

INERTIAL MEASUREMENT UNIT CALIBRATION AND ORIENTATION TRACKING



Presented to
MEEN 689 Robotic Perception
Spring Semester, 2020

Zihui Lang, Bin Wu, Yinsu Zhang & Zilong Zhang
Department of Mechanical Engineering
Texas A&M University
College Station, Texas

Outline

Introduction

- Motivations
- Objective
- Related work

Methods

- IMU Calibration (LSM6DSM, iPhone 7)
- Orientation Tracking
 - Extended Kalman filtering
 - High & low pass filtering
 - Mahony filter

Experiment Result

Conclusion and Further Work

Reference

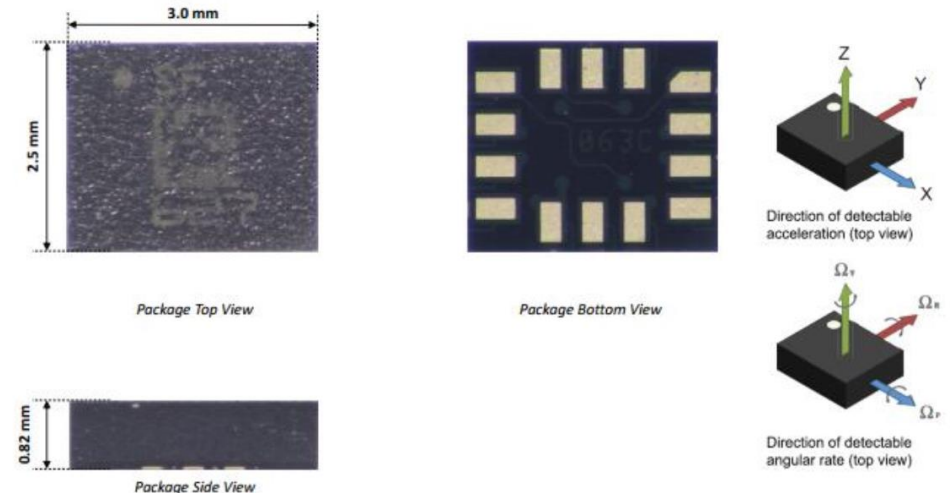
Introduction

Motivation

- Orientation tracking is one of most fundamental problems for many problem like navigation and mapping
- IMU is the most popular solution for the attitude estimation

Objectives

- Explore the calibration process without external equipment
- Compare three basic sensor fusion algorithm



LSM6DSM (Credit: http://www.mems.me/mems/device_analysis_201612/3801.html)

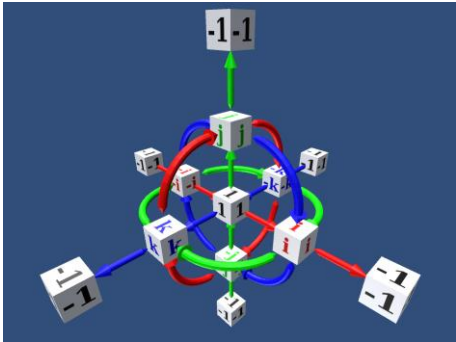
Introduction

Related work

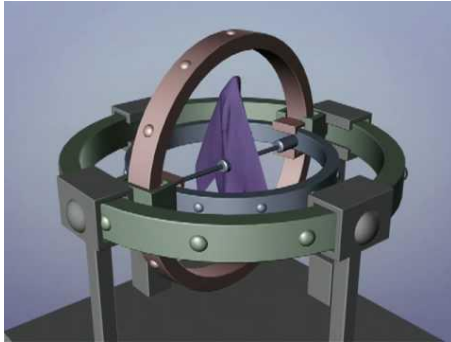
Rotation representation

Quaternion

- Less computational overhead
- No gimbal lock



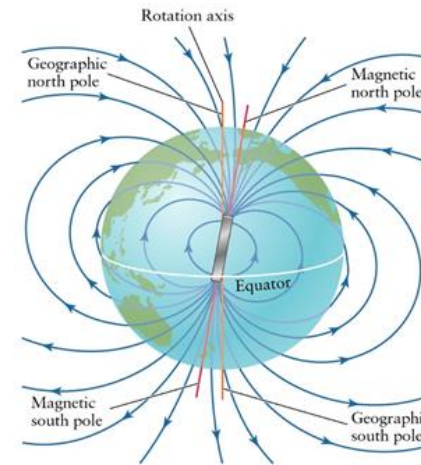
Credit:
https://www.reddit.com/r/math/comments/42yc0i/visualizing_quaternions/



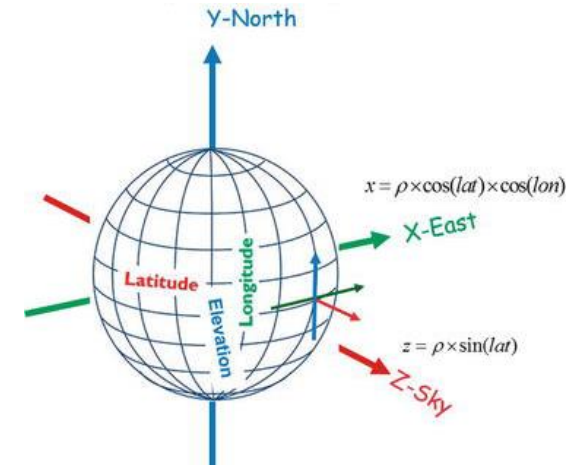
Credit:
<https://www.youtube.com/watch?v=zc8b2Jo7mno>

Magnetometer

Vm: Calibration for north direction



Credit: <https://www.uavnavigation.com/support/kb/general/general-system-info/introduction-magnetometers>

