GPS-aided Global Attitude Estimation Using IMU Measurements

Soulaimane Berkane and Abdelhamid Tayebi

ABSTRACT

The attitude estimation is an important problem that has received a broad interest in many applications such as unmanned aerial vehicles (UAV), autonomous underwater vehicles (AUV) and micro satellite systems. We present a hybrid nonlinear attitude observer that is aided by earth-fixed linear velocity measurements. The observer is implemented by fusing measurements from a low-cost inertial measurement unit (IMU) and a global positioning system (GPS). The proposed estimator allows to obtain attitude estimates directly on the Special Orthogonal group SO(3) while estimating the gyro bias and the unknown apparent acceleration of the vehicle. We prove global exponential stability of the estimation errors.

BACKGROUND

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

(Translational model) $\dot{\boldsymbol{v}}(\boldsymbol{t}) = \boldsymbol{g}\boldsymbol{e}_3 + \boldsymbol{R}(\boldsymbol{t})\boldsymbol{b}_{\boldsymbol{a}}(\boldsymbol{t})$

(Rotational 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, $\boldsymbol{v}(\boldsymbol{t})$ is the linear velocity of the vehicle and $\mathbf{b}_{\mathbf{a}}(\boldsymbol{t})$ is the body-frame acceleration and $\boldsymbol{g}$ is the gravity.

The available low-cost sensors on-board of the vehicle are:

- GPS velocity receiver
- Accelerometer
- Gyroscope
- Magnetometer

OBJECTIVES

- Fuse low-cost IMU sensors with a GPS receiver to **estimate the attitude** of an accelerated vehicle.
- Design a proven globally convergent and stable 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

- Use hybrid techniques to achieve better domain of asymptotic stability. By evaluating a certain measurable cost, the estimation state is **reset** to a value that **gives less** estimation error.

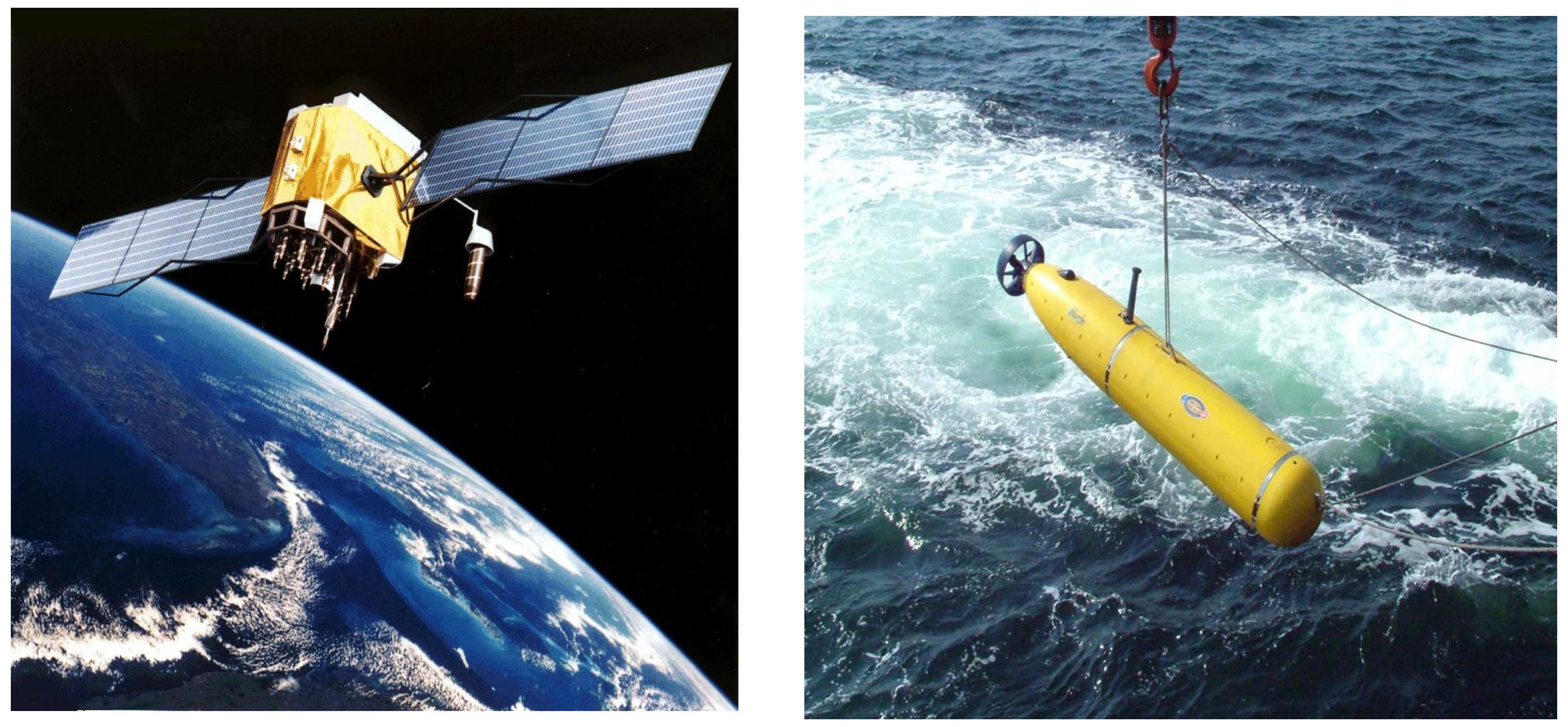
$$\begin{cases} \dot{\hat{v}} = ge_3 + \hat{R}b_a + k_v\sigma_v, \\ \dot{\hat{R}} = \hat{R}[\omega_y - \hat{b}_\omega + k_R\sigma_R]_\times, & (\hat{v}, \hat{R}, \hat{b}_\omega) \in \mathcal{F}, \\ \dot{\hat{b}}_\omega = \mathrm{Proj}(\hat{b}_\omega, -k_b\sigma_R), \end{cases}$$

