History of GPS at Stanford University

- Prof. Brad Parkinson
  - First Program Director of NAVSTAR/GPS
  - Principal Researcher Gravity Probe B
- Joined Stanford Faculty in 1984
  - Ph.D. Stanford 1966
  - Retire USAF 1978
One Thing Leads to Another...

- GP-B
  - GPS based attitude
- Attitude system for landing airplane
  - LAAS
  - JPALS
- Attitude system for
  - UAV
  - Tractor
  - Boat
- WADGPS
- WAAS
- Loran Data Channel
Global Positioning System Errors

- Ephemeris Error
- GPS Clock Error
- Ionosphere Delay
- Troposphere Delay
- Multipath
- Receiver Noise
GPS Laboratory Today

• Director: Prof. Per Enge
  – Prof. Powell, Prof. Parkinson

• Four major research programs
  – WAAS, LAAS, Loran, JPALS
    • GPS for Aviation – Safety of Life
  – Associated GPS/Navigation research

• 6 Full time research staff
  – + Supporting engineers, post doctoral fellow

• 12+ PhD Students
  – A/A, EE, ME
Stanford GPS Laboratory
Wide Area Augmentation System (WAAS)

- Wide Area Augmentation System – Augmentation to GPS that provides the ability to conduct precision approaches using GPS
Wide Area Augmentation System

Master Station
Reference Station

Geo-stationary satellite

GPS satellite

Geo-satehony
WAAS Timeline at Stanford

1990
- Enge, Nagle and Kinal present the GIC [Nagle et al., 1990]
- Kee and Parkinson propose WADGPS [Kee et al., 1990]

1992
- Kee demonstrates WADGPS [Kee et al., 1992]
- Stanford joins the NSTB and installs the West-Coast Reference stations

1994
- First flight tests with Stanford code (full separation of errors) [Walter et al., 1994]

1995
- Validation of RTCA message format with Stanford flights [Tsai et al., 1995]
- Juan Ceva studies the use of dynamic orbits [Ceva et al., 1995]

1996
- NSTB provides nationwide coverage and monitoring
- Integrity Equation derived and demonstrated [Walter et al., 1996, 1999]

1997
- Ionospheric tomography derived and demonstrated [Hansen et al., 1997, 1998]
- Alaskan and Hawaiian stations added

1998
- Use of POR on L1 for Alaskan flight tests [Comp et al., 1998]
- Use of POR and AOR-W on L1 for dual-GEO tests [Fuller et al., 1999]

1999
- Dai begins work on interoperability of augmentation systems [Dai et al., 1998, 2000]
- Effects of ionospheric scintillation for both high and low latitudes studied [Nichols et al., 1999]
- GEO ranging and orbit determination [Fuller, 2000]

2000
- 4D modelling study of the ionosphere begun [Hansen et al., 2000]
- Effects of missing messages on integrity availability studied [Fuller, 2000]
- WAAS Ionospheric algorithm & storm detector [Walter et al. 2000]
- Message Type 28 - ephemeris error bounding [Walter et al. 2001]
- Participation in the WIPP - providing WAAS integrity
LAAS provides the safety, accuracy needed to conduct CAT I to CAT III precision approaches. These include “zero-zero” approaches.
LAAS Achievements at Stanford

• 1992 – 1995: Development and flight-test demonstration of Carrier DGPS (CDGPS)-based Integrity Beacon Landing System (IBLS)

• 1996 – 1997: Development and flight-test demonstration of CDGPS-based Intrack Airport Pseudolite (APL) System

• 1998 – 1999: Development of carrier-smoothed-code DGPS-based LAAS Ground System Integrity Architecture

• 2000 – 2002: Development and validation of Integrity Monitor Testbed (IMT) LAAS Ground Facility (LGF) Prototype
Joint Precision Approach Landing System (JPALS)

- JPALS: Precision Landing System using Carrier DGPS for Armed Forces – two systems: Shipboard (SRGPS) & Land (LDGPS)
- Research Area: Controlled Reception Patch Antenna (CRPA), Inertial Integration, Integrity Monitoring
- Ship (SRGPS): Landing system capable of auto-landing an aircraft onto a carrier

**SPGPS**

**JSIM:** Detect and Isolate Signal-In-Space and Shipboard System Failures

**Differential Corrections and Integrity Messages**

**User Avionics:** Detect and Isolate Anomalies Seen by the Aircraft Only (e.g. RFI) as well as Signal-In-Space Failures
JPALS: Dual frequency, differential carrier phase system

Targeted Hook
Touch Down Point
Between 2 & 3 Wires

1 Wire
2 Wire
3 Wire
Hook engages 3 wire
4 Wire
JPALS - LDGPS

User Avionics: Detect and Isolate Anomalies Localized to Aircraft as well as Signal-In-Space Failures

LDGPS Ground Station and JLIM: Generate and Broadcast high quality corrections.