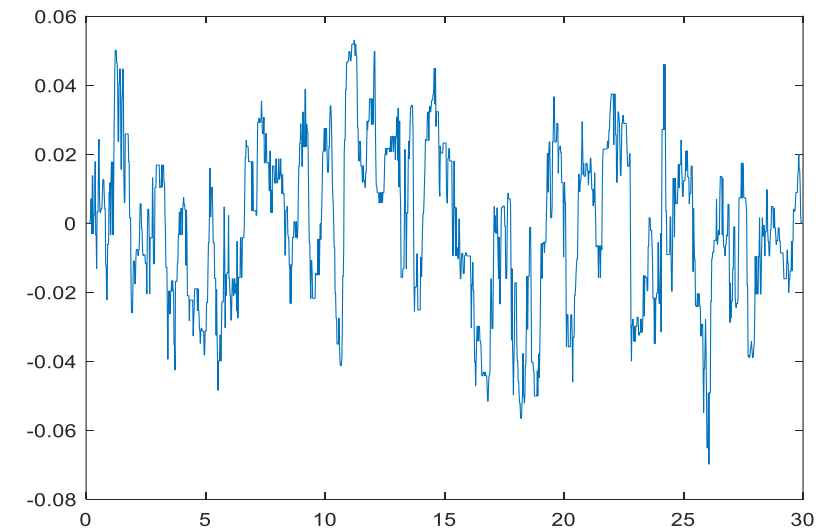
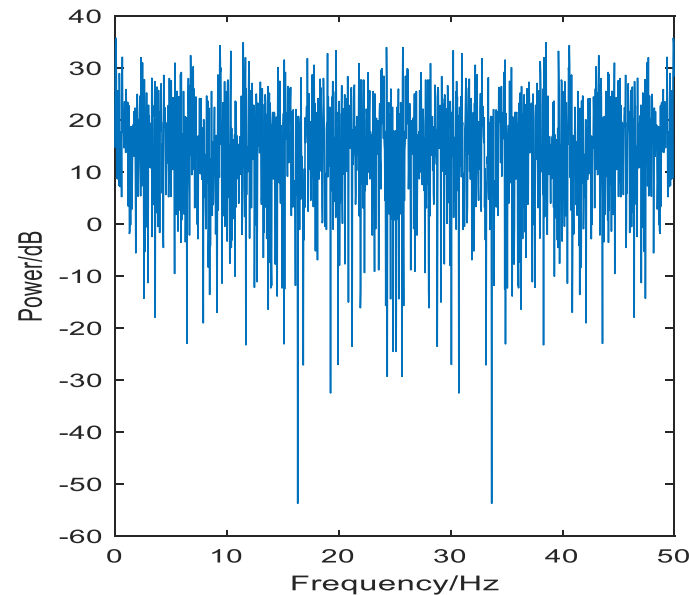
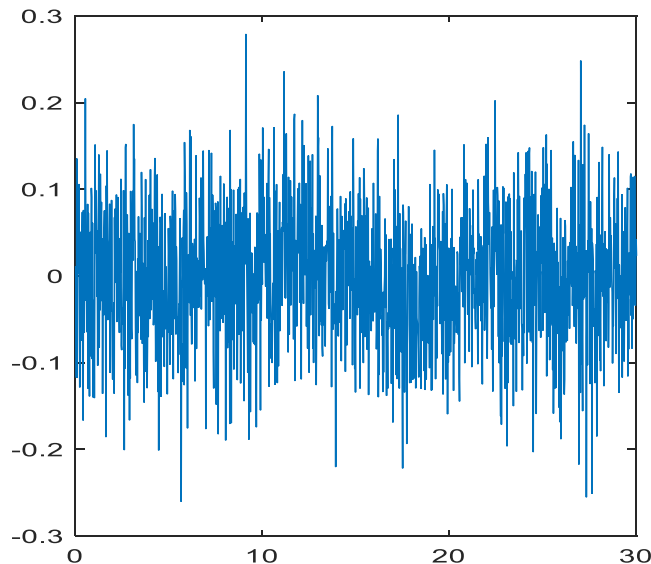


Calibration

- Types of error (Bias)
 - Non-accurate scaling
 - Axis misalignments
 - Bias instability (non zero biases)
- Methods to measure the IMU errors & biases
 - The averaged gyro signal = Bias (static)
 - Sum of (bias + projection of G) = Local precise gravity (rotating)
 - Magnetic off-center circle = Hard & soft iron distortions

Calibration (Gyroscope)

- Bias instabilities (low-cost embedded IMU sensor)
- Calibration procedure for the Gyroscope (static)
 - I. Gaussian filtering (identify the noise type)
 - II. Median filtering for nonlinear signal (non-zero, un-Gaussian noises)
 - III. Obtain the error compensation function (parameters)

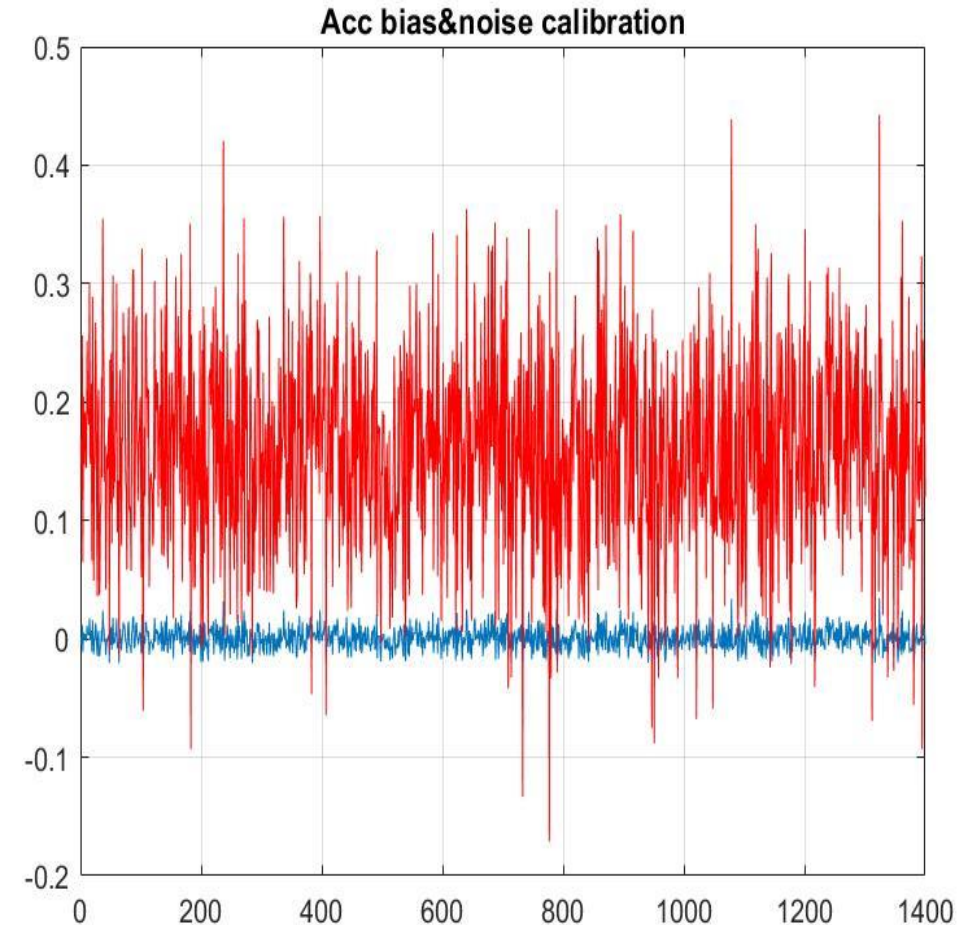


Calibration (Accelerometer)