$$\begin{cases} \hat{v}^+ = \hat{v}, \\ \hat{R}^+ = \mathcal{R}_a(\pi, u)\hat{R}, & (\hat{v}, \hat{R}, \hat{b}_\omega) \in \mathcal{J}, \\ \hat{b}_\omega^+ = \hat{b}_\omega, \end{cases}$$

$$\mathcal{F} = \{(\hat{v}, \hat{R}, \hat{b}_\omega) :\ \Phi(\hat{v}, \hat{R}) \leq \delta\}$$

$$\mathcal{J} = \{(\hat{v}, \hat{R}, \hat{b}_\omega) :\ \Phi(\hat{v}, \hat{R}) \geq \delta\}$$

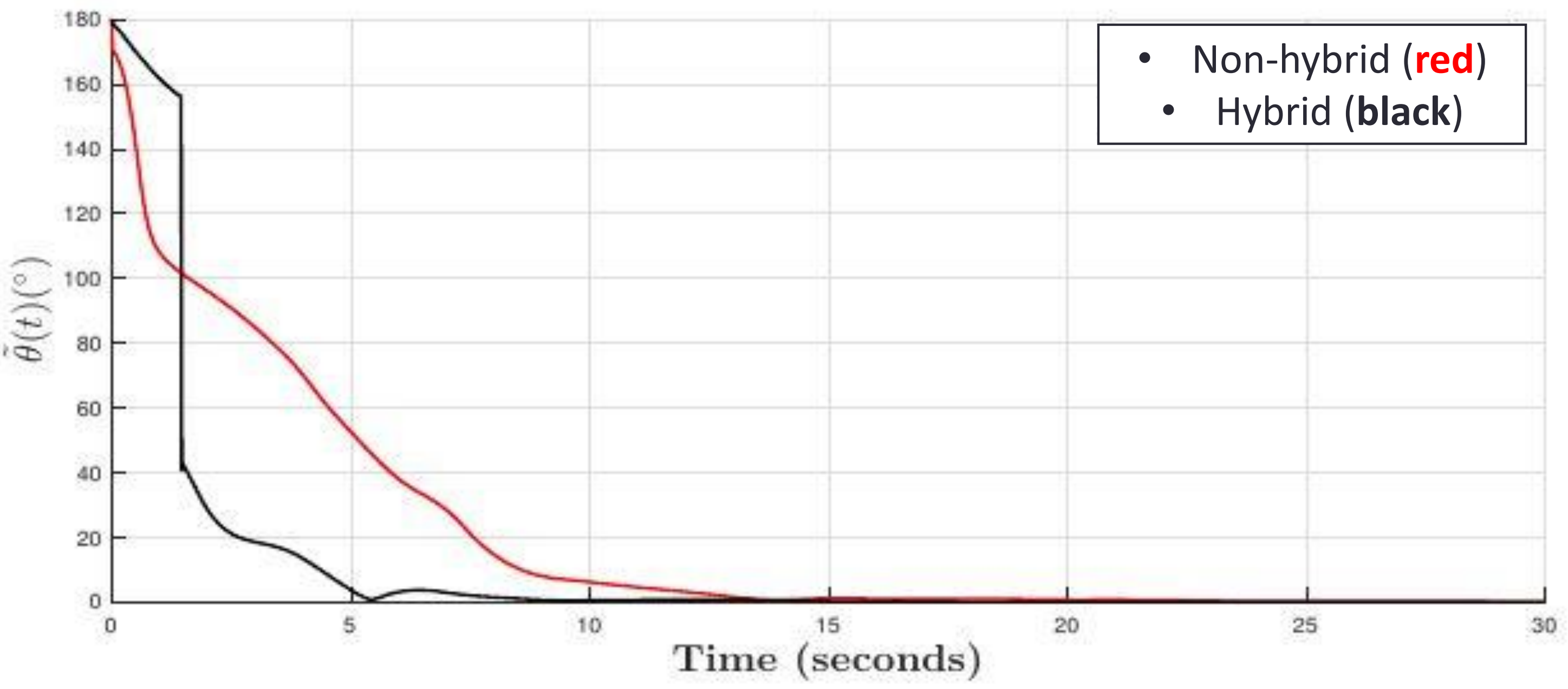
where k_v, k_R, k_b are constant gains, σ_R, σ_v are correction terms and Φ is a cost function.



