Autonomous Calibration of Sensor Arrays under Arbitrary Motion

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WASP | WALLENBERG AUTONOMOUS SYSTEMS PROGRAM

Positioning of Autonomous Systems

- **Availability:** the system needs to position itself in all types of weather, many types of environments, anywhere, anytime, etc.
- **Reliability:** a correct estimation of the position uncertainty is also needed for reliable decision making.
- **Scalability:** the positioning solution needs to be scaled to multiple agents yielding requirements on computational effort and capacity of communication.

Introduction

- **Reduced cost of sensors:** the smart-phone technology advancement has yielded cheap sensors, and in particular accelerometers and gyroscopes. Usually, they do not have very good performance.
- **Sensor fusion:** To overcome inadequate performance of each sensor, we place multiple Inertial Measurement Units (IMU) on a single chip to enhance the estimation using sensor fusion.
- **Calibration:** Manufacturing tolerances impose uncertainty on static parameters, such as the position of accelerometer transducers. This error will impair the accuracy of the estimate.

Device - Multiple IMUs

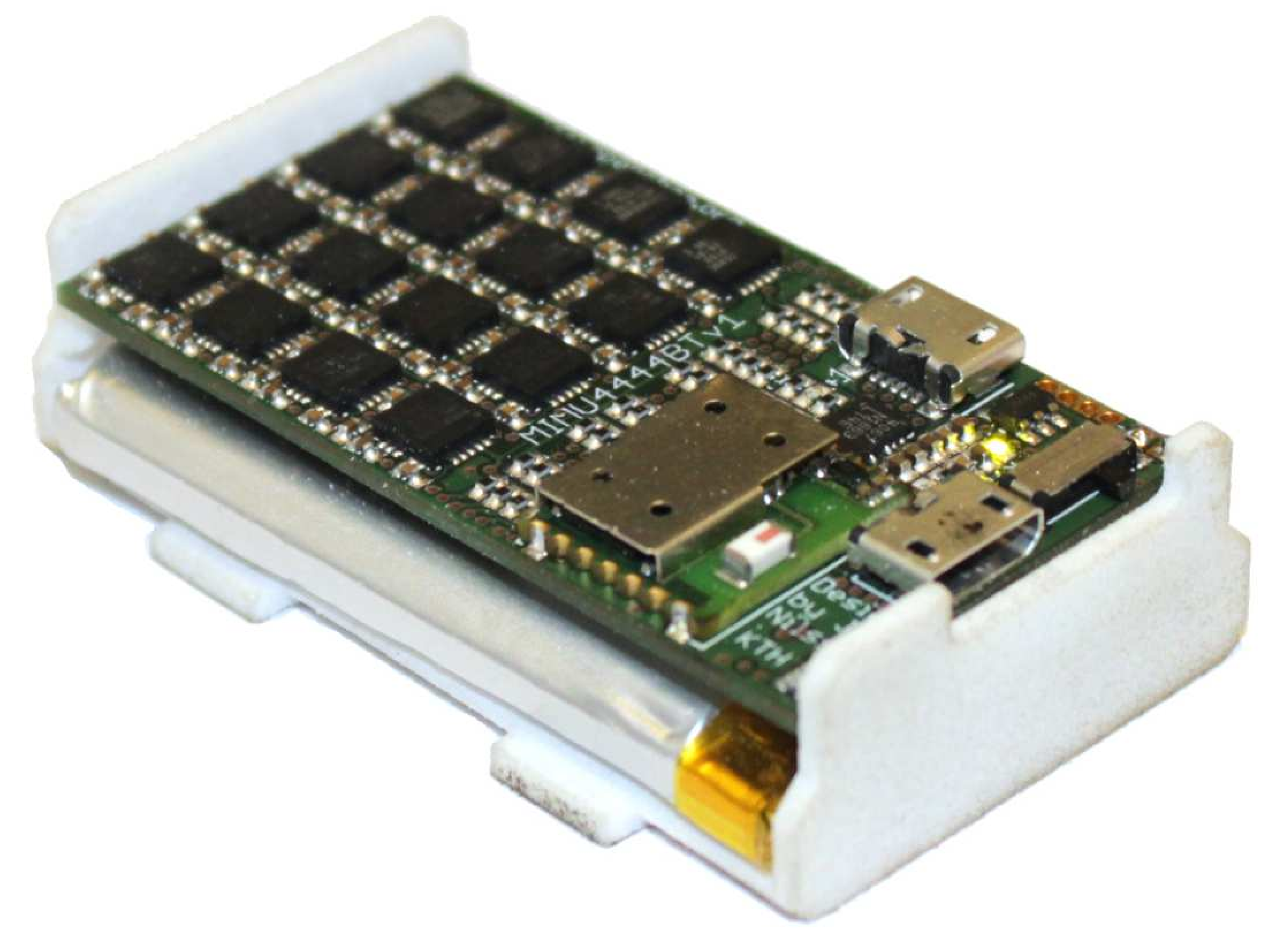

Figure 1: An in-house designed embedded system with an inertial sensor array. The array consists of 32 MPU9150 Invensense inertial sensor chipsets, each containing an accelerometer triad, a gyroscope triad, and a magnetometer triad. The device measures 53 mm x 33 mm.