- Variable biases and measurement noise
- Misalignments
- Scale factor errors

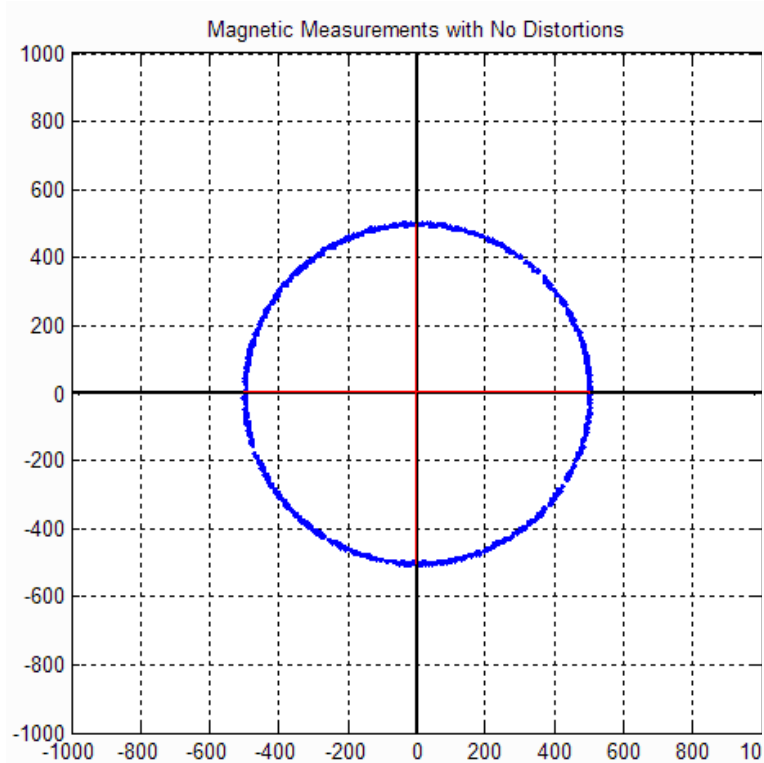
Basic calibration framework for accelerometer

- I. Find the exact value of local gravity
- II. Cost function used to estimate accelerometers' parameters (sum of (Bias + projection g – local g))
- III. Employ the Levenberg-Marquardt (LM) algorithm to minimize the cost function
- IV. Obtain the offset parameters

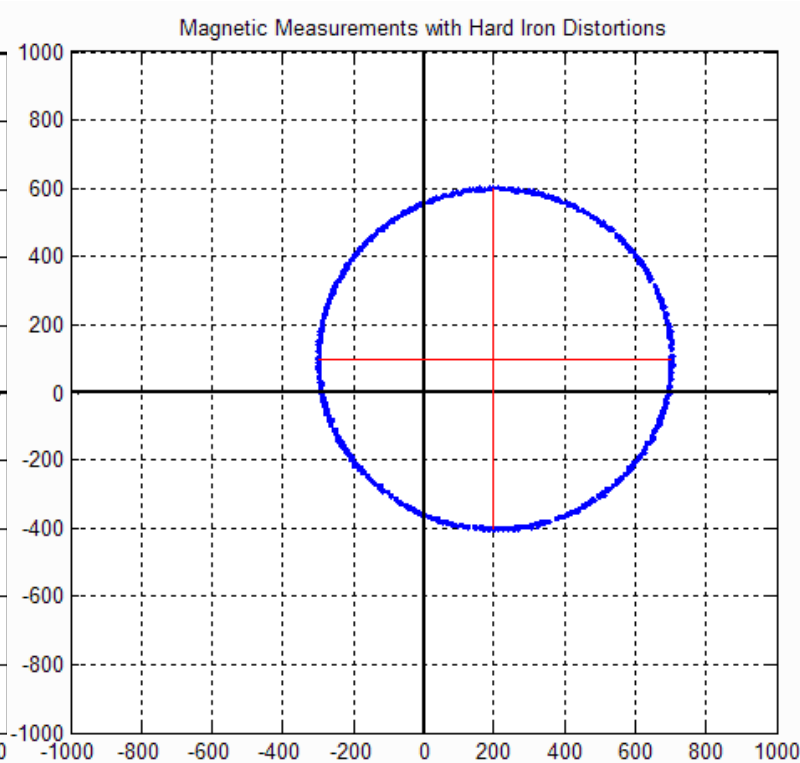


Calibration (Magnetometer)