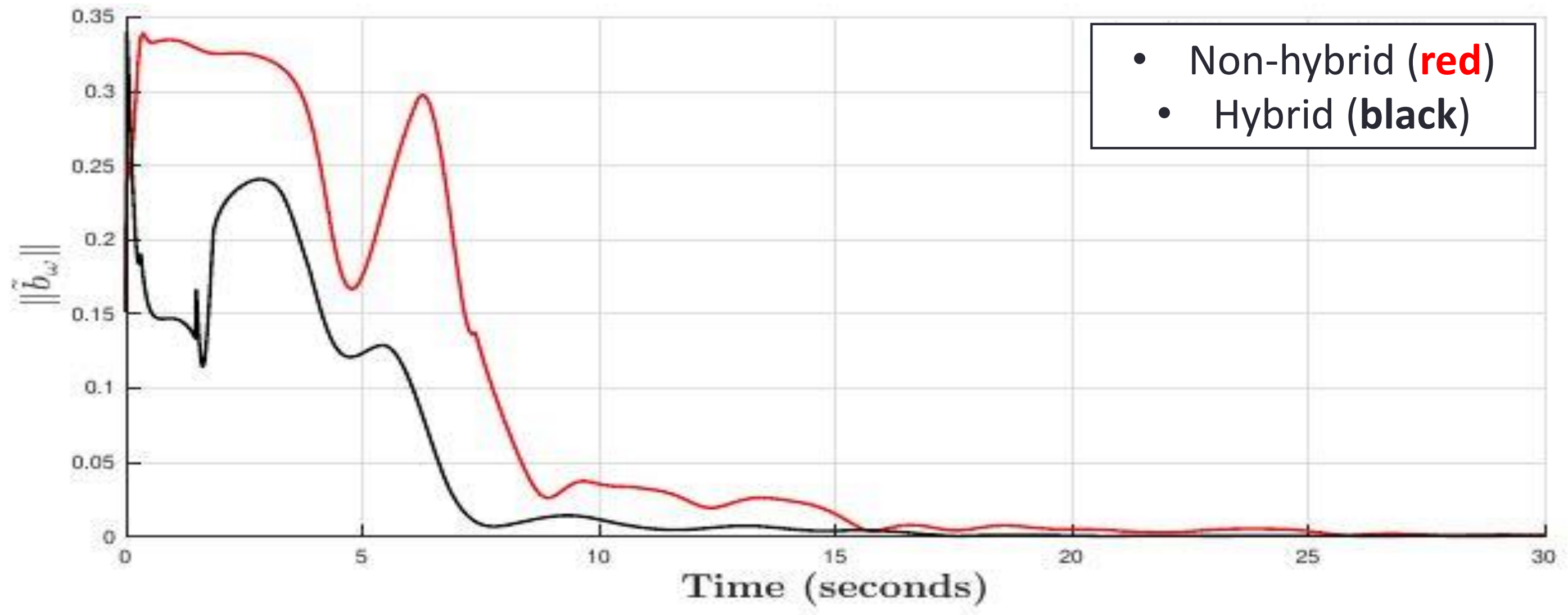
- Robotic vehicles with an attitude estimation control unit.

