Estimation of 3D Orientation From Inertial Sensors With Different/Nonuniform Sampling

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ABSTRACT

The ability to estimate the orientation (attitude) of an autonomous vehicle (*e.g.* Unmanned Aerial Vehicle (UAV)) from on-board sensors is important for its operation. As such, the attitude estimation problem has attracted the attention of many researchers and industrials for several decades. The attitude information is usually reconstructed using a set of body-frame measurements of known inertial vectors. In this work, the attitude estimation problem is considered under the assumption that the sensors measurements have (possibly) different bandwidths and are subject to packet dropouts.

BACKGROUND

The **attitude (orientation)** of a vehicle in 3D space is represented by a rotation matrix $\boldsymbol{R(t)}$; element of the Special Orthogonal group SO(3). The attitude matrix $\boldsymbol{R(t)}$ evolves according the following mathematical model:

$$\dot{\boldsymbol{R}}(\boldsymbol{t}) = \boldsymbol{R}(\boldsymbol{t})[\boldsymbol{\omega}(\boldsymbol{t})]\times$$

where $\boldsymbol{\omega}(\boldsymbol{t})$ represents the body-frame angular velocity vector and $[\cdot]_\times$ is the skew symmetric matrix map. The available low-cost sensors on-board of the vehicle are:

- **Gyroscope:** provides continuous measurements of $\omega(t)$
- **Body-frame vector** measurements $b_i = R^\top a_i$ arriving at some intermittent instants of times t_k^i. The instants of times where measurements are available can be different and nonuniform. These measurements can be obtained from low-cost IMU sensors, camera landmark measurements or GPS receivers.

OBJECTIVES

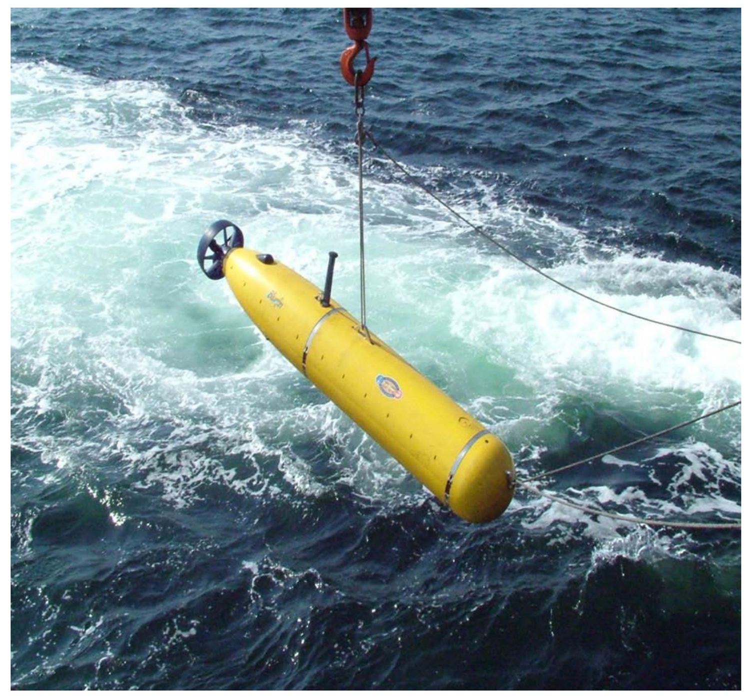
- Fuse all the available sensor measurements to **estimate the attitude** of an accelerated vehicle.
- Design a **proven globally convergent** attitude estimation algorithm
- Test the designed estimation algorithm using **realistic simulations**
- Obtain experimental results when implementing the estimator on-board of a **quadrotor UAV**

METHODS

- We propose a measurement-triggered estimation scheme. The angular velocity measurements (gyroscope readings) are used to continuously predict the attitude which is corrected, via an instantaneous jump mechanism, upon the arrival of new measurements. The estimation scheme is written as follows:

$$\begin{cases} \dot{\hat{R}}(t) = \hat{R}[\omega(t)]_\times & t \neq t_k^i \\ \hat{R}(t^+) = \boldsymbol{R}(\sigma_i(t))\hat{R}(t) & t = t_k^i \\ \sigma_i(t) = \rho_i[\hat{R}b_i]_\times a_i & \end{cases}$$