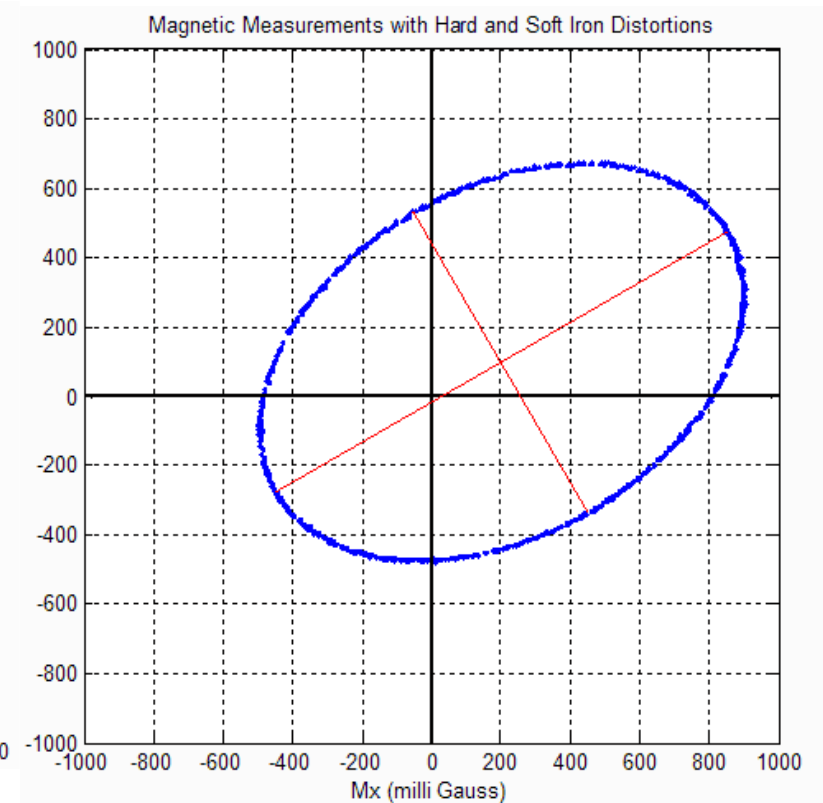
Non-distortions



Hard iron distortions



Soft & Hard iron distortions



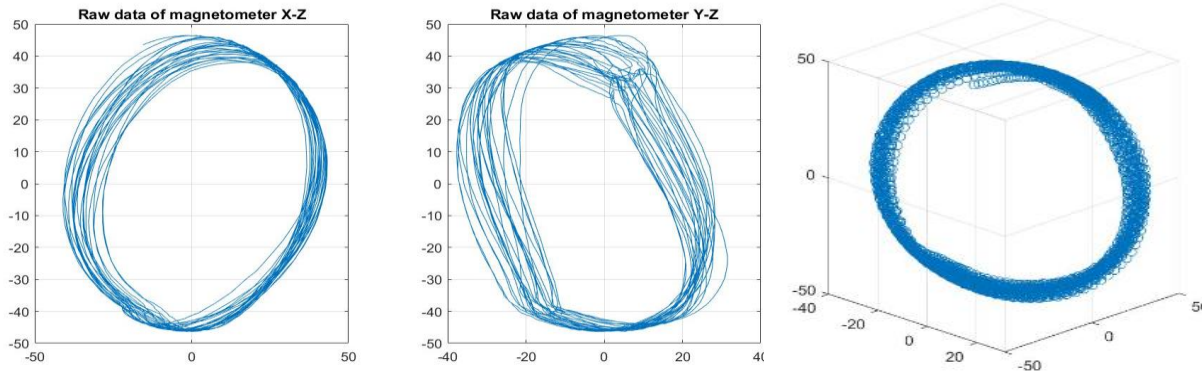
Hard iron distortions have a much larger contribution to the total uncorrected error than soft iron distortions

Calibration (Magnetometer)

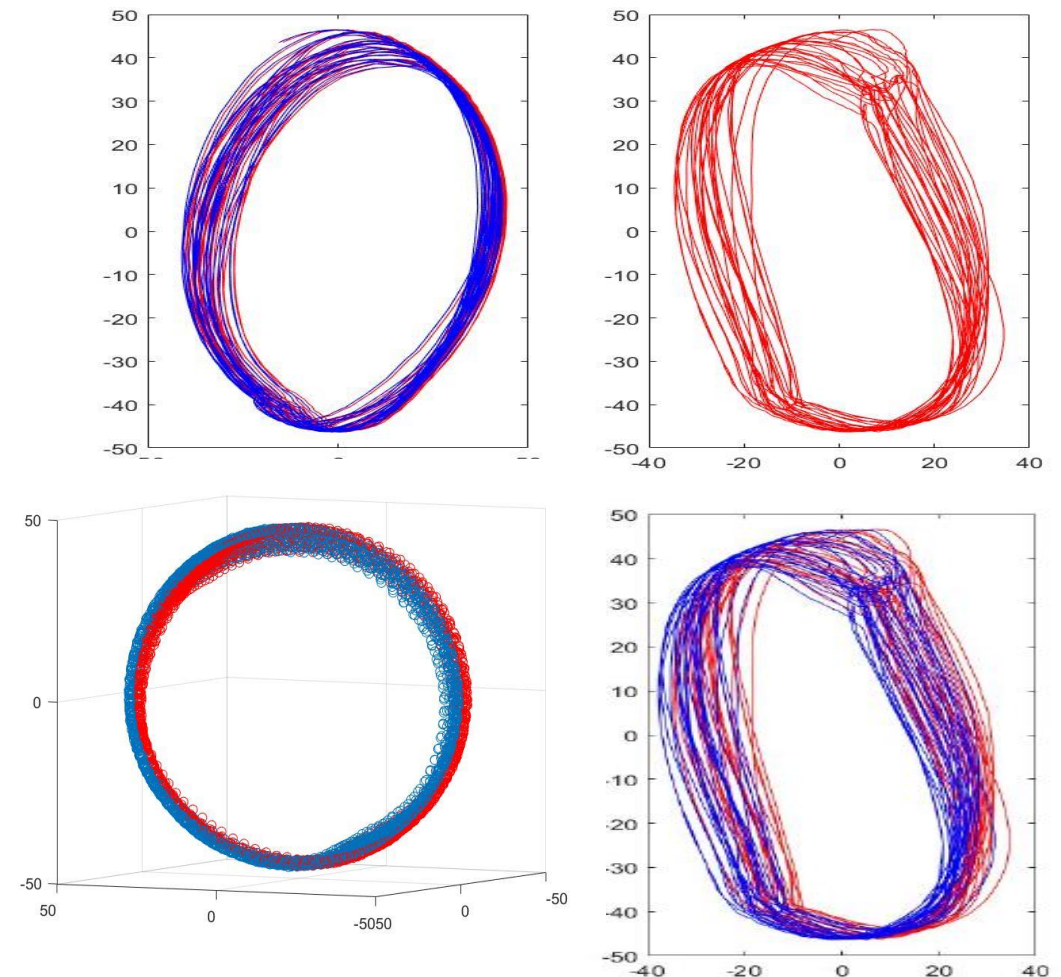
Calibration procedure for the magnetometer

- I. Sweep the device through eight figure pattern
- II. Draw the magnetic measurements of raw data
- III. Built the error model and obtain the offset distance
- IV. Optimize the cost function
- V. Obtain the final triaxial compensation parameters

Magnetic measurement of raw data ('8' rotating)

