Modelling the Noise of GNSS Signals under Jamming Conditions

Introduction

Global Navigation Satellite Systems (GNSS) are increasingly used as the main source for Positioning, Navigation and Timing (PNT) information for maritime and inland water applications. With the rising availability of cheap jamming devices such as Personal Privacy Devices (PPD), there is a real threat to GNSS based navigation. Therefore, it becomes of upmost importance to estimate the accuracy of the satellite signals, even under disturbance.

The presented work examines the influence of jamming on the noise of the signals and if it can be modelled. Laboratory experiments showed that it is possible to accurately estimate the noise in jamming conditions which is even consistent with undisturbed measurements. Hence, the derived model describes the noise of GNSS signals in scenarios with and without jamming. It uses the elevation angles of the satellites and the Signal-to-Noise Ratio (SNR) of its signals to estimate the respective noise. The parameters of the model are calculated by fitting them to real measurement data of scenarios with different amount of jamming. The initial results show that this model estimates the noise of the signals better than classic weighting schemes using only the elevation angles or just the SNR.

This shows the potential of the model to be used in multi-sensor fusion scheme as a weighting scheme in an iterative least squares position solver or as a variance estimator in a Kalman filter setup in demanding environments.

Measurement Setup

Reliable navigation of maritime vessels is based on accurate positioning which is mainly obtained using GNSS. However, those signals can be easily disturbed using jamming or spoofing which was verified in several measurement campaigns. The question arises if it is still possible to estimate the accuracy of the signals in these difficult environments.

A measurement campaign using the civilian maritime jamming testbed in the Baltic Sea, established by the DLR in cooperation with the German Federal Network Agency, yielded the surprising result that the noise of the jammed signals was actually smaller than the undisturbed ones having the same SNR due to a higher elevation angle. This evoked the need for a more thorough investigation of the noise which cannot be estimated only by the SNR.

Therefore, additional experiments in the laboratory were conducted to develop a refined model for the noise of GNSS signals under jamming conditions.

The experiment setup consisted of one antenna on the roof of the Institute of Communications and Navigation in Neustrelitz, Germany, connected to two receivers. For one of the receivers the incoming signal was disturbed using a standard jammer connected to several fixed as well as variable damping elements which allowed for adjusting the amount of disturbance.

Each of the four experiments lasted 48 hours with a data rate of 2 Hz. The jamming caused a decrease in the SNR of about 9 dB, 10 dB, 16 dB and 19 dB with respect to the undisturbed signals. This way even data for high elevation angles but low SNR could be obtained which hardly occurs in normal measurement environments.

The noise of the GPS signals is then determined using a linear combination of code and phase measurements in both L1 and L2 frequency. The carrier ambiguity is removed by applying a cycle slip detector. Afterwards, the variance of the linear combination is computed for different pairs of intervals of SNR and elevation angles.

Preliminary analysis of the results

The first analysis of the measurements of the GNSS signals indicates that the noise of the L1 code measurements increases with smaller elevation angle and smaller SNR in a monotonous manner. Furthermore the samples of the different scenarios are consistent with each other and show that the variance can be described in a continuous way. Therefore, it should be possible to estimate the noise with and without jamming in a single formula.

In the following, three models are compared whose parameters are determined using a weighted least squares ansatz with the goal of providing the best fit with regards to the samples. Two classic models – SNR based weighting described by an exponential term and elevation angle based weighting using a sine term were regarded. The third model combines both weighting schemes in an additive way as both inputs are assumed to be uncorrelated which is supported by the initial analysis of the measurements. Hence, the noises, i.e. the variances, can be added.

The evaluation of the computation yielded the result that the additive model has the best fit in both L_1- and L_2-norm. The classic weighting schemes using exclusively the elevation angles or the SNR have a worse fit than the model using both of them as input values, especially with respect to the quadratic error. Furthermore, the SNR based model is better in describing the noise of the GNSS signal than the classic elevation based model.