Prior Work

- A MLE method was established to estimate the specific acceleration s, angular velocity ω and angular acceleration $\dot{\omega}$ of the board, given the positions of the accelerometers r_k and acceleration measurements $y_k(i)$ using

$$y_k(i) = s(i) + \omega(i) \times \omega(i) \times r_k + \dot{\omega}(i) \times r_k + \epsilon_k(i), \quad (1)$$

for accelerometer triad k and time-step i.

- As seen in Figure 2, with perfect knowledge of the positions r_k, the error in estimating angular velocity ω decreases with higher dynamics. However, with noisy positions the error grows instead.

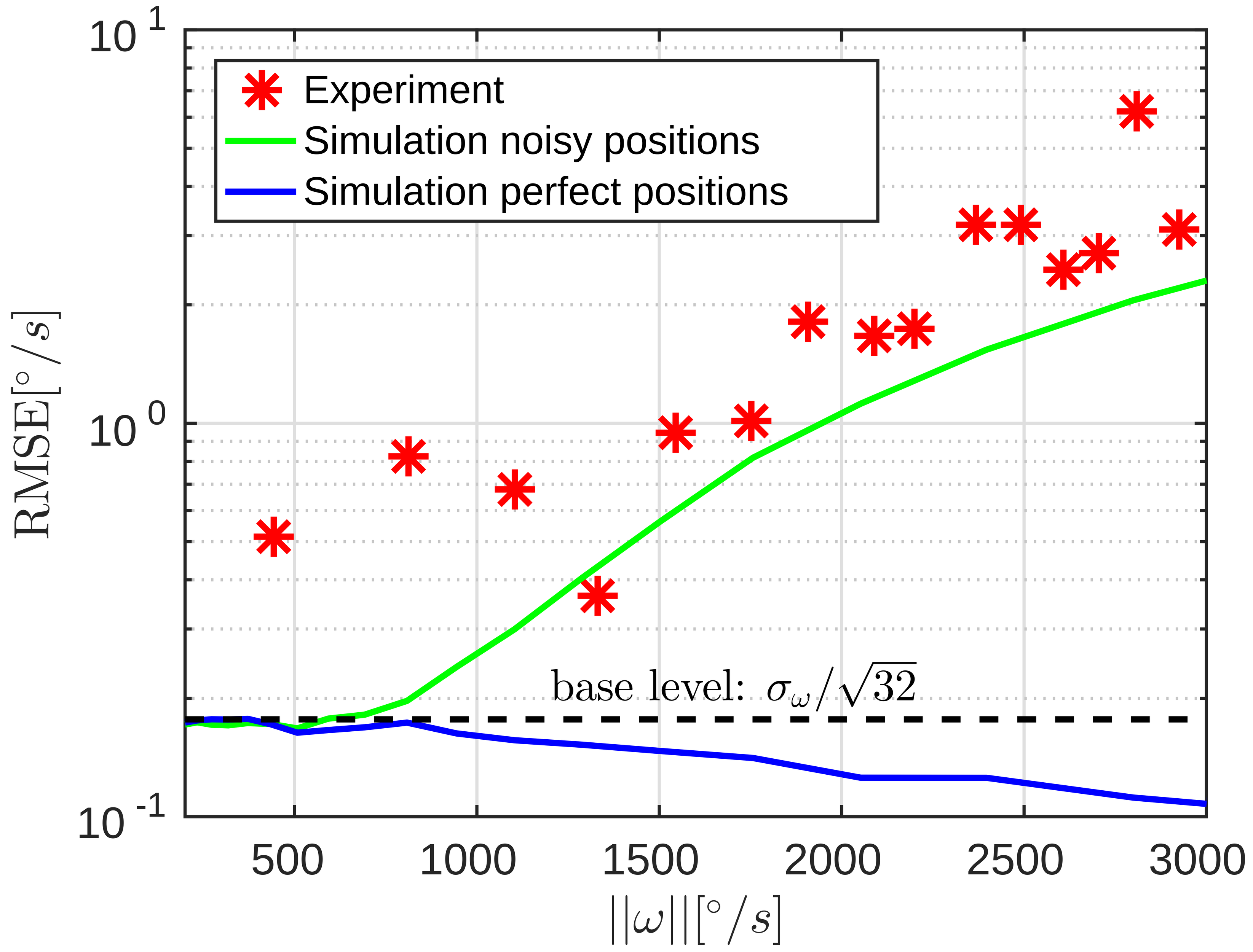

Figure 2: RMSE of experimental measurements, simulations with imperfect positions, and simulations with perfect positions. σ_ω is the standard deviation of a single gyroscope.

