The Fourth Layer in Collaborative Navigation – Going Underground

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Principle of Collaborative Navigation

Ubiquitous positioning requirement in applications where a group of users has to be navigated led to the development of collaborative navigation.

Integrated positioning solution employing multiple location sensors with different accuracy on different platforms for sharing of their absolute and relative localizations.

Main goals:
- Robust multi-sensory navigation
- Seamless transition between different environments using different sensors, different platforms and different navigation approaches
- Optimal estimation of platform positions using sensor fusion of all currently available measurements

after Grejner-Brzezinska and C. Toth, OSU, USA
Application Fields and Sensors

Need for collaborative navigation and guidance in GNSS-challenged environments for:
- Dismounted soldiers,
- Emergency crews,
- Swarms of UAV’s,
- Team of robots,
- ...

Sensor augmentation of GNSS:
- IMU’s,
- Accelerometer,
- Magnetometer,
- Odometer,
- Compass,
- Gyroscope,
- Barometer,
- Optical systems,
- ...

Sensors and Positioning Techniques

<table>
<thead>
<tr>
<th>SENSOR / TECHNIQUE</th>
<th>NAVIGATION INFORMATION</th>
<th>TYPICAL ACCURACY</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS</td>
<td>X, Y, Z, v_x, v_y, v_z</td>
<td>~ 10 m (DGPS: 1–3 m)</td>
</tr>
<tr>
<td>Pseudolites (e.g., Locata)</td>
<td>X, Y, Z</td>
<td>comparable to GPS</td>
</tr>
<tr>
<td>UWB</td>
<td>X, Y, Z</td>
<td>dm-level</td>
</tr>
<tr>
<td>Wi-Fi Fingerprinting</td>
<td>X, Y</td>
<td>3–5 m</td>
</tr>
<tr>
<td>RFID cell-based Fingerprinting</td>
<td>X, Y</td>
<td>depending on cell size</td>
</tr>
<tr>
<td>INS</td>
<td>Accelerometer</td>
<td>$\delta_{x, y, z}$ &lt; 0.03 m/s^2</td>
</tr>
<tr>
<td></td>
<td>Gyroscope</td>
<td>heading $\varphi$</td>
</tr>
<tr>
<td>OPTICAL SYSTEMS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Image-based</td>
<td>X, Y, Z</td>
<td>few meters</td>
</tr>
<tr>
<td>Optical sensor network</td>
<td>X, Y (Z optional)</td>
<td>few meters</td>
</tr>
<tr>
<td>Laser</td>
<td>X, Y, Z</td>
<td>cm to dm</td>
</tr>
<tr>
<td>OTHERS</td>
<td>Digital compass / magnetometer</td>
<td>heading $\varphi$</td>
</tr>
<tr>
<td></td>
<td>Barometric pressure sensor</td>
<td>Z</td>
</tr>
<tr>
<td></td>
<td>Temperature sensor</td>
<td>T</td>
</tr>
</tbody>
</table>

Extended excerpt from Retscher and Thienelt (2004) and Grejner-Brzezinska and Toth (2013)
Emergency Scenario Concept

Inter-nodal Range Measurements

<table>
<thead>
<tr>
<th>TYPE</th>
<th>OBSERVATION</th>
<th>CHARACTERISTICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>RADIO FREQUENCY SIGNALS IN WIRELESS SENSOR NETWORKS</td>
<td>Received signal strength RSS</td>
<td>Channel attenuation which increases with distance Computed from known position of transmitters and the received power Cell-based positioning (Cell-of-Origin CoO), lateration or location fingerprinting</td>
</tr>
<tr>
<td>Time of Arrival ToA</td>
<td></td>
<td>Distance is computed by signal’s travel time as long as the network is synchronized</td>
</tr>
<tr>
<td>Time Difference of Arrival TDoA</td>
<td></td>
<td>Time difference of ToA Hyperbolic positioning method</td>
</tr>
<tr>
<td>Angle of Arrival AoA</td>
<td></td>
<td>Angle between the propagation direction of an incident wave and some reference direction</td>
</tr>
<tr>
<td>RANGING BASED ON OPTICAL SENSORY DATA</td>
<td>Laser ranging</td>
<td>High accuracy but high power requirement</td>
</tr>
<tr>
<td></td>
<td>Computer vision-based estimation</td>
<td>Detection of land marker or distinct feature in the image facilitates the distance measurement</td>
</tr>
</tbody>
</table>

Modified excerpt from Grejner-Brzezinska et al., 2010
Inclusion of UAVs in a 3rd Layer

Underground as 4th Layer
RFID Positioning Scenarios

Strategy 1:
RFID readers are installed at specific locations or waypoints of interest
User is equipped with an RFID tag and can be located in a certain section between two waypoints

Strategy 2:
Tags are mounted at certain known locations of interest (i.e. active landmarks)
The mobile user is equipped with a reader
The tag's ID and 3-D coordinates can be retrieved in the given read range if the user passes by

Positioning in Underground Networks:
2nd strategy

Concluding Remarks

Advantages
- Collaborative Positioning can bridge GNSS signal losses successfully and enables navigation in otherwise challenging environments
- Higher positioning accuracies, availability and reliability if tight integration of all sensor observations is performed

Challenges
- Sensor calibration required
- Time synchronisation between sensors and nodes essential

Call for international collaboration
Further tests are initiated investigating the use of the underground layer
Collaborative Navigation with Ground Vehicles and Personal Navigators

International Collaboration with:
Allison Kealy and Azmir Hasnur-Rabiani
University of Melbourne, Australia

Dorota Grejner-Brzezinska and Charles Toth
Ohio State University, USA

Terry Moore and Gethin Roberts
University of Nottingham, UK and China

Vassilis Gikas and Chris Danezis
National Technical University of Athens, Greece

Andrew Dempster and Nima Alam
University of New South Wales, Australia

http://ubpos.net/