JPALS Land-based Integrity Monitor (JLIM): Detect and Isolate Signal-In-Space and Ground System Failures

- Land (LDGPS): Civilian compatible landing system capable of “zero-zero” landings
GPS is Below Noise Floor

- It does not take a lot of power to interfere with ("jam") GPS locally
GPS Interference/Jamming

- JPALS will use many systems to mitigate interference
  - Array antenna & beam steering
  - Inertials
  - Military signals (including new M code)
Loran is a terrestrial navigation system developed in the 1940s and 1950s.
Loran Research at Stanford

- Research has focused on enhancing Loran to provide redundancy to GPS for aviation

- **1999 – 2001**: Development and on air test of high data rate Loran Data Channel to broadcast the WAAS integrity message. Flight test in Alaska

- **2001 – 2003**: Development, design and analysis of enhanced Loran for Non Precision Approach

Multi Program Research & Testing

• Software Defined Radio
• Flight Displays
  – WAAS
  – GPS Attitude
  – Runway Incursion
  – Wake Vortex
• Location Based Encryption
• Data Collection
  – High gain antenna (Stanford Dish)
    • Three Frequency Measurements
  – Mobile and Indoor collection
• Other Research Areas
  – Radio Frequency Interference
  – Noise Floor Study
    • GPS Spectrum Management
An Introduction to the Software Radio Concept

- Initial attention in May 1995 as it was the focus of the IEEE Communications Magazine with many follow-up papers
- Objective: Position the analog-to-digital converter (ADC) as close to the antenna as possible and process the resulting samples using a programmable microprocessor

- Capture a wide spectrum of signal and digitally filter and decimate the specific band of interest

Courtesy: Prof. Dennis Akos
Software Define Receivers

- Flexible receiver tool for research
- Test specialized algorithms, tracking techniques, etc.
  - Galileo Signals, GPS L2C, L5
  - CRPA (Antenna Array)
  - INS Integration
  - Loran indoor tracking, frequency & timing
- Data Collection (test & validate)
Flight Displays & Operational Benefits

- Integrates Navigation Information (GPS, Loran, Inertials)
- Enhanced Situational Awareness (Air & Runway Traffic, Terrain, Wake Vortex)
- Enhanced Operations (Curved Approaches, Closely Spaced Parallel Approaches, etc.)
- Available to GA pilots
Data Collection

- Observation of Galileo GIOVE-A signal without having the code
- Observation, monitoring and fault detection on GPS signals
Viewing GNSS Spectrum

- Galileo GIOVE-A L1 and E6 both seen
Graduates of the Stanford GPS Laboratory (48)

7 companies founded by GPS Lab graduates (20)

Novariant:
  Clark Cohen, co-founder
  Stewart Cobb, co-founder
  Dave Lawrence, co-founder
  Paul Montgomery
  Mike O'Connor
  Frank Bauregger

GeoTrax (originally SportBug)
  Roger Hayward, co-founder
  Jock Christie, co-founder (now with SRI)
  Rich Fuller, co-founder
  Jon Nichols
  Aubrey Chan

Nav3D
  Andy Barrows, co-founder
  Keith Alter, co-founder
  Chad Jennings, co-founder

M Shift: Awele Ndili, co-founder

Rosum: Matt Rabinowitz, co-founder
  Guttorm Opshaug

Televigation: Y.C Chao, co-founder
  Donghai Dai

Meta-VR: Andrew Hansen, co-founder

Large Company/Government (3)
  Lockheed: Thomas Bell
  John Deere: Andy Rekow
  US Government: Jenny Gautier (ION Executive Fellow)

Faculty (7)
  Penny Axelrad: UC Boulder
  Changdon Kee: Seoul National University
  Boris Pervan: Illinois Inst. of Technology
  Glenn Lightsey: UT Austin
  Gabe Elkaim: UC Santa Cruz
  Shau-Shiun Jan: National Cheng Kung U.
  Demoz Gebre: Univ of Minn.

University Researchers (7)
  Todd Walter, Sr. Res Engineer, Stanford
  Sam Pullen, Sr. Res. Engineer, Stanford
  Eric Phelts: Research Associate, Stanford
  Sherman Lo: Research Associate, Stanford
  Juan Blanch: Research Associate, Stanford
  Ming Luo: Research Engineer, Stanford
  Jiyun Lee: Postdoctoral Fellow, Stanford

Government Labs (3)
  Konstantine Gromov: JPL
  Ran Gazit: Rafael (Israel)
  Hiro Uematsu: NASDA

Small or Medium Size Companies (8)
  Ping-Ya Ko: Taiwan
  Yeou-Jyh Tsai: Taiwan
  Jaewoo Jung: Trimble Navigation
  Harris Teague: Seagull Technology
  Sharon Houck: Seagull Technology
  Eric Abbott: Transparent Networks
  Gang Xie: CentralityComm
  Alexander Mitelman: NordNav
Companies Started by GPS Laboratory Students
Stanford Center for Position Navigation & Timing
Stanford Center for Position Navigation & Timing

- Mission: position and trajectory determination at the centimeter level - anywhere, anytime
- Develop GPS technology to operate in difficult navigation environments: indoor, urban canyons, space, remote, mountainous terrain, jungle/foliage, undersea, underground and be resistant to EMI and jamming.
Making GPS More Robust in More Places

Indoor

Obstructions

Attenuation

Jamming
Address Limitations of GPS

• Loss of signal:
  – an obstructed line of sight
  – radio interference

• Examine use of other sensors
  – MEMS, atomic scale time, inertials
  – Loran, TV, other signals of opportunity

• Examine better use of technology
  – Antenna, receiver architecture, sensor integration
Stanford CPNT
Multi-Disciplinary Research

SCNT
Stanford Center for Navigation and Time

ASIC/Circuit Design
RFIC
ADC
Low power
Systems

Signal Processing/Communications
Algorithms
System Arch
Adaptive arrays
Vector estimator

Antenna & Propagation
Precision timing
MEMS
VDSM

Hardware & User Interface
HW
Adv GPS
Intelligent MMI
Multimode

Wireless
Multimode
wireless
Network
optimization

Semiconductor & Device

Low power Systems

ASIC/Circuit
Design

Wireless

Semiconductor & Device

RFIC
ADC

Wireless