrete electrical components, as seen in Fig. 7. This was all powered off a single, 11.1V rechargeable battery, much how like a similar production ready version would be powered off the WHILL’s onboard battery pack. In this initial prototype circuit, each color channel was controlled by an individual potentiometer, including the white LED strip. This allowed us to explore the range of possible color combinations for our final design and gave us experience in programming the Arduino to drive the LED strips properly.
Initial Testing

After developing the first control circuit and firmware, we tested the effectiveness of our LED system to confirm whether or not it would be sufficiently bright to provide a safe level of illumination for WHILL users.

![Initial LED control circuitry prototype](image)

**Fig. 7 Initial LED control circuitry prototype**

![Headlight testing at night](image)

**Fig. 8 Headlight testing at night**
As evident from Fig. 8, our headlights were exceptionally bright in the darkness and could flood a sizeable area with light. After seeing that our headlight modules were more than adequate for lighting the WHILL’s way, we connected the white LED strips in series with the RGB sidelights to evaluate our overall system design. Fig. 9 shows our initial prototype as a single unit with two different color settings for the RGB strips. The colored strips provide a nice, vibrant glow that is extremely visible from the side and from the front and back edges of the wheel panel. From this testing, we were confident that our design premise was sound and that we would be able to develop a fully integrated lighting system for a safer WHILL user experience.

![Initial prototype at night, with RGB sidelights and white headlight](image)

**Fig. 9** Initial prototype at night, with RGB sidelights and white headlight

### Results

After significant work on a more fully fleshed out second prototype, we were able to meet each of our design goals. The first, illumination, was achieved by installing the pure white LED strips on the arms of the wheelchair, as shown in Fig. 10. The LEDs and panel are placed such that they illuminate the immediate foreground, enabling users to see cracks in the sidewalk, uneven pavement, or other obstacles that are otherwise difficult to see at night. Users can adjust the brightness of these headlights according to their environment and comfort level - at the brightest setting, the headlights can illuminate the user’s path up to ten feet ahead. The placement of the headlights provide illumination mostly in the downward direction, which ensures that WHILL users don’t get glare from the lights and other pedestrians won’t be blinded by direct light.
Our second design goal, visibility, was met through lighting panels on the side profile of the WHILL model. We placed the RGB LED strips on the front and rear sides of each wheel cover behind matte white acrylic panels, as shown in Fig. 11. These LED strips are placed such that they are visible from the side, front, and back of the wheelchair, ensuring complete 360 degrees of visibility. The shape and placement of the LED strips and their adjustable brightness levels make the WHILL noticeable, but not distracting, to drivers or other pedestrians. The user can also control the color of these LEDs, and even opt for a “light show” mode to show off their awesome wheelchair!
The placement and form of our LEDs creates a sleek design that integrates well with WHILL’s unique appearance and complements its form (Fig. 12). The use of thin LED strips protected by a layer of heat-formed, light-diffusing acrylic does not add any bulk to the arms or sides of the wheelchair, preserving WHILL’s minimalistic design and sleek contours. We have also integrated a light sensor that can automate the lighting system – the lights will turn on when in a dark environment, and turn off when there is light (ex. daytime or in a well-lit room). This automation, as well as a manual override switch, further simplifies the user’s interaction with the WHILL.

Fig. 12 The final prototype at night

Features
Our final lighting system design has four basic control modes: manual off, automatic (based on light sensor), manual on, and light show. Manual on and off serve as overrides to the automatic setting, but it is the intention that the system would be left in auto mode for the majority of the time during use. It is programmed to smoothly turn on in dark settings and turn off in well-lit environments so that a WHILL user won’t even have to think about staying safe all the time. A lightshow mode is also included for entertainment, and will flash multiple times per second between randomly selected colors.

Physical controls for our prototype were housed in a custom 3D-printed case that was tethered to the main control circuit (Fig. 13). One large, 4-way switch at the top chooses between all the operation modes, and two dial potentiometers are also included to adjust the brightness level and particular color hue of the RGB strips. The brightness knob controls the white and RGB LEDs in tandem, so the whole system will dim or brighten together, and the
“rainbow” dial allows the user to smoothly transition to a specific, static color for the RGB LEDs.

Fig. 13 Tethered control box

The light panels themselves were tightly integrated into the WHILL frame, including routing the headlights’ wiring harness down through the hollow arm structure for an unobtrusive look that appeared natural to the rest of the chair’s aesthetics (Fig. 14).

Fig. 14 Integrated headlight panel wiring and control circuit underneath seat frame
The headlight wiring and side panel wiring emerged near the base of the chair at the rear, and there they were connected to the main control electronics and battery power source. We tucked the Arduino and soldered protoboard circuit underneath the chair’s seat frame when testing, but it was easily accessible if needed (Fig. 14). The light sensor wiring also emerged from this circuit board, and the sensor itself was mounted up behind the seatback of the WHILL for a fairly unobstructed vertical view of the environment.

