Tightly-Coupled Opportunistic Navigation for Deep Urban and Indoor Positioning

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THE PROBLEM

GPS signals are insufficient for deep urban canyon and indoor navigation as they attenuate 30–50 dB.

SOLUTION: EXPLOIT SOPs

Ambient signals of opportunity (SOPs) may enhance and assist conventional navigation techniques.

Desirable Characteristics

- Known or predictable timing offset
- Stable transmitter clock
- Known or predictable location
- High received signal power
- Wide bandwidth
- Continuous carrier
- Known signal structure

SOP Comparison

<table>
<thead>
<tr>
<th>SOP</th>
<th>Signal Power (dBW)</th>
<th>Freq. Stability</th>
<th>Tx Pos. known?</th>
<th>Tx timing offset known?</th>
</tr>
</thead>
<tbody>
<tr>
<td>GNSS</td>
<td>~ -150</td>
<td>10^−14</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>CDMA</td>
<td>~ -110</td>
<td>10^−10 – 10^−11</td>
<td>Not always</td>
<td>Rough sync. ~ μsec</td>
</tr>
<tr>
<td>Iridium</td>
<td>~ -130</td>
<td>10^−10 – 10^−11</td>
<td>~100m</td>
<td>×</td>
</tr>
</tbody>
</table>

Tightly-Coupled

Signals are downmixed and sampled with the same clock and signal observables are fused at the carrier phase level allowing absolute time correspondence at the nanosecond level.

Opportunistic

Receiver continuously searches for signals from which to extract navigation and timing information. The receiver employs on-the-fly signal characterization to estimate:

- Clock stability
- Clock offset
- Carrier-to-noise ratio C/N0
- Transmitter location

Central Estimator

State Vector:

\[ \mathbf{x}_{\text{rec}} = \begin{bmatrix} r \\ \delta_t \\ \delta_{t,\text{SSP}} \\ \delta_{t,\text{DOP}} \\ \gamma \end{bmatrix}, \quad \mathbf{x}_{\text{SOP}} = \begin{bmatrix} r_{\text{SOP}} \\ \delta_{t,\text{SOP}} \\ \delta_{t,\text{DOP}} \\ \gamma_{\text{SOP}} \end{bmatrix}, \quad \mathbf{x} = \begin{bmatrix} \mathbf{x}_{\text{rec}} \\ \mathbf{x}_{\text{SOP, 1}} \\ \vdots \\ \mathbf{x}_{\text{SOP, N}} \end{bmatrix} \]

Dynamics Model:

\[ x(k+1) = \Phi(k)x(k) + \Gamma(k)w(k), \quad w(k) \sim \mathcal{N}[0, Q(k)] \]

Observation Model:

i) GPS Carrier Phase

\[ \phi_C(t_R) = \frac{1}{\lambda}||\mathbf{r}(t_R) - \mathbf{r}_{SV}(t_R - \delta t_{SV} - \delta t_{TOF})|| + \frac{c}{\lambda}(\delta t_{SV} - \delta t_{SV}(t_R - \delta t_{TOF})) + \gamma + \epsilon_{\text{iono}}(t_R) + \epsilon_{\text{tropo}}(t_R) + \nu_{\text{SNR}}(t_R) \]

ii) CDMA Carrier Phase

\[ \phi_C(t_R) = \frac{1}{\lambda}||\mathbf{r}(t_R) - \mathbf{r}_{CDMA}(t_R - \delta t_{SV} - \delta t_{TOF})|| + \frac{c}{\lambda}(\delta t_{SV} - \delta t_{SV}(t_R - \delta t_{TOF})) + \gamma + \nu_{\text{CDMA}}(t_R) \]

iii) Iridium Carrier Phase

\[ \phi_I(t_R) = \begin{cases} \frac{1}{\lambda}||\mathbf{r}(t_R) - \mathbf{r}_{Iridium}(t_R - \delta t_{SV} - \delta t_{TOF})|| + \frac{c}{\lambda}(\delta t_{SV} - \delta t_{SV}(t_R - \delta t_{TOF})) + \gamma \\ + \epsilon_{\text{iono}}(t_R) + \epsilon_{\text{tropo}}(t_R) + \nu_{\text{SNR}}(t_R) \end{cases}, \quad \text{within a burst} \]

TCON Attributes

Potential SOPs

- GNSS: GPS, GLONASS, Galileo
- Other SVs: Iridium, CDMA, GSM, 4G LTE, Misc.
- Cell: Wi-Fi, HDTV, AM, FM

Simple TCON Demo

REFERENCES