Master Degree Project in Signal Processing: Experimental Performance Assessment of an Inertial Sensor Array

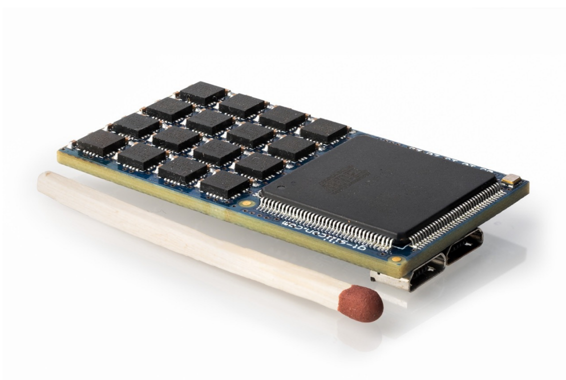

Fig. 1. In-house developed inertial sensor array with 288 sensing elements. The array is built out of 32 InvenSense MPU9150 sensor chips.

I. Background

Today, miniaturized inertial sensors, accelerometers and gyroscopes, can be produced at unprecedented volumes and at low prices. Unfortunately, the performance of these ultra-low-cost sensors is too poor to enable reliable localization in many applications, such as human motion analysis, indoor navigation and robotics. However, by exploiting the small size, low price, and low power consumption of the sensors, it is feasible to construct arrays with hundreds of sensing elements and fuse their measurements to create "super sensors" with high performance-to-price ratios [1], see Figure 1. An observation model to fuse the measurements of redundant accelerometers is

$$\boldsymbol{a} = \boldsymbol{s} + \boldsymbol{\omega} \times (\boldsymbol{\omega} \times \boldsymbol{r}) + \dot{\boldsymbol{\omega}} \times \boldsymbol{r} \tag{1}$$

where $\boldsymbol{a}$ is the measured acceleration. Further $\boldsymbol{s}$, $\boldsymbol{\omega}$, $\dot{\boldsymbol{\omega}}$, $\boldsymbol{r}$ denote the translational acceleration, angular velocity, angular acceleration and the relative position of the sensing element, respectively. Inertial navigation consists of estimating these quantities.

A requirement for these "super sensors" to achieve the theoretical performance, is that the spatial geometry of the accelerometers is known with high accuracy, in the order of micrometers. Thus, an accuracy is needed that can exceed the manufacturing tolerances of the accelerometers.

We have developed an algorithm to calibrate these uncertainties that does not require any external equipment, it is sufficient with arbitrary motion. Although the theoretical performance of this calibration algorithm have been assessed, experimental verification is still needed.

II. Aim of this work

The work consists of designing an experiment to create and measure a reference angular velocity for an inertial sensor array, for assessment of the developed calibration algorithm. Thus, the error of the estimated angular velocity using the experiment should be much smaller than the estimation error using the sensor fusion algorithm. The optimal performance of the sensor fusion algorithm is described in [1].

Included in this work is to:

- design and setup an experimental rig,
- conduct experiments and collect data,
- create an observation model for the setup,
- propose an estimator for the model,
- evaluate the accuracy of the estimator.

A suggestion for the experiment is to attach the sensor array to a bicycle wheel, and spin the wheel with a constant angular velocity. Thus, instead of using a model for the general motion (1), a model for the measured acceleration, which is now constrained, could be

$$\boldsymbol{a}(t) = \boldsymbol{g} \sin(\omega t + \varphi),$$

where $\boldsymbol{g}$ is the gravity, ω is the angular frequency, t is the time and φ is the phase. With multiple sequential measurements of $\boldsymbol{a}$, one can use the Fourier transform to estimate the angular frequency.

III. Application Information

The student should preferably have taken courses related to: digital signal processing, measurement technology, estimation theory, mechanics (inertial frames, rotations). Additionally, the student should be comfortable in building technical systems.

To apply for this master thesis position, please send your CV and transcripts to:

- Håkan Carlsson (hakcar@kth.se), supervisor.
- Joakim Jaldén (jalden@kth.se), examiner.

References

[1] I. Skog, J.-O. Nilsson, P. Händel, and A. Nehorai. Inertial Sensor Arrays, Maximum Likelihood, and Cramér-Rao Bound. *IEEE Transactions on Signal Processing*, 64(16):4218–4227, Aug 2016.