Final Testing

After fully integrating our prototype system into a WHILL model, we set out to verify that our design met its objectives of nighttime visibility and forward illumination (Fig. 16). We mounted one half of our lighting system onto the WHILL and left the other side untouched for a direct, side-by-side comparison. Nighttime evaluation of this setup provided the most compelling evidence that our design was a significant improvement over the current implementation, as can be seen in Fig. 17 and 18. The old lighting was fairly dim from the backside, and only marginally more visible from the front when not blocked by the armrest. Side visibility was alright, but seeing our system next to it demonstrates just how much better it could be. Our lighting design also cast a nice colorful glow all around the side of the chair, providing more illumination and visibility than first envisioned.
We believe that the combination of our headlights, side lighting, unique aesthetic design, and automated controls provides a simple yet effective solution that improves night visibility of the WHILL model, ensures the safety of WHILL users, and adds a little more enjoyment to the entire WHILL experience.
Discussion

Although we successfully integrated our lighting system with a current model of the WHILL, we found through extensive user testing and trial runs that a number of challenges that still remain. Improvements can be made to the custom housings and panels that we thermoformed in order to better fit our LEDs onto the WHILL. More experimentation with the type of plastic as well as the thickness of the sheets would enable us to better modulate the diffusivity of the light from the LEDs. One of the challenges that we face currently is that despite using a frosted acrylic layer to cover the lights, distinct LED bulbs remains visible. This does not impede the user’s visibility when using the system, but the sharp intensity of the headlights from close distance can be irritating for onlookers and drivers on the road. Thus, by improving the materials that we are using in our housing, we can soften the look of our lighting system and ideally have a more gentle glow from our lights that still provide sufficient visibility.

Another challenge we have currently is in making better panels that can attach securely to the WHILL’s frame. At the moment, we are using tape and a rough snap-fit to mount our panels, which is useful for us because we can easily alter a design by pulling out and switching the desired parts. However, this method will not be sufficient as development continues and the low fidelity parts will need to switched out with parts of higher quality. Some ways to accomplish this would be to experiment with alternate plastic manufacturing and forming methods such as vacuum forming and injection molding. By machining precise molds for our parts, we would be able to better fit our system onto the WHILL or better yet, allow us to seamlessly integrate the LEDs into the actual body panels of the chair.

Other challenges that still remain include better integrating our light controls into the actual WHILL arms. This is where using manufacturing methods such as vacuum forming and injection molding would be most useful as we could easily create our own plastic panels to replace the existing ones on the WHILL and also modify them to fit our controls in the desired location. We would also work on the logical next step in refining our user controls, which would be to develop an iPhone or Android compatible app that would control the lighting system via a Bluetooth connection. These are the primary next steps for this project as we work to seamlessly integrate our hardware and electronics into the current WHILL model.

Acknowledgements

We’d like to thank Dave Jaffe for teaching this course on assistive technology and for his useful advice at our weekly meetings throughout the quarter. We’d also like to acknowledge Fernanda Castelo for bringing this project to us in the first place and providing valuable insight into the perspective of a WHILL user. Last but not least, we would like to recognize the corporate team at WHILL including Chris Koyama, Naoto Sakakibara, and Tri-Thien Che who have taught us much about the technology inside of their product and provided us with many useful resources.
Appendix A: Circuit Schematic
Appendix B: Arduino Source Code

/*
* Written by Joaquin Carcache (Team LED Zeppelin)
* March 2015
*
* For Engineering 110
* Enhanced Visibility Project
* Stanford University
*/

/*** Using Arduino Uno***/
This program controls the prototype LED lighting system developed by Team LED Zeppelin, which consists of RGB and white LEDs. Color and brightness are determined by PWM outputs to each color channel. Control modes for the system include manual off, automatic (using light sensor), on, and lightshow. Additional controls for RGB color and brightness level are also included for greater functionality and user friendliness.
*/

// auto isn't valid arduino var, so autO used instead
int off, autO, on, show, R, G, B = 0;
double lit, brt, rgb = 0.0;
long prevMillis = 0;

long SHOW_INTERVAL = 250;  // milliseconds between new colors

// PWM output pins
int RED_OUT = 9;  // individual color channels
int GRN_OUT = 10;
int BLU_OUT = 11;
int WHT_OUT = 3;

