Tuning and calibration of foot-mounted ZUPT aided INS

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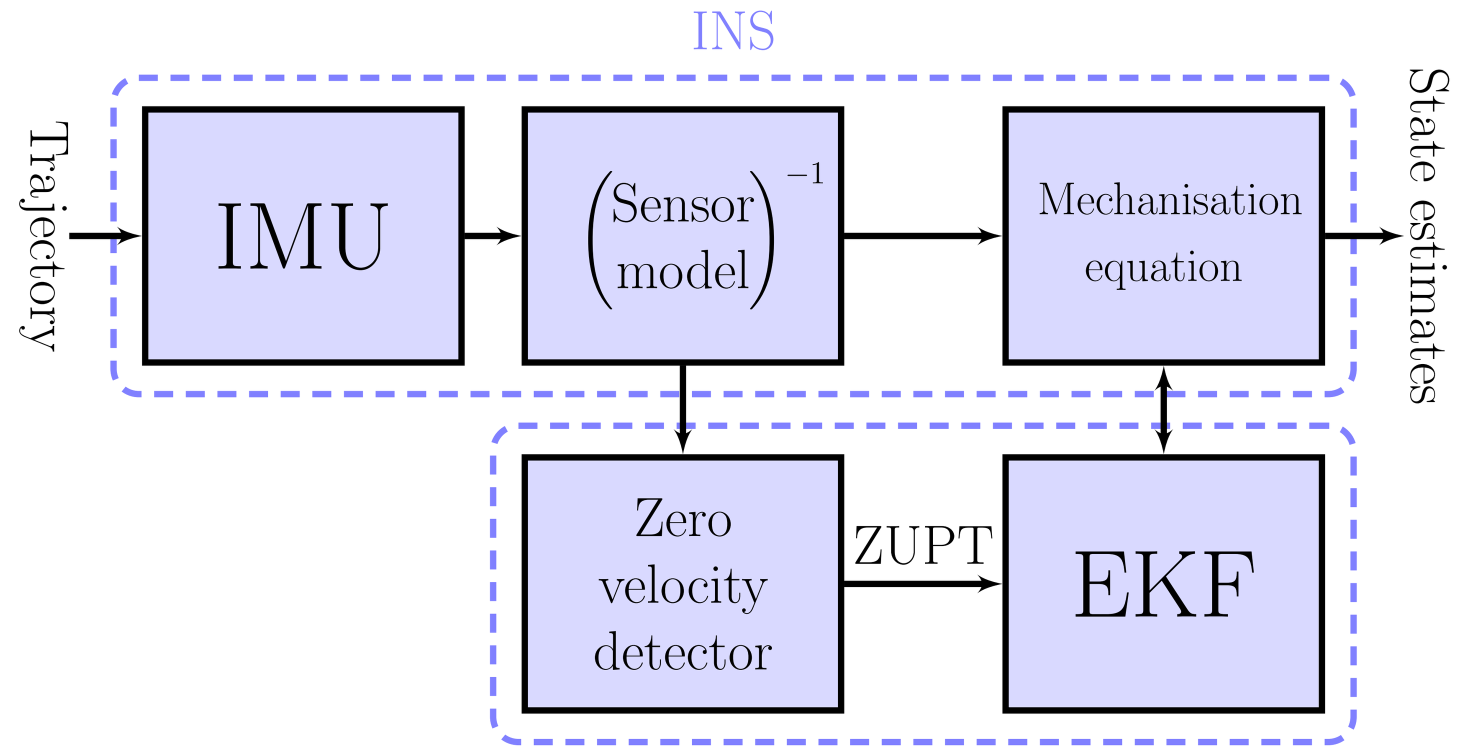
1 Premises and goals

The underlying model of the foot-mounted zero-velocity update (ZUPT) aided inertial navigation system (INS) are the inertial measurement unit (IMU) *sensor model*, the INS *kinematic equations/mechanization equations*, and the *dynamic model* (zero-velocity). These models together with the *filter* including the *detector*, the *hardware set-up*, and the *true trajectory* contain and constitute the design choices and parameters affecting the performance of the system. Based on this division a low-complexity subset of the design choices has been studied, the system has been tuned, and calibrated. The goal of the work is to understand the behavior of the system and establish a performance base-line for a simple system set-up for constrained environmental conditions.