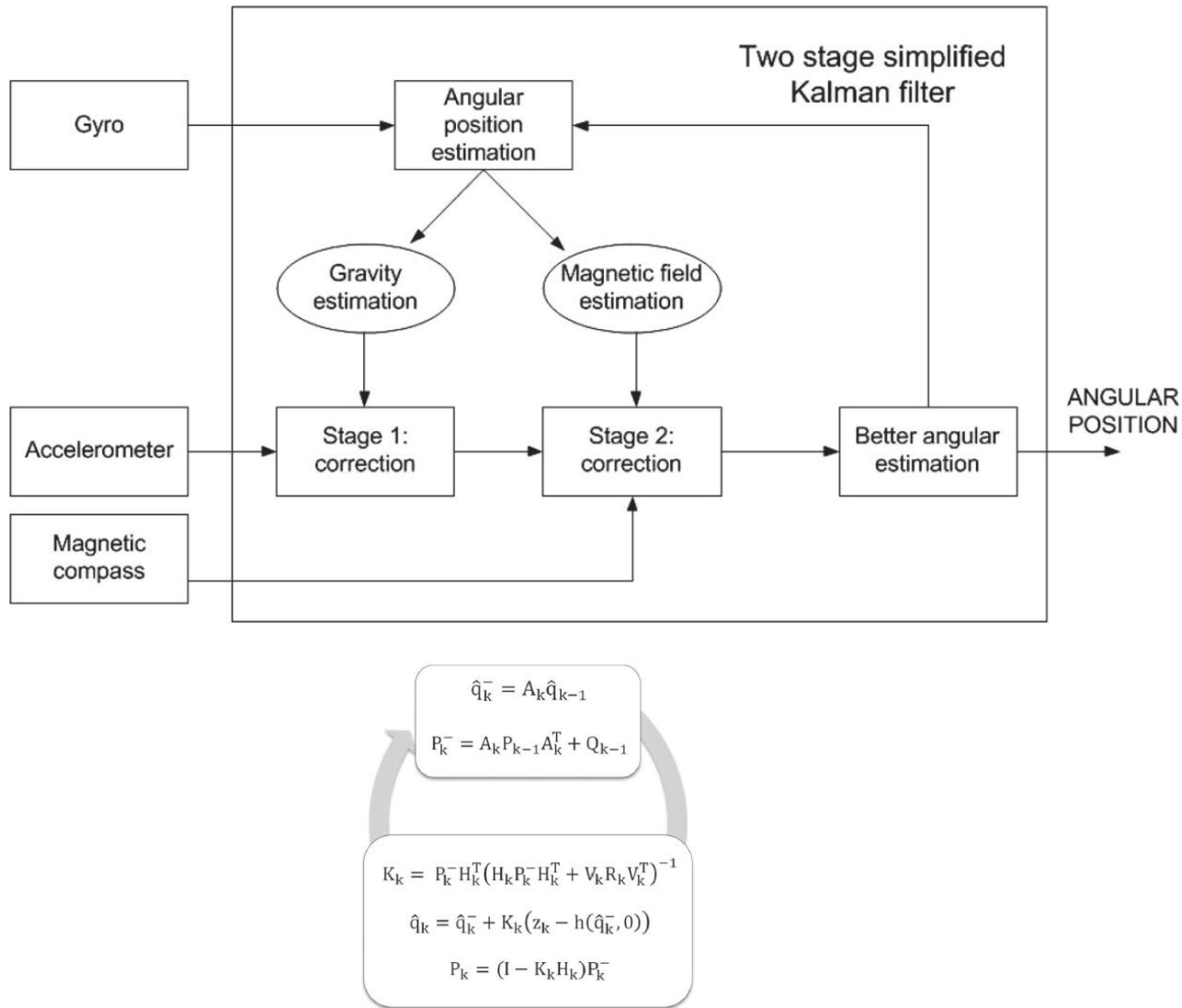


Magnetic measurement after calibration



Double Stage Kalman Filter

Double Stage Kalman Filter



$$h_1(q_k) = \hat{g} = R_n^b \begin{bmatrix} 0 \\ 0 \\ |g| \end{bmatrix} = |g| \begin{bmatrix} 2q_1 q_3 - 2q_0 q_2 \\ 2q_0 q_1 + 2q_2 q_3 \\ q_0^2 - q_1^2 - q_2^2 + q_3^2 \end{bmatrix}$$

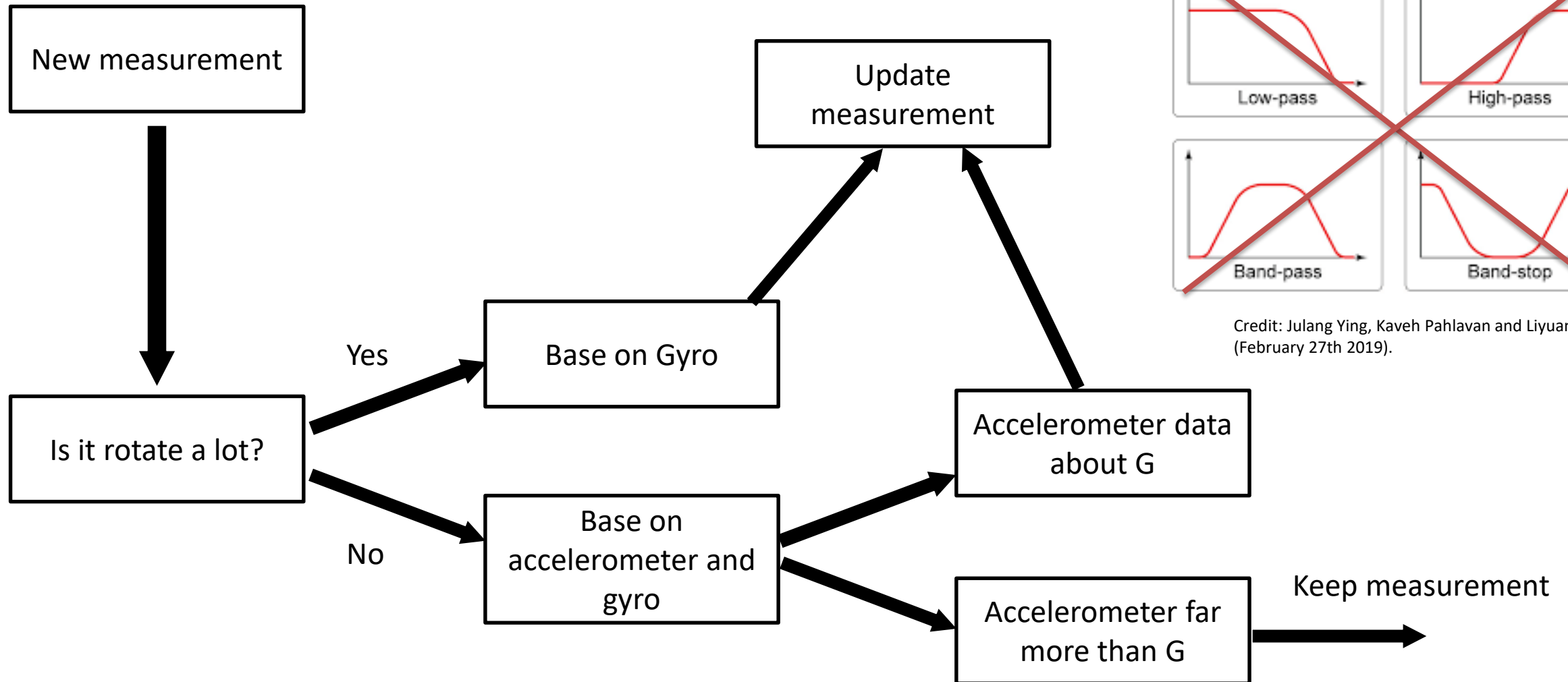
$$R_n^b = \begin{bmatrix} q_0^2 + q_1^2 - q_2^2 - q_3^2 & 2q_1 q_2 + 2q_0 q_3 & 2q_1 q_3 - 2q_0 q_2 \\ 2q_1 q_2 - 2q_0 q_3 & q_0^2 - q_1^2 + q_2^2 - q_3^2 & 2q_2 q_3 + 2q_0 q_1 \\ 2q_1 q_3 + 2q_0 q_2 & 2q_2 q_3 - 2q_0 q_1 & q_0^2 - q_1^2 - q_2^2 + q_3^2 \end{bmatrix}$$

$$H_{k1} = \frac{\partial h_1[i]}{\partial q[j]} = \begin{bmatrix} -2q_2 & 2q_3 & -2q_0 & 2q_1 \\ 2q_1 & 2q_0 & 2q_3 & 2q_2 \\ 2q_0 & -2q_1 & -2q_2 & 2q_3 \end{bmatrix}$$

