Window Based GPS Integrity Test using Tight GPS/IMU Integration Applied to a Sounding Rocket

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This poster presents an *integrity monitoring method* for tight integration of an Inertial Measurement Unit (IMU) and a GPS receiver. The method is applied to data from a *Maxus sounding rocket* used for microgravity research. It is crucial to determine the rocket position during launch to ensure a safe landing location. Today, the navigation relies on IMU integration only. Involving a GPS receiver enhances the position accuracy but there is a need for protection against faulty satellite range measurements. Monitoring over a *sequence of the measurements* gives higher confidence to the tests. The results have previously been published in [1].

Integrity Monitoring

- The linearized *rocket dynamics* is described in *batched form* over a time window of length L as

$$\mathbb{Y} = \mathcal{O}_t x_{t-L+1} + \bar{H}^u_t \mathbb{U} + \bar{H}^f_t \mathbb{F} + \bar{H}^v_t \mathbb{V} + \mathbb{W},$$

  where signal vectors are stacked like $\mathbb{Y} = \left(y^T_{t-L+1}, \dots, y^T_t\right)^T$. Also define an output with input influence removed as $\mathbb{Z} \triangleq \mathbb{Y} - \bar{H}^u_t \mathbb{U}$.
- The *parity-space* idea is to project the output on a space that is orthogonal to the influence of the initial state, the parity space. A *residual* is calculated with a projection as

$$r = \mathcal{B}^T_{\mathcal{O}^\perp}\mathbb{Z} \sim \mathsf{N}(\mathcal{B}^T_{\mathcal{O}^\perp}\bar{H}^f\mathbb{F}, I).$$

- To decide if there is a fault or not a *hypothesis test* is formulated as

$$\mathcal{H}_0: \; r \sim \mathsf{N}(0, I)$$
$$\mathcal{H}_1: \; r \sim \mathsf{N}(\mathcal{B}^T_{\mathcal{O}^\perp}\bar{H}^f\mathbb{F}, I).$$

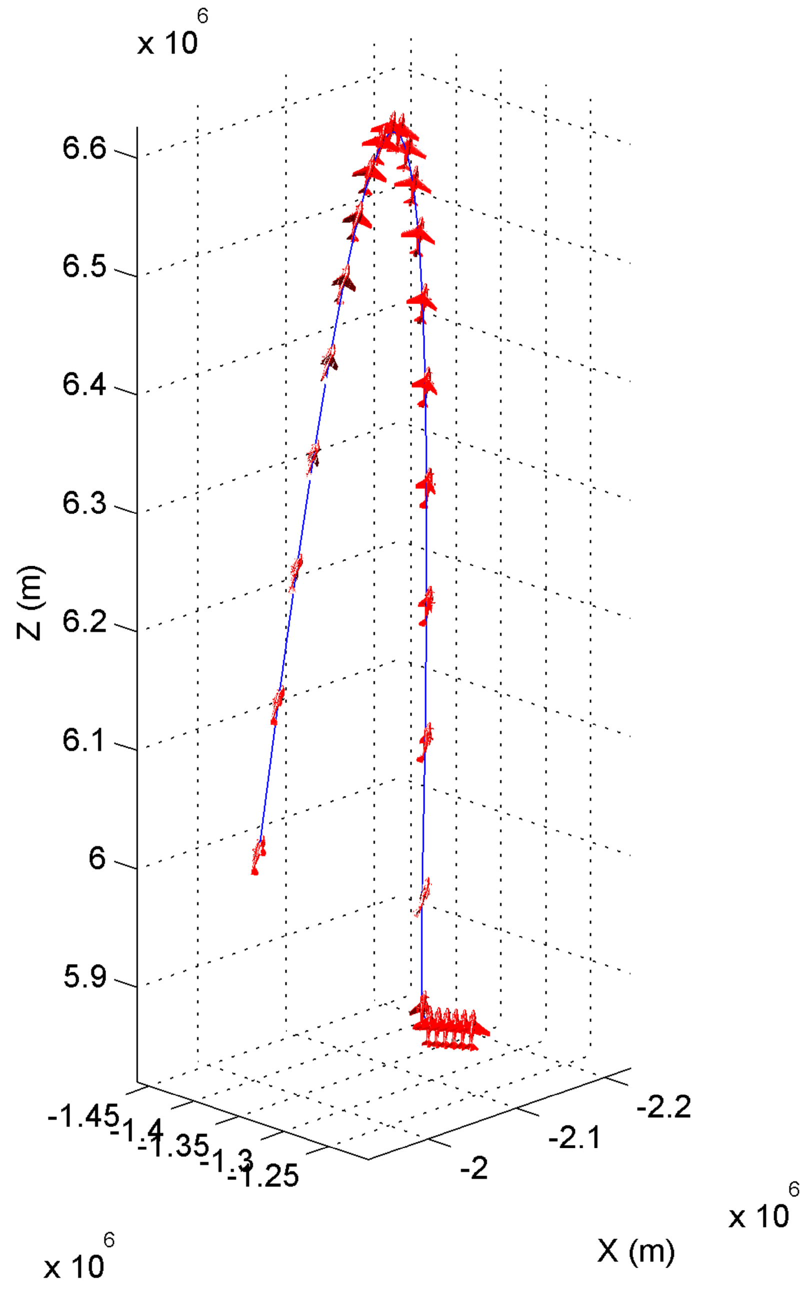
- From the hypothesis test, a *Generalized Likelihood Ratio* test is formed which yield a chi-square distributed *test-statistic*

$$\mathcal{T} = r^T \mathcal{P}_{\mathcal{B}^T_{\mathcal{O}^\perp}\bar{H}^f} r \sim \chi'^2_\nu(\lambda).$$