Self-calibration - Arbitrary motion

1. Estimate specific force, angular velocity, and angular acceleration with the MLE estimator, given an initial guess of the positions.
2. Use the estimated values to re-estimate the relative positions of the accelerometers using the least sqaure formulation of Equation 1.
3. Then repeat step 1 with the new estimate of the positions, until satisfaction. Results in an alternating optimization scheme, without the need to compute derivatives.

Results and discussion

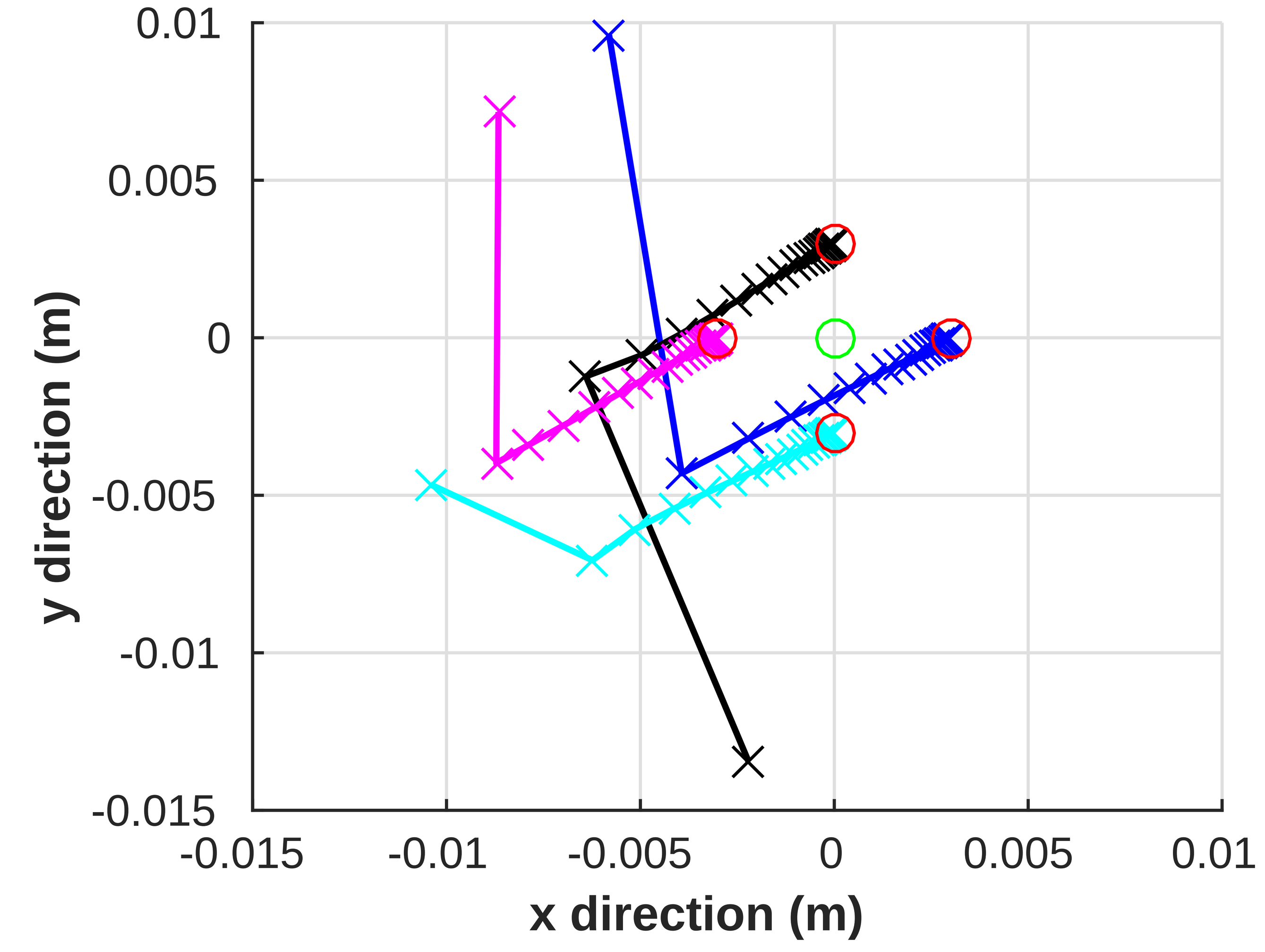

Figure 3: Convergence of the positions of 5 accelerometers in the xy-plane, the green circle is the reference accelerometer, and the red circles are the true positions.