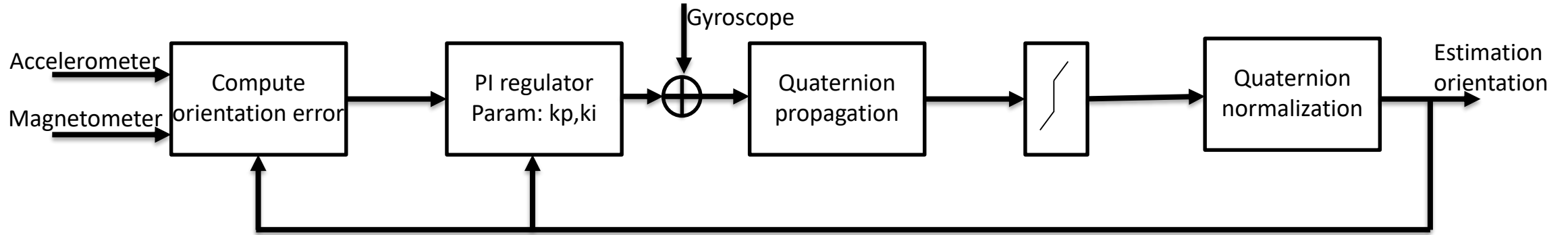
$$h_2(q_k) = \hat{m} = R_n^b \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} = \begin{bmatrix} 2q_1 q_2 + 2q_0 q_3 \\ q_0^2 - q_1^2 - q_2^2 - q_3^2 \\ 2q_2 q_3 - 2q_0 q_1 \end{bmatrix}$$

$$H_{k2} = \frac{\partial h_2[i]}{\partial q[j]} = \begin{bmatrix} 2q_3 & 2q_2 & 2q_1 & 2q_0 \\ 2q_0 & -2q_1 & -2q_2 & -2q_3 \\ -2q_1 & -2q_0 & 2q_3 & 2q_2 \end{bmatrix}.$$

High Low Pass Filter



Mahony Filter



Correction to the gyroscope

$$k_p * e_m + k_i * e_i$$

e_m: sensor error of the gyroscope

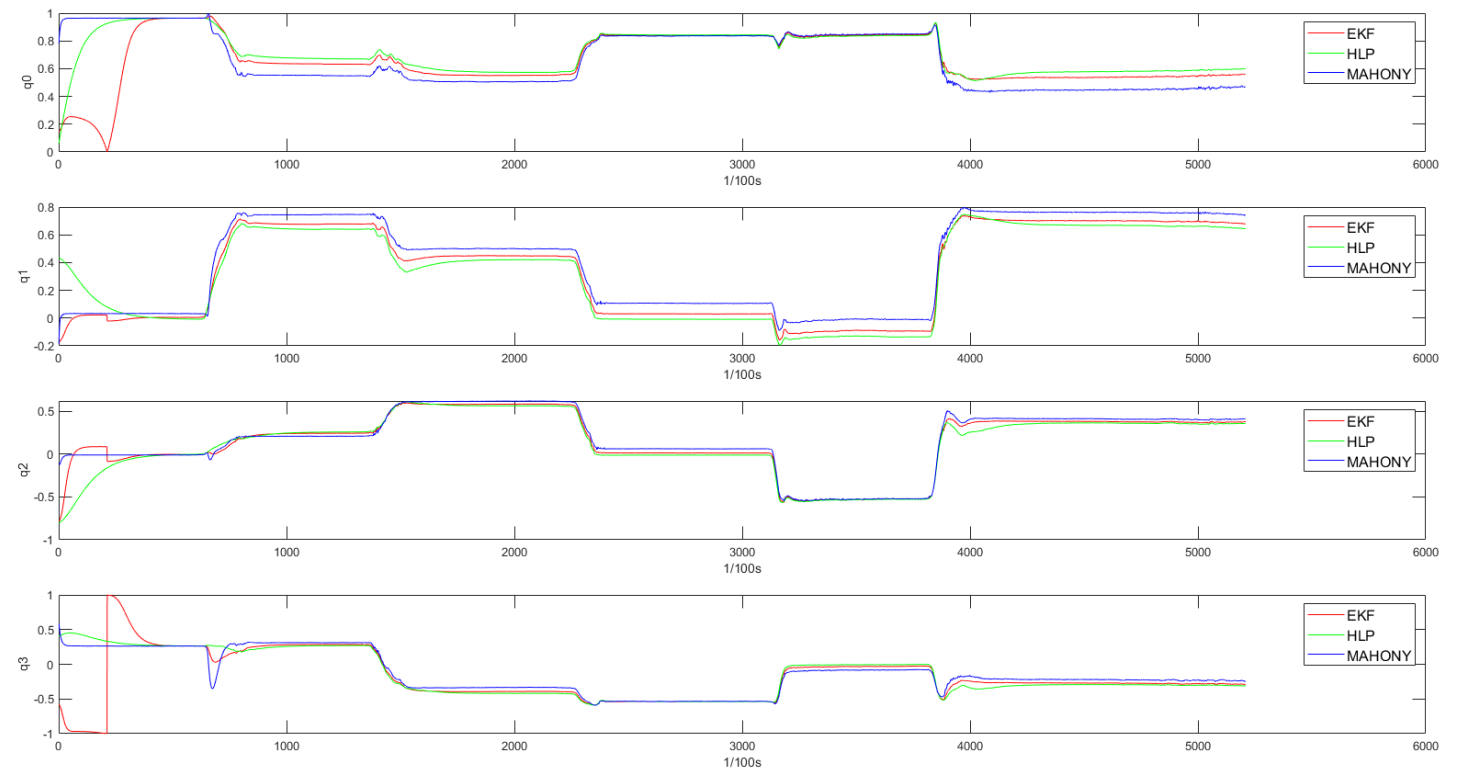
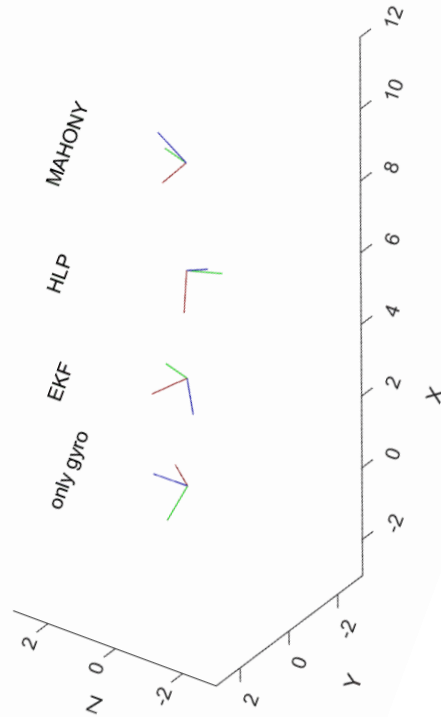
e_i: integral error

