Precision Positioning System – Autonomous GPS-Denied Navigation for the Dismounted Soldier

WPI Indoor Personnel Location and Tracking for Emergency Responders
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Operational objectives
- Produce a robust and precise navigation solution to support Situational Awareness and Tactical Planning for small units of operation

Performance objectives
- Accuracy <3-5 Meters Horizontal and Vertical (Locate to a floor and room)
- Mission duration > 1/2 hour Fully GPS Denied; 24 Hours with Intermittent GPS
- Environments – Navigate through significant GPS signal degradation or denial

PPS Program
- Funded by Army and Draper Laboratory for soldier system integration and field test
Aided and Unaided GPS in an Urban Canyon

- Test Course
  - 8-10 Story Buildings
  - Significant Satellite Blockage and Multipath
  - Local Magnetic Field Distortions
- All three systems tied to a single GPS antenna
What’s the Trade Space for Indoor Geolocation \textit{without} Pre-Installed Infrastructure?

- **Dead reckoning**
  - \textit{Initialization} (non-trivial in many locations)
  - Magnetic attitude + Stride estimation
  - Gyro assisted magnetic attitude
  - Inertial navigation with augmentation
    - Velocimeters
    - Baro-altimeter
    - ZUPT sensors / \textit{foot mounted} IMU
  - Vision based feature tracking

- **Multi-lateration**
  - Indoor GPS
  - RF ranging from portable beacons or mobile assets
  - Multipath navigation (vs. mitigation)
PPS Architecture Groundrules

- **Autonomous operation**
  - No reliance on emplaced or ad hoc infrastructure (other than GPS)

- **Reliable operation**
  - Output both position and *statistically valid* estimate of position quality

- **Straightforward and rapid system initialization**

- **Military GPS compliance**

- **Component sensors with a future...**
  - Roadmap for low cost production
  - Roadmap for evolutionary size and power reduction
  - Ability to leverage COTS/ MOTS technical base
Sensors
- Tactical Grade MEMS gyros and accelerometers (Draper/Honeywell design)
- 3-axis magnetometer
- Baro-altimeter
- W-band mm wave Doppler velocimeter (Automotive radar legacy)
- P(Y) code GPS receiver

Software
- Deep Integration of sensor data with GPS tracking loops
- Confidence checks on sensor data for
  - Pressure anomalies
  - GPS multipath
  - Doppler returns from moving targets
PPS Rapid System Initialization

Initialization with GPS-in-view
- 45 second GPS acquisition (warm start)
- Heading initialization with on-board magnetometer and accelerometers
- < 1min roof-top traverse with GPS all-in-view to calibrate inertial sensors (dark blue trace)

Operation
- Eight floor descent inside cinder block stairwell (red trace)
- Exit onto street with very small heading error
- Navigation across urban canyon
- Indoor (two floor) traverse

Color coding:
- > 4 satellites blue
- 3: cyan
- 2: green
- 1: yellow
- 0: red
Putting it all together....

- Initialize with good view of satellites
- Traverse long urban corridors with significant multipath
- Navigate inside Draper building
Technology Square, Cambridge Outdoor Urban Canyon

- *Initializations* both with clear view of GPS and in urban canyon
- Operate *GPS challenged* – Satellite obscuration and significant multipath
- Navigation system challenges
  - Ability to reacquire GPS after dropouts
  - Reject GPS multipath driven position errors
  - Magnetic anomalies; Gait variations; Doppler radar clutter

Draper *Outdoor – Indoor – Outdoor Scenario*

- *Initializations* both with clear view of GPS and in urban canyon
- Operate GPS denied (~20 minutes) followed by GPS reacquisition
- Demonstrate
  - Vertical position accuracy – Geo-locate to a floor
  - Horizontal position accuracy – Geo-locate to a hallway or room
  - Staircase navigation
  - Performance through thermal steps (50°F outdoor to indoor) and also through
  - Magnetic anomalies, Doppler radar clutter

PPS co-tested with two pedometry based systems developed for the Army
Urban Canyon Navigation

Color coding by number of GPS satellite measurements used by navigation filter
Blue >=4, cyan 3, green 2, yellow 1, red 0

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<thead>
<tr>
<th></th>
<th>Horizontal errors (m)</th>
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<tbody>
<tr>
<td></td>
<td>50% - 5.2</td>
<td>50% - 3.6</td>
<td>50% - 3.2</td>
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<tr>
<td></td>
<td>RMS - 7.2</td>
<td>RMS - 4.6</td>
<td>RMS - 4.2</td>
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<tr>
<td>Vertical errors (m)</td>
<td>50% - 8.2</td>
<td>50% - 7.5</td>
<td>50% - 3.6</td>
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<tr>
<td></td>
<td>RMS - 8.8</td>
<td>RMS - 7.6</td>
<td>RMS - 4.1</td>
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In indoor navigation, a three-dimensional view and overlay onto a floor plan are shown. The hallway width is 4½ ft. A jump from end of 15 minutes GPS-denied dead reckoning to GPS position is about 5 m.

- CEP averaged over four normal gait runs in Urban Test sequence is 5¾ m, 19 min GPS denied.

- Dominant error source in tests with poor performance is error in position and heading at building entry.
Instantaneous Body Pose

- Plot shows PPS heading vector plotted on navigated track in urban canyon
- Fixed correction applied for chassis boresite to body forward

- **Heading estimates do not rely at all on magnetic field measurements**
- **Heading is consistent with direction of motion on roof, in urban canyon, and indoors**

Color coding by route segment: 1 red, 2 blue, 3 black, 4 cyan
Conclusions

- **PPS successes**
  - Developed and integrated compact soldier navigation system
  - Urban canyon/Indoor navigation and body pose determination – PPS performed accurately and repeatedly in presence of significant GPS dropouts, multipath, and magnetic anomalies

- **Next steps**
  - CONOPS/algorithm modifications to optimize performance under diverse environments
  - SWAP reduction
    - Next-gen GPS receiver insertion
    - Velocimeter optimization
    - Insertion of additional/alternative navigation sensors