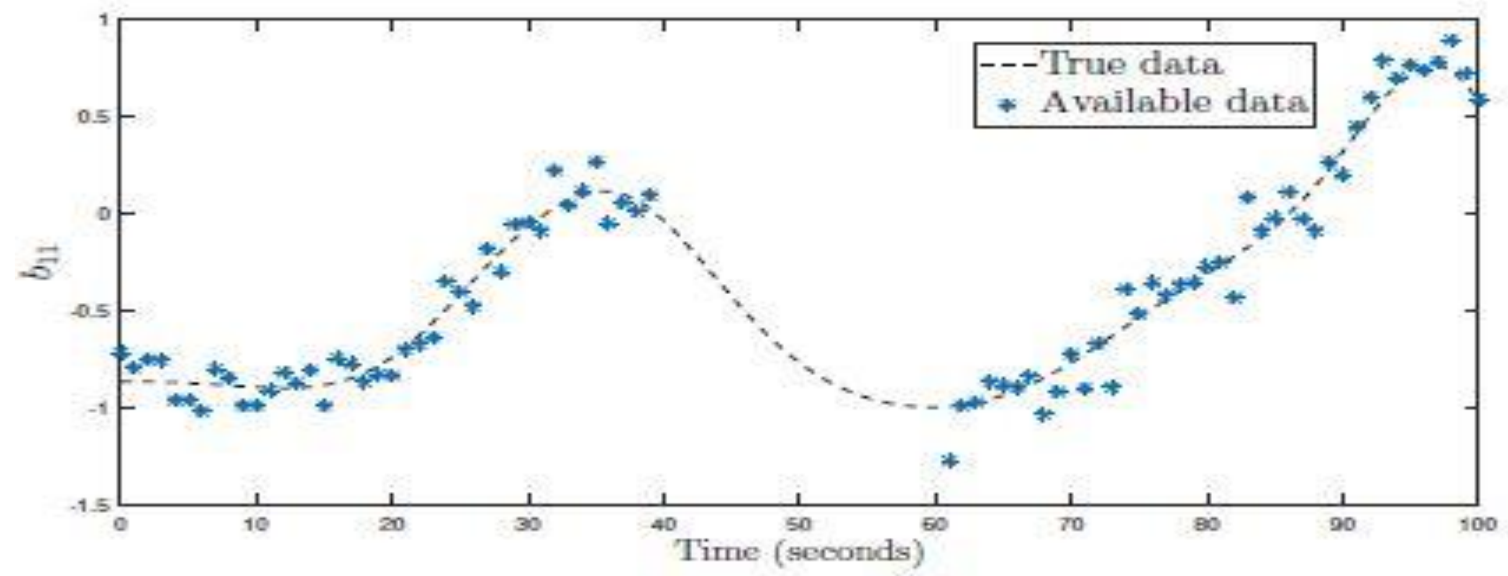
- Where $\boldsymbol{R}(\cdot)$ is a given rotation map and $0 < \rho_i < 1$ are tuning parameters.
- The above estimator can be improved by adding N additional observer states which will be averaged to obtain a better filtering.
- Virtual timers are introduced to capture the constraints on the sensors transmission times which results in a hybrid dynamical model that allows to state the convergence of the estimator.



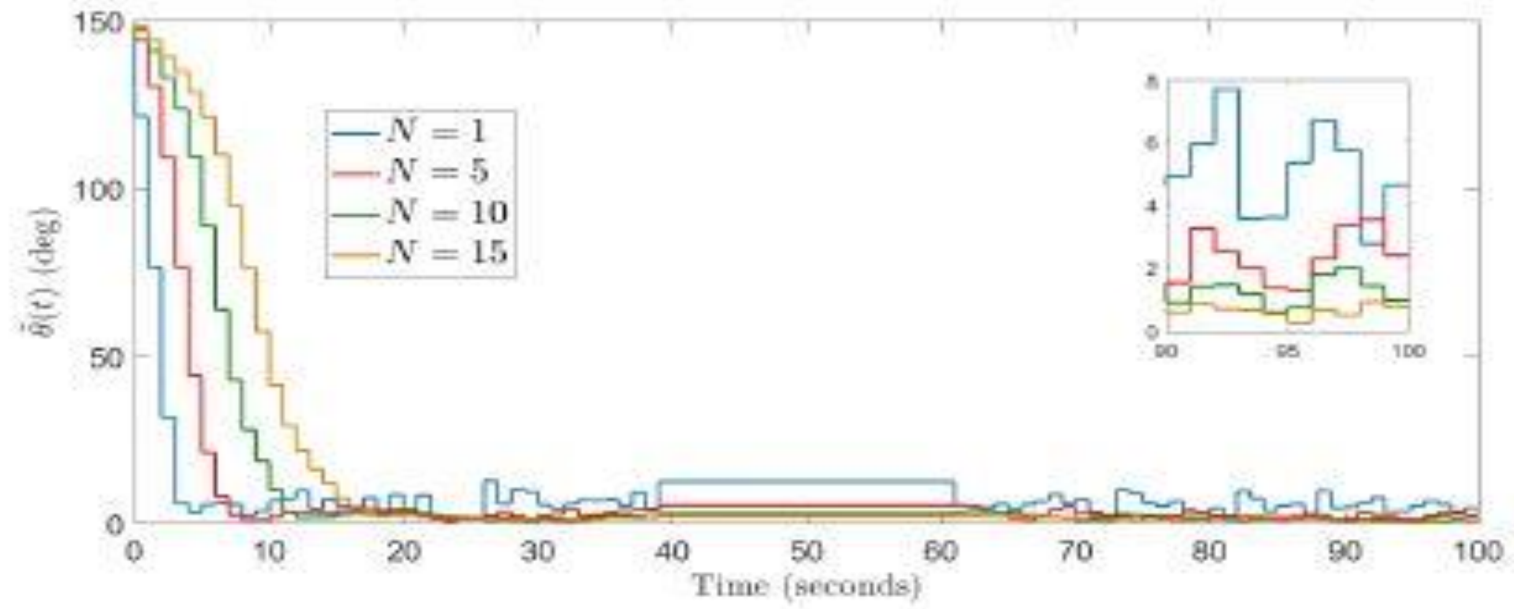
- Robotic vehicles with an attitude estimation control unit.

- **Amazon Air Prime** quadcopter for 30-minutes package delivery missions.

SIMULATION RESULTS



- Available information for the x-axis component of b_1



- Time evolution of the attitude estimation error (angle of rotation)

CONCLUSIONS & PERSPECTIVES

- We dealt with the problem of attitude estimation using **intermittent sensors measurements** which takes into account some practical constraints related to the sensors bandwidth and packets loss.
- The structure of the proposed observer as well as the parameters are adequately designed to guarantee the convergence of the attitude estimates to the true attitude values.
- The proposed attitude estimation algorithms will not only benefit the area of aerial vehicles engineering but also the robotics and biomedical engineering community in large.