Kp: proportional gain

Ki: integral gain

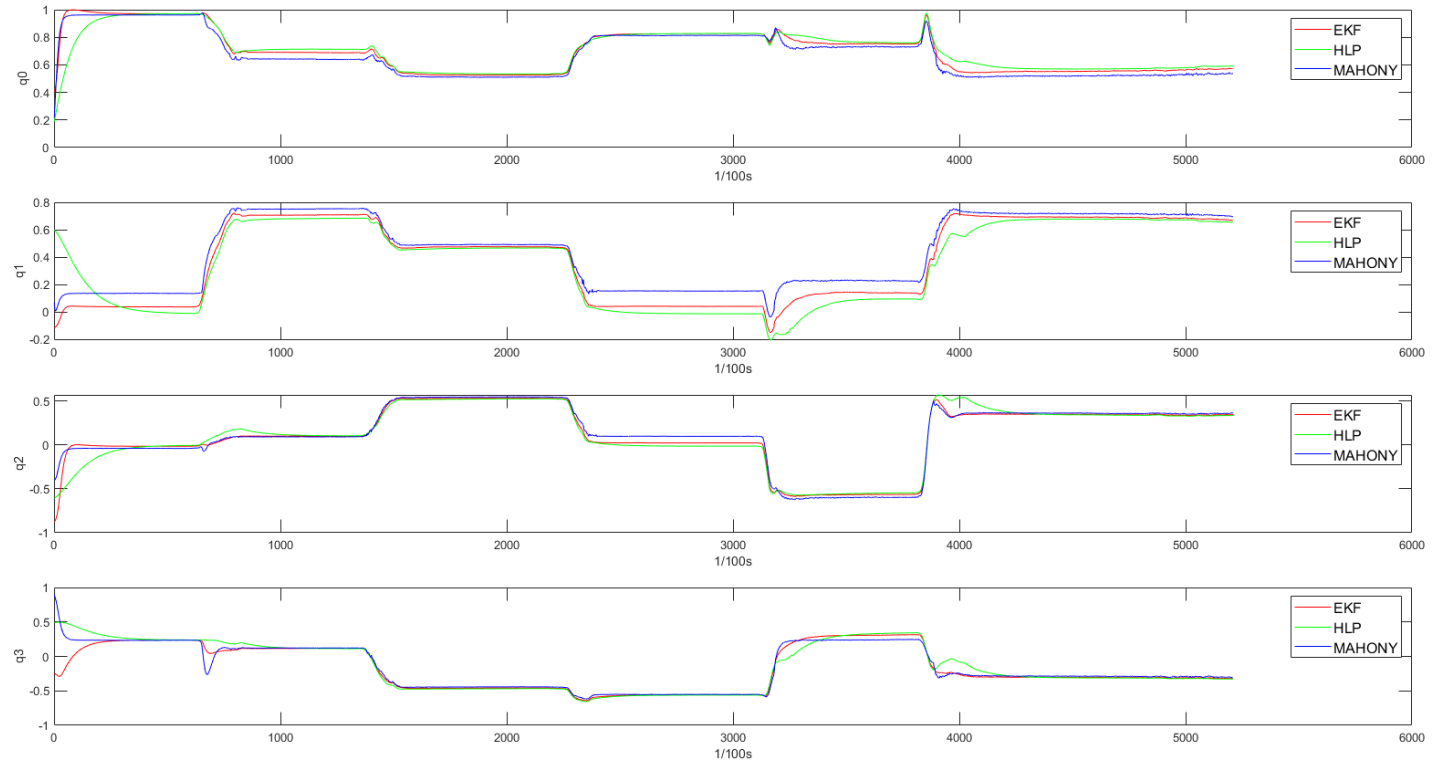
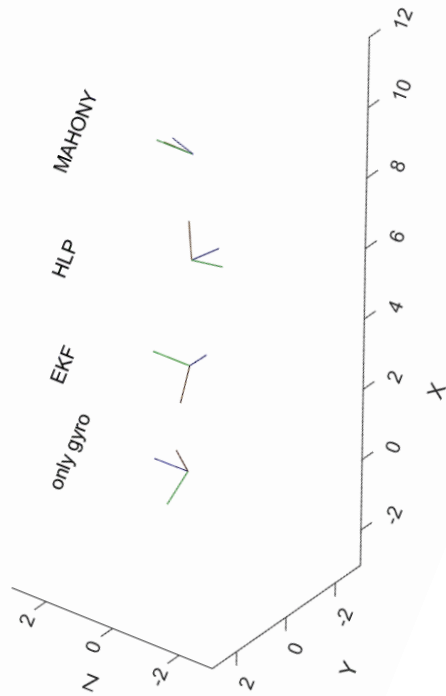
Experiment Result