// Control Input Pins
int LIT_IN = A0;  // ambient light level
int BRT_IN = A1;  // brightness control level
int RGB_IN = A2;  // color control level
int OFF = 4;  // manual override off
int AUTO = 5;  // auto mode based on ambient light level
int ON = 6;  // manual override on
int SHOW = 7;  // lightshow mode

void setup() {
    Serial.begin(9600);
    // set LED PWM pins as outputs:
    pinMode(RED_OUT, OUTPUT);
    pinMode(GRN_OUT, OUTPUT);
    pinMode(BLU_OUT, OUTPUT);
    pinMode(WHT_OUT, OUTPUT);
}
```c
void loop() {
  // Read control values
  lit = analogRead(LIT_IN)*5./1024;   // 0-5V
  brt = 1-analogRead(BRT_IN)/1023.;   // 0.1-1.0
  rgb = 13-analogRead(RGB_IN)/78.;    // 0.0-13.0
  off = digitalRead(OFF);
  auto = digitalRead(AUTO);
  on = digitalRead(ON);
  show = digitalRead(SHOW);

  // Print out values for checking correctness
  Serial.print("LIT: ");
  Serial.print(lit);
  Serial.print(" , BRT: ");
  Serial.print(brt);
  Serial.print(" , RGB: ");
  Serial.print(rgb);
  Serial.print(" , OFF: ");
  Serial.print(off);
  Serial.print(" , AUTO: ");
  Serial.print(auto);
  Serial.print(" , ON: ");
  Serial.print(on);
  Serial.print(" , SHOW: ");
  Serial.println(show);

  unsigned long curMillis = millis();

  // RGB Color Calculation
  // Done in stepwise fashion for smooth color transitions using 1 variable input
  // ROYGBIV spectrum from 0-1.9, 11.0-13.0 reserved for white hues
  // Red
  if(rgb<=2)
    {
      R = 255;
    }
  else if(rgb>2 && rgb<4)
    {
      R = rgb*255/2+1020/2;
    }
  else if(rgb>=4 && rgb<8)
    {
      R = 0;
    }
  else if(rgb>=4 && rgb<10)
    {
      R = 255*rgb/2 - 2040/2;
    }
  else if(rgb>=10 && rgb<14)
    {
      R = 255;
    }
  else if(rgb>=11)
    {
      R = 255;
    }
  // Green
  if(rgb<=.01) // rgb flickers between 0 & 0.1, want stable red color
    {
```
G = 0;

} else if(rgb>.01 && rgb<2)
{
    G = 255*rgb/2;
}
} else if(rgb>=2 && rgb<6)
{
    G = 255;
}
} else if(rgb>6 && rgb<8)
{
    G = -255*rgb/2 + 2040/2;
}
} else if(rgb>=8 && rgb<11)
{
    G = 0;
}
} else if(rgb>=11)
{
    G = 255;
}

//Blue
if (rgb<=4)
{
    B = 0;
}
} else if(rgb>4 && rgb<6)
{
    B = rgb*255/2-1020/2;
}
} else if(rgb>=6 && rgb<=10)
{
    B = 255;
}
} else if(rgb>10 && rgb<11)
{
    B = -127*rgb + 1525;
}
} else if(rgb>=11)
{
    B = 127*rgb/2-1141/2;
}

if (off & !auto & !on & !show) //off
{
    analogWrite(RED_OUT, 0); //turn LEDs off
    analogWrite(GRN_OUT, 0);
    analogWrite(BLU_OUT, 0);
    analogWrite(WHT_OUT, 0);
} else if(!off & auto & !on & !show) //auto
{
    if(lit>4) //it's dark out //can add hysteresis later for delayed transitions
    {
        analogWrite(RED_OUT, R*brt); //multiply RGB setting by brightness setting
        analogWrite(GRN_OUT, G*brt);
        analogWrite(BLU_OUT, B*brt);
        analogWrite(WHT_OUT, 255*brt);
    }
    else //it's light out
    {
        analogWrite(RED_OUT, 0); //turn LEDs off
        analogWrite(GRN_OUT, 0);
    }
analogWrite(BLU_OUT, 0);
analogWrite(WHT_OUT, 0);
}
} else if(!off & !auto & on & !show) //on
{
analogWrite(RED_OUT, R*brt);
analogWrite(GRN_OUT, G*brt);
analogWrite(BLU_OUT, B*brt);
analogWrite(WHT_OUT, 255*brt);
} else if(!off & !auto & !on & show) //show
{
    if(curMillis-prevMillis > SHOW_INTERVAL) //transition to next color
    {
        prevMillis = curMillis;
analogWrite(RED_OUT, random(256)*brt); //random colors
        analogWrite(GRN_OUT, random(256)*brt);
analogWrite(BLU_OUT, random(256)*brt);
        int channel = random(1,4);
        if(channel == 1) //ensure at least 1 channel is always maxed out
        {
            //for more vibrant colors
            analogWrite(RED_OUT, 255*brt);
        } else if(channel == 2)
        {
            analogWrite(GRN_OUT, 255*brt);
        } else
        {
            analogWrite(BLU_OUT, 255*brt);
        }
        analogWrite(WHT_OUT, 255*brt);
    }
} else
{
    //do nothing, error
}