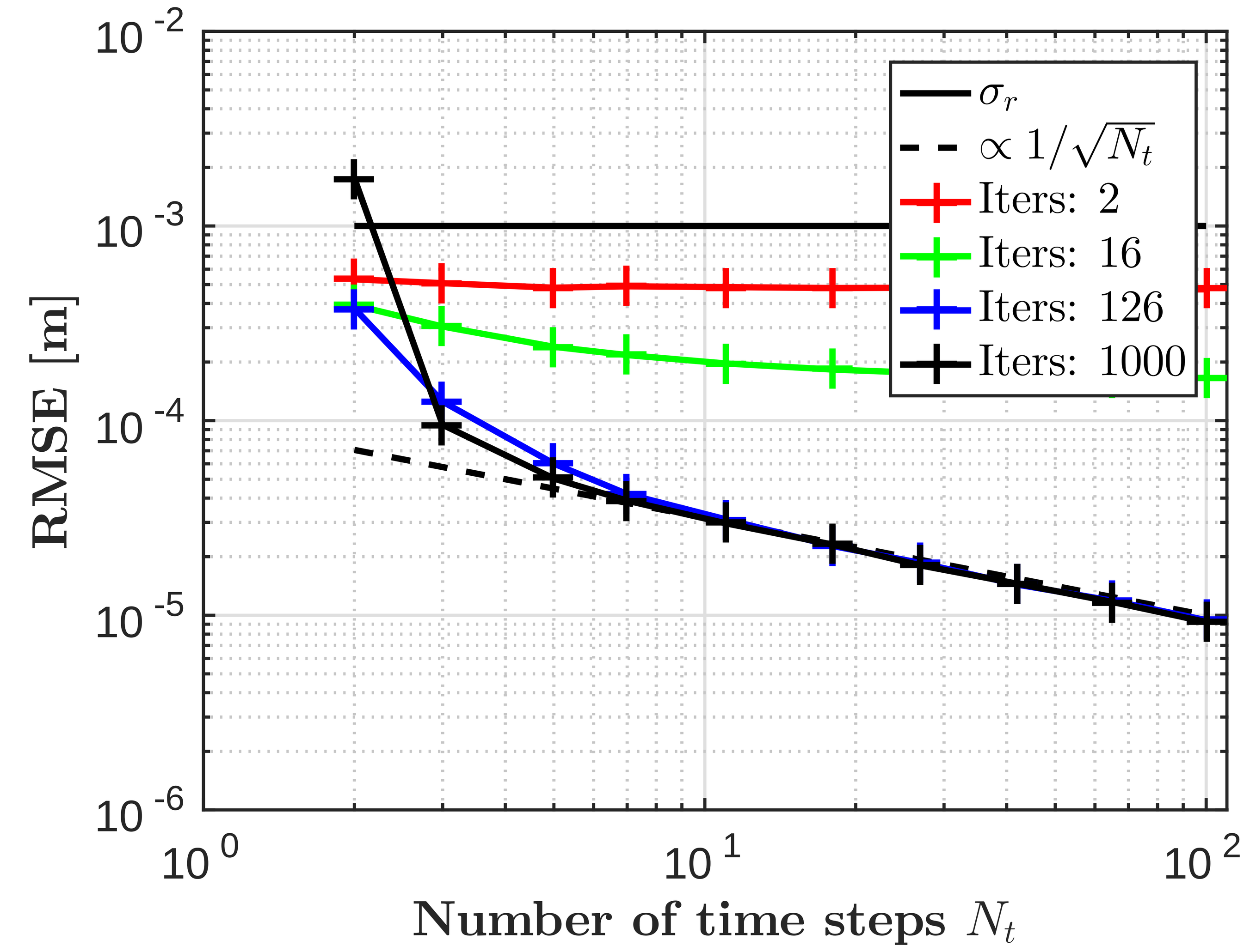

Figure 4: Monte Carlo Simulations for the error of positions for different amount of iterations in the alternating optimization scheme. More recorded time-steps yields better accuracy of the estimated r_k. σ_r is the standard deviation of the positions r_k.

- Question remain if the calibration method will converge for every initial guess of the positions.
- How good can a calibration method perform for this problem, i.e. what is the lower bound of the estimation error?