Identification of Multi-Faults in GNSS Signals using RSIVIA under Dual Constellation

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Introduction

As described in the Market Report from European Global Navigation Satellite Systems Agency (GSA), satellite-based navigation will substantially contribute to the future innovation of self-driving vehicles (see [1]). In autonomous applications, especially in safety-critical scenarios, a false estimation of vehicle state can result in catastrophic accidents, which requires the high accuracy and integrity of the navigation solution. To maintain the integrity of a global navigation satellite system (GNSS)-based navigation system, the faulty GNSS observations caused by signal interferences and other possible reasons shall be detected, identified and excluded. Since the open service of the newly developed EU satellite navigation system Galileo is in operation, the combination of GPS and Galileo provides the modern navigation systems more available satellites in view. However, a higher number of satellites also increases the possibility that satellite observations contain a fault or even multi-faults. Therefore, identification of multi-faults becomes a crucial and challenging task to maintain the integrity of GNSS-based navigation systems.

The previous work [2] presents the development of a fault detection and exclusion (FDE) algorithm of GNSS measurements. The approach is an extension of an existing tightly-coupled navigation filter, which integrates the measurements from GNSS and an inertial measurement unit (IMU). In [2], FDE bases on the receiver integrity monitoring (RAIM) approach, which is a pure statistical method. RAIM predicts pseudorange residual, which is based on estimated reference vehicle state using least square method, and uses the residual to detect and identify pseudorange faults. This method might not be adequate, when many of the measurements are faulty, since it is originally developed under single fault assumption. This work concentrates on multi-faults identification, when the conventional statistic based approach cannot provide a correct identification solution certainly.

In recent years, an alternative localization method, Set Inversion via Interval Analysis (SIVIA), is developed under such concern in [3] and applied to realize robot localization in [4]. SIVIA guarantees integrity and estimates a trust region of the antenna position fulfilling a predefined confidence level. Further, robust SIVIA (RSIVIA) approach is applied for satellite positioning in [5], which allows to estimate the trust region under the assumption of erroneous pseudorange measurements. Hereby, it is possible to identify outliers in the GNSS observations by checking the compatibility of each GNSS measurement and the estimated trust region. This trust region is calculated as a wrap of several sub-pavings, which makes it less sensitive with the pseudorange errors, i.e. the pseudorange error should be relatively big to be identified. Another drawback of this approach is its computational load, because RSIVIA begins with an initial guess of an arbitrary big box, bisects it into small boxes and operates on them separately and iteratively.

The present research applies RSIVIA for fault detection and identification in a dual-

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constellation based-navigation system, where RSIVIA is executed in an iterative process: it starts with the assumption that no fault exists in the observed measurement space. Whenever an empty trust region is returned, RSIVIA assumes one more fault existing in the measurements. This iterative process continues until a non-empty trust region is estimated. Instead of checking the compatibility of each GNSS measurement with the estimated trust region [5], which is a wrap of several sub-pavings, the compatibility of these measurements with each existing sub-paving is checked to identify the faults. To reduce the computational load, RSIVIA does not start with an arbitrary big box, instead, the middle point of the initial box is the estimated states from the navigation filter and the size is calculated as a function of maximum dynamic from the experimental vehicle.

This extended abstract contains the following contents: First, the background of current work was introduced, including the motivation and previous work. Then, the approach applied in this work was described briefly. Further, the next section describes the measurement setup that is used to validate the approach and provides the first experimental results. Finally, the last section draws the conclusion and provides an outlook for the ongoing and future developments.

Experimental Validation

Measurement Setup

The test trajectory in the experimental validation is defined and simulated in a NCS TITAN GNSS simulator from IFEN GmbH. The TITAN generates GNSS observables and supports all existing GNSS systems and provides up to 256 signal channels. Further, the inertial measurements are also simulated by TITAN, with respect to the defined trajectories, the virtual vehicle characteristic and the noise level of a real LORD MicroStrain 3DM-GX4-25 industrial-class IMU-sensor. Compared to

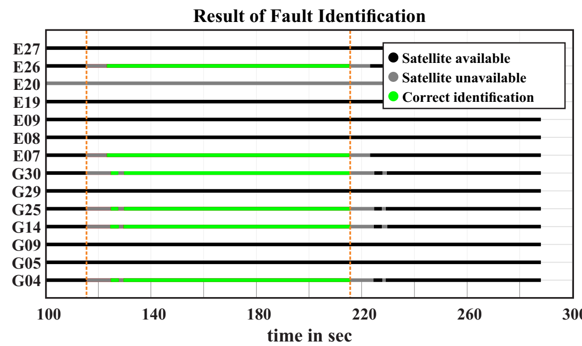

Figure 1: Identified erroneous satellite signals

real world measurement campaign, the TITAN can generate the GNSS signals with feared event, which is the scenario containing pseudorange errors, and record it, which can be used as the reference of the fault identification outputs.

The generated GNSS signal is received and decoded by a Septentrio AstRx3 HDC receiver at a rate of 10 Hz. The navigation filter is implemented on a 900 MHz single core Rapid Control Prototyping (RCP) unit, called MicroAutoBox from the manufacture dSPACE. The communication between the receiver and the RCP unit is achieved via serial interface. The receiver provides a pulse per second (PPS). Using the PPS, the communication and processing delays of the receiver are compensated (see [6]). All the GNSS and IMU measurements are recorded and the test scenario with RSIVIA is reproduced in a post-processing environment.

Experimental Results

Figure 1 shows the first experimental results of the fault identification of multi-faults in GNSS measurements. In Figure 1, the label of y-axis shows all satellites that are simulated in this test, where 'G' stands for GPS and 'E' for Galileo satellites. In total, seven GPS L1/L2 satellites and seven Galileo E1/E5a satellites are simulated. In this figure, the black parts of the lines show the epochs, when a satellite is available for the RSIVIA, otherwise, it is in gray. Satellite E20 is simulated during the entire test, but blocked by the navigation filter because of its low elevation angle. The area between the two orange dashed lines shows when the feared events occurs. As recorded, six of the 14 simulated satellites have pseudorange errors with a constant amplitude of 50 meters. At the beginning of the feared events and shortly after the feared events, when the receiver observed a rapid change in the pseudoranges, it stops transmitting those suspicious signals. As a result, the recorded feared events are identified correctly using RSIVIA, which is showed in green. In this experiment, missed detection or false identification does not occur, with a proper choice of the maximum acceptable size of sub-pavings, which is 5 meters.

Conclusion

The present work applies RSIVIA in a GNSS-based navigation system for the fault detection and identification, which concentrates on a more reliable identification of multi-faults in GNSS signals. The approach was validated in a test campaign with a GNSS simulator. The result shows that, all six satellites with feared events was successfully identified by RSIVIA, which makes it a promising alternative for conventional integrity methods like RAIM.

The present extended abstract only provides the first results of the on-going work, which concentrates on comparing RSIVIA with conventional RAIM and research a concept to combine them both.

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