Mild orientation changing without calibration



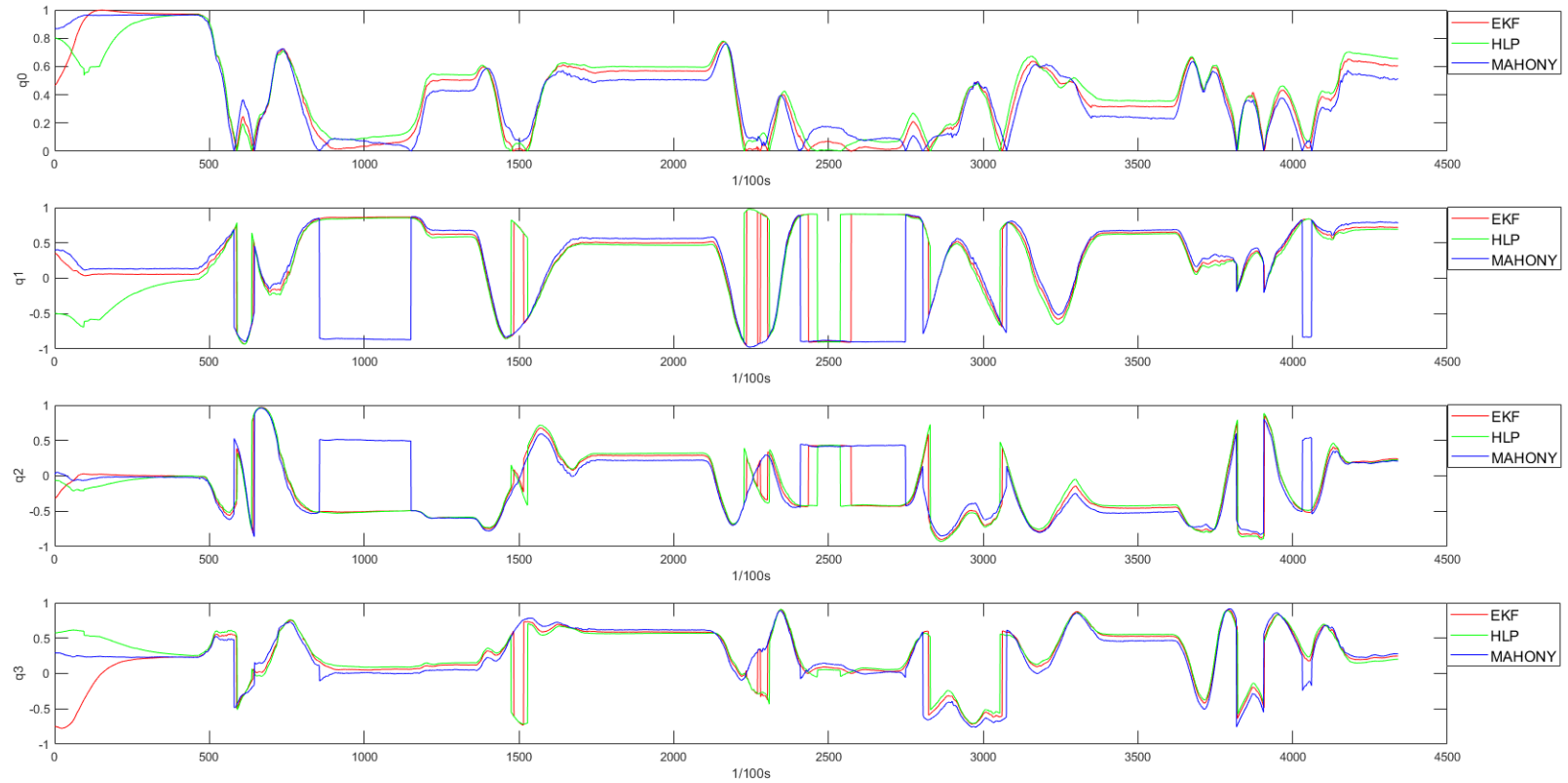
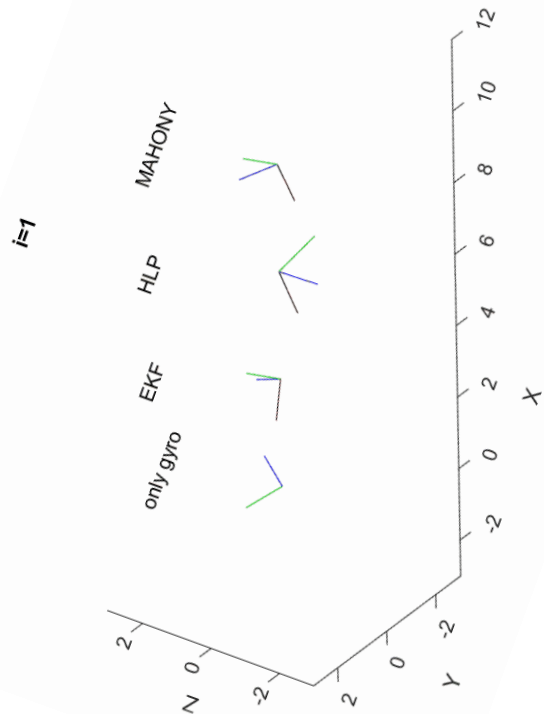
Experiment Result

Mild orientation changing with calibration



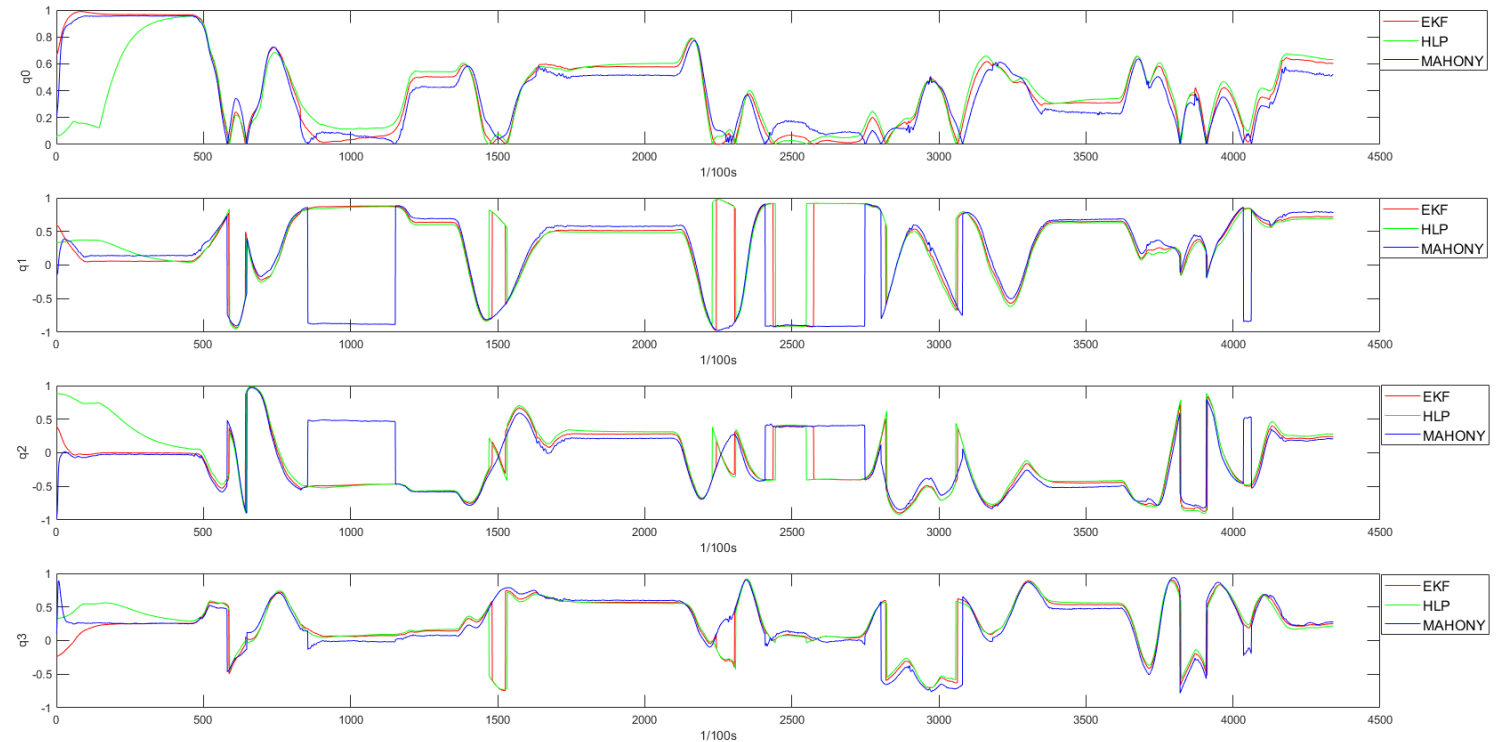