2 Filter design choices

The filter of the study has been limited to complimentary filter structure featuring an extended Kalman filter (EKF). The INS mechanisation equations are fixed to tangent plane first order mechanisation equations with suchlike error model. The deterministic part of the dynamic model are fixed from the problem formulation (zero-velocity). From consideration of the dynamics of the system, aim at low-complexity, and initial tuning attempts, a simple sensor output model of the true value plus a white noise was chosen. Based on analysis and testing the SHOE detector was found the most suitable. The full system structure is seen below.

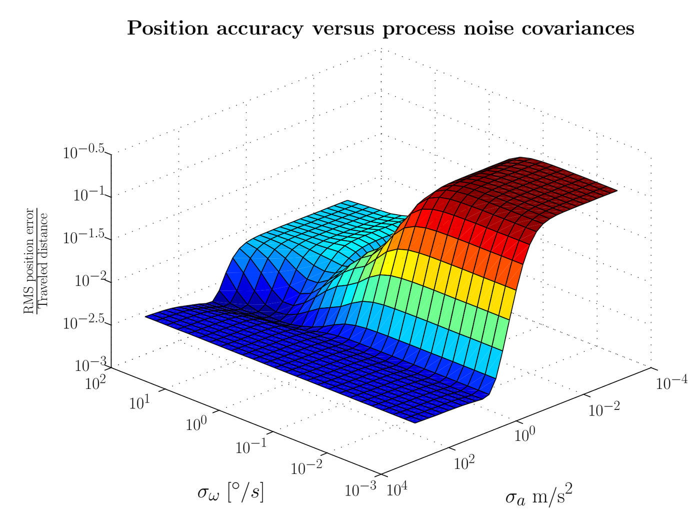


3 Hardware design choices

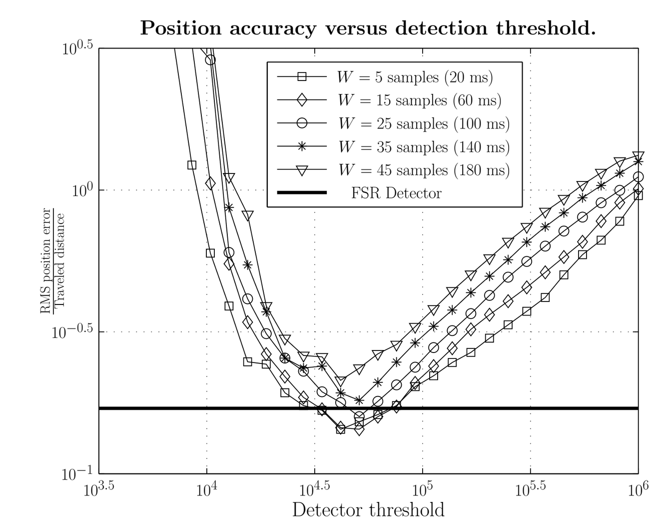
The hardware set-up design choices are essentially the IMU-placement and the IMU-specifications. The IMU was placed below the instep. Based on initial measurements the necessary dynamic range of the IMU was estimated to be approx. 14g and 900°/s. The IMU used was a 3DM-GX2® from MicroStrain® with 18g and 1200°/s dynamic range. The IMU was sampled with 250Hz.
To facilitate the tuning of the filter parameters an independent zero-velocity reference system based on force sensitive resistors (FSR) was constructed.