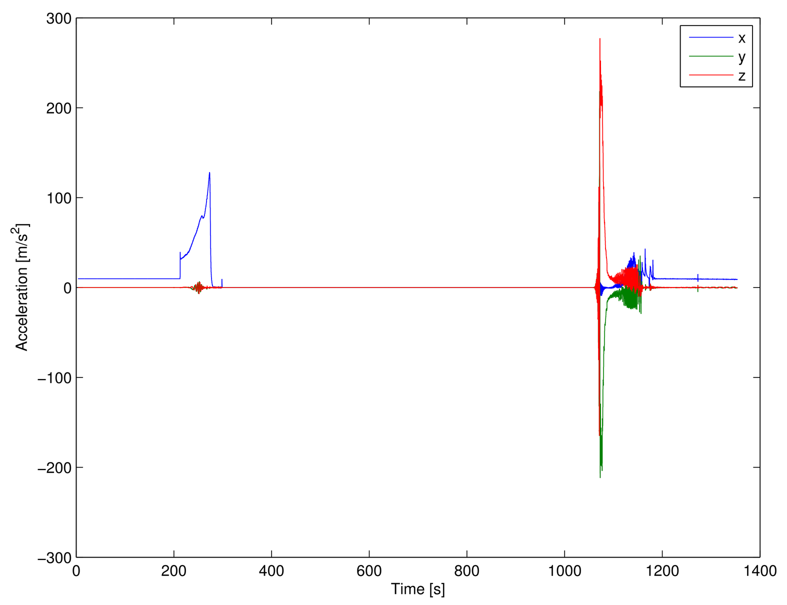
  For decision, the test-statistic is compared to a threshold selected from the chi-square distribution.
- The *Receiver Autonomous Integrity Monitoring* (RAIM) is used today in GPS-receivers, it only considers a time *window of length one*.
- Our method, *window based* RAIM is an extension of RAIM considering a window of measurements where also the IMU measurements are used.

Data

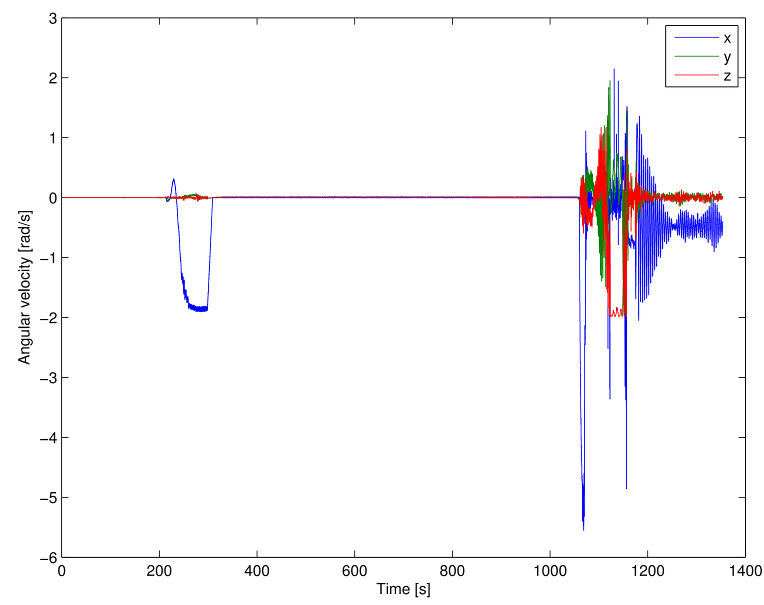
Data is collected during a flight with the Maxus sounding rocket. The full trajectory and orientation, estimated using the IMU alone, is shown below.



The IMU measurements are measured during flight (and shown below) but GPS measurements are simulated using the Constell toolbox. For the first 210 s the rocket is standing on the launch pad prior to liftoff. At liftoff the rocket accelerates during the motor burn phase of about 64 s. The payload separates from the motor, and then flies in a zero-g orbit until it enters the atmosphere at 1060 s. Finally, the parachute is deployed and the payload lands safely.