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

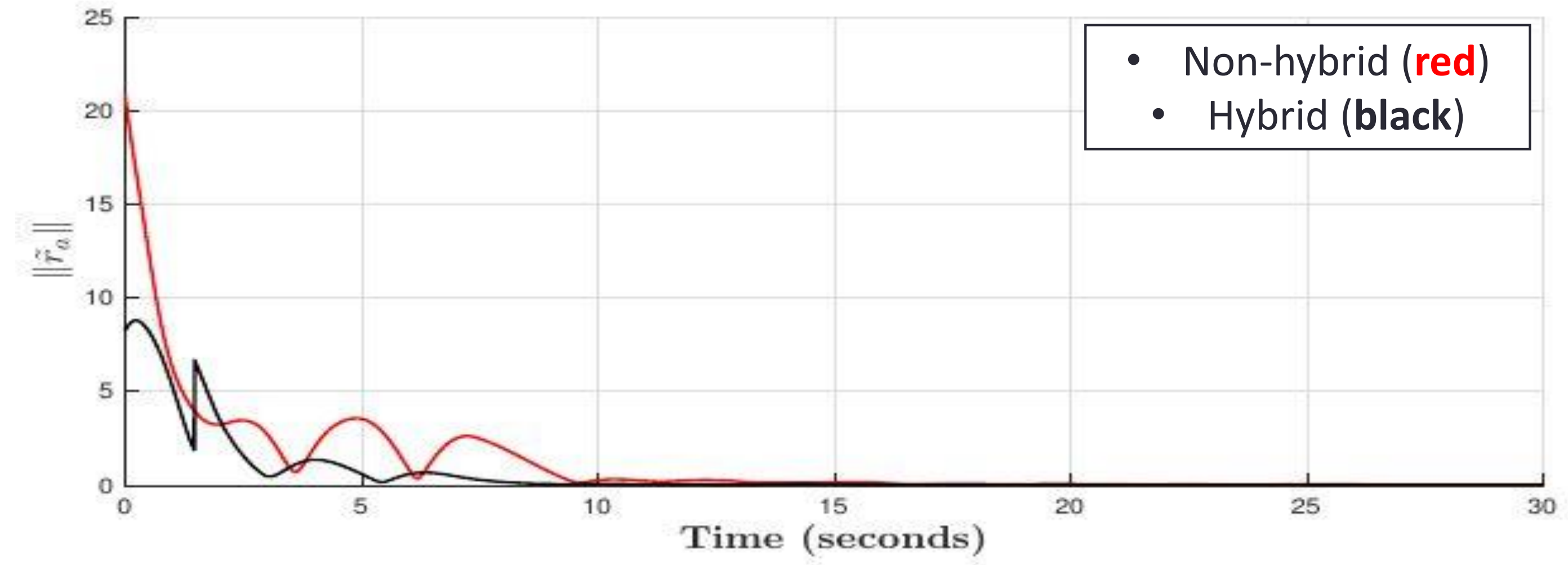
RESULTS



- Attitude error angle (in degrees): non-hybrid observer (red) and hybrid observer (black).



- Bias estimation error.



- Apparent acceleration error.

CONCLUSIONS & PERSPECTIVES

- Hybrid techniques are used to design attitude estimation algorithms that can be **easily tuned and implemented** on-board of most aerial and underwater autonomous vehicles such as UAVs and AUVs.
- Our proposed techniques use **less sensors** and **fewer** available data.
- Our novel methods may pave the way to **lower the cost** of quadcopter UAVs and **reduce their size** .
- Future work will be devoted to deal with the problem of different sensors' frequencies (IMU sensors at 100 Hz and the GPS receiver at 5Hz).