4 Filter tuning

The filter parameters are essentially the accelerometer and gyro process noise covariance, the zero-velocity measurement noise covariance, and detector window length and threshold. For the process and observation noise tuning, the FSR detector was used. For the detector tuning, noise values found from the process and measurement noise tuning were used.
Order of magnitude 100 measurement sets were used for the tuning. The position accuracy was 0.10-0.40% of the traveled distance depending on measurement conditions. Examples of closed-loop root-mean-square (RMS) position accuracy for certain test conditions are seen below.



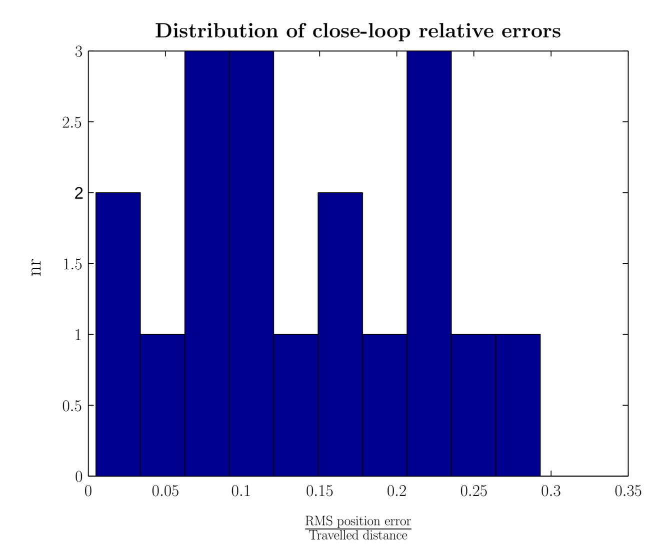
Position accuracy with $\sigma_{zero} = 0.01m/s^2$. *The red and blue flat areas can be identified as free inertial navigation and hard zero-velocity update respectively.*



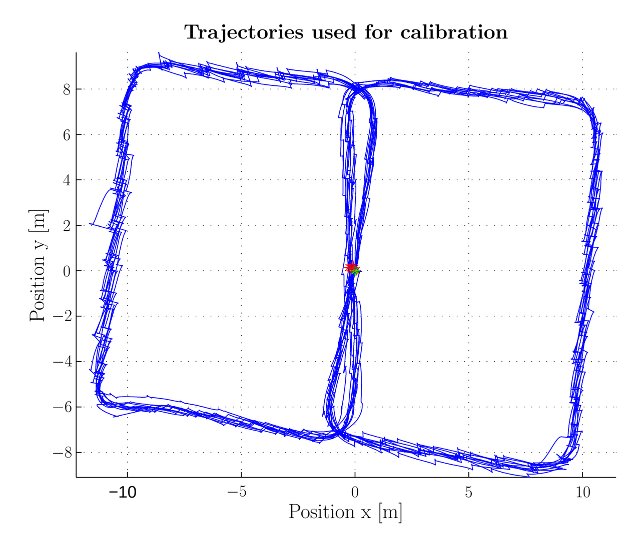
Results for the SHOE detector at 5km/h walk. The detector marginally out-performs the external FSR detector. A short window length is desirable.

5 Calibration

Calibration of the system with indoor symmetric trajectories gave a horizontal RMS error of approx. 0.15% of the traveled distance. This was in good agreement with expected accuracy from tuning procedure. The distribution of the errors and the trajectories are indicated in the figures below.



Distribution of magnitude of closed-loop error relative to the traveled distance in percent. Total number of trajectories was 20 of approx. 100m length. The walking speed was approx. 5km/h.



Plot of some of the calibration trajectories. The environmental conditions (indoor) and pathes of the calibration trajectories were similar to those of the tuning trajectories.

6 Conclusion

Foot-mounted ZUPT aided INS with a simple sensor model and filter structure can give a RMS accuracy of approx. 0.10-0.40% of the traveled distance depending on experimental conditions. This gives a baseline for more complicated filtering which should perform better in some sense to be justified. For example it is questionable if bias-only modelation of the sensors is justified.