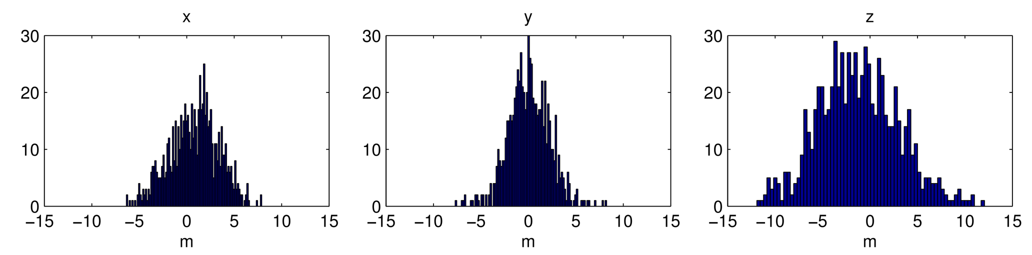
Accelerometer



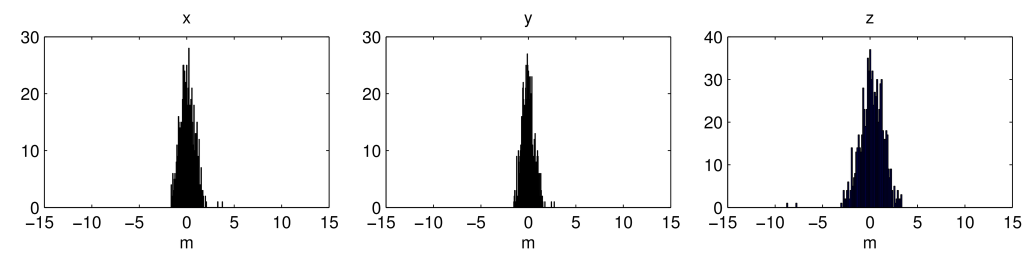
Gyroscope

Results

Using the IMU substantially improves the positioning accuracy, which can be seen in the position error histograms below.



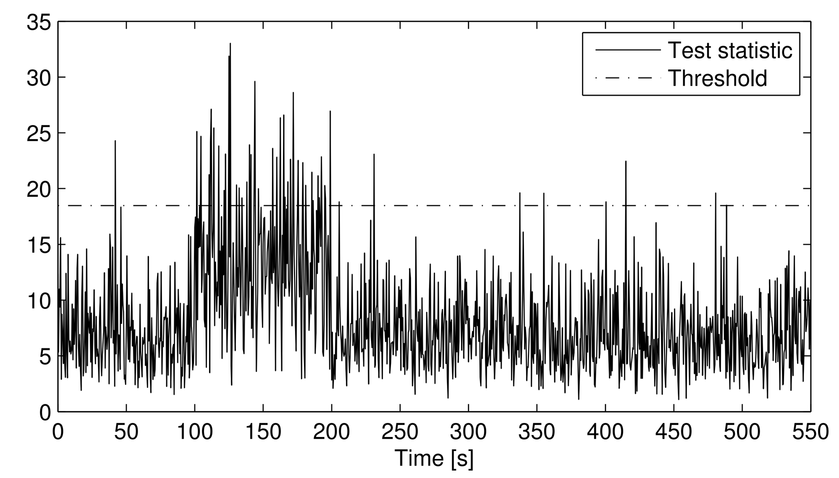
Without IMU



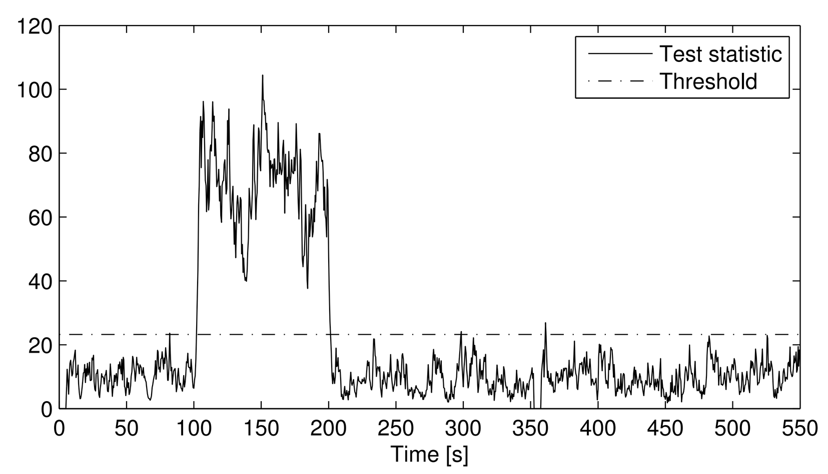
With IMU

Below, the test statistics $\mathcal{T}$ for RAIM and window based RAIM are shown. Some properties that can be noted are:

- Window based RAIM has a higher gain to the fault than the regular RAIM algorithm. This *increases the probability* of detection.
- The threshold is here selected to give a prob of false alarm of 0.01.
- A fault is simulated in the interval 100 to 200 s.
- A window length of 10 samples (5 seconds) is used.



RAIM



Window-based RAIM with IMU

References

[1] D. Törnqvist, A. Helmersson, and F. Gustafsson, "Window based GPS integrity test using tight GPS/IMU integration applied to a sounding rocket," in *Proceedings of IEEE Aerospace Conference*, Big Sky, Montana, USA, 2010.