Modelling the Noise of GNSS Signals under Jamming Conditions

Christoph Lass, Ralf Ziebold
German Aerospace Center (DLR)
1. Motivation

2. Theory

3. Experimental Setup and Noise Models

4. Results

5. Outlook
1. Motivation

- Positioning, Navigation and Timing information mainly derived from GNSS

- GNSS signals can easily be disturbed by Personal Privacy Devices (PPD)

- PPD of vehicle affecting WRS at Leesburg, Virginia, USA on 9\textsuperscript{th} of April 2011\cite{1}

Motivation II

- Measurement campaign in the Baltic Sea using allocated civilian maritime GNSS jamming testbed\(^2\)

- Using GNSS + onboard sensors in Kalman filter

- How to estimate “quality” of GNSS observations?

- Estimating noise of signals without position reference

Jamming on selective frequencies

Jammer K1001 at GPS L1: 1575.42 MHz

- Common way of jamming: sweeping with linear increasing frequency around center frequency of L1
- Here band with only 17 MHz
- Jamming Galileo E1 too
- GLONASS L1 not affected by jamming

=> Generation of reference trajectory possible
GPS single point positioning results of the three antennas
2. Theory

• Code and phase measurements [m] for different frequencies (Li):

\[
R_i = \rho + c(\delta t_{rcv} - \delta t^{sat}) + Tr + I_i + M_i + \epsilon_i
\]
\[
\Phi_i = \rho + c(\delta t_{rcv} - \delta t^{sat}) + Tr - I_i + \lambda_i N_i + \lambda_i w + m_i + \epsilon_i
\]

• \( R_i, \Phi_i \): Code and phase measurement of Li [m]
• \( M_i, m_i \): Multipath error
• \( \epsilon_i, \epsilon_i \): Receiver noise

• Use linear combination of code and phase measurements to get noise:

\[
\tilde{\sigma}_1 = R_1 - \Phi_1 - \frac{2}{\gamma - 1} (\Phi_1 - \Phi_2)
\]
Code-carrier residuals with bias and cycle slips
3. Experimental setup

- One antenna on the roof of the Institute of Communications and Navigation in Neustrelitz, Germany, connected to two receivers (Javad Delta receiver, dual frequency)

- Strength of jamming adjusted using variable attenuator
Two 48 hours 2 Hz measurements (A and B) with different jamming strength

Decrease in C/N₀ compared to unjammed signal: 9.4 dB-Hz (A), 10 dB-Hz (B)
Noise models

• Elevation angle weighting:

\[ \sigma_1^2 = \frac{a_1}{\sin^2 \alpha} \]

• Additive noise model:

\[ \sigma_2^2 = \frac{a_2}{\sin \alpha} + 10^{-b_2 \cdot \frac{C/N_0}{10}} + c_2 + d_2(a_2, b_2, c_2) \]

• Multiplicative noise model\[^3\]:

\[ \sigma_3^2 = \frac{10^{-a_3 \cdot \frac{C/N_0}{10}} + b_3}{\sin^2 \alpha} + c_3 \]

4. Results - Noise of GPS signals w.r.t. elevation

Residuals in most bins follow a Gaussian distribution!
Noise of GPS signals w.r.t. $C/N_0$

Residuals in most bins follow a Gaussian distribution!
Number of measurements (Reference & Jamming)

Sample variance over EA and C/N₀, number of samples as colour
Variance from measurement scenarios

Sample variance of CC residuals over EA and C/N₀
Additive Model

Additive variance of CC residuals over EA and $C/N_0$
### Quality of fit

<table>
<thead>
<tr>
<th>Noise model</th>
<th>$L_1$ residual fit</th>
<th>$L_2$ residual fit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevation angle</td>
<td>2.35 $\cdot 10^{-1}$</td>
<td>1.08 $\cdot 10^{-1}$</td>
</tr>
<tr>
<td><strong>Additive</strong></td>
<td>3.43 $\cdot 10^{-2}$</td>
<td>4.59 $\cdot 10^{-3}$</td>
</tr>
<tr>
<td>Multiplicative</td>
<td>1.65 $\cdot 10^{-1}$</td>
<td>4.23 $\cdot 10^{-2}$</td>
</tr>
</tbody>
</table>

- Additive model: Best fit
- Elevation model good for low elevation
Reminder - Motivation II

- Measurement campaign in the Baltic Sea using allocated civilian maritime GNSS jamming testbed\[2\]

- Using GNSS + onboard sensors in Kalman filter

- How to estimate “quality” of GNSS observations?

- Estimating noise of signals without position reference

Positioning results from campaign in Jamming testbed
5. Outlook

• Noise model for GNSS signals depending on C/N$_0$ and elevation angle that works with and without jamming $\Rightarrow$ Variance estimation in a Kalman filter

• Conduct more measurement scenarios

• Weighting scheme for least squares position solver

• Potential to be used as a Jamming detector
Thank you for your attention!

Christoph.Lass@dlr.de
Common Jammers – Personal Privacy Devices (PPD)

- Low transmitting power: model K320
- Blocks single frequency (GPS L1)
- Range 2 – 10 m (producer)
- Measured disturbances: up to 50 m (loss of lock)

- High transmitting power: model K1001
- Blocks several frequencies (GPS L1, L2; GSM, Wi-Fi, …)
- Range 5 – 15 m (producer)
- Measured disturbances: up to 1500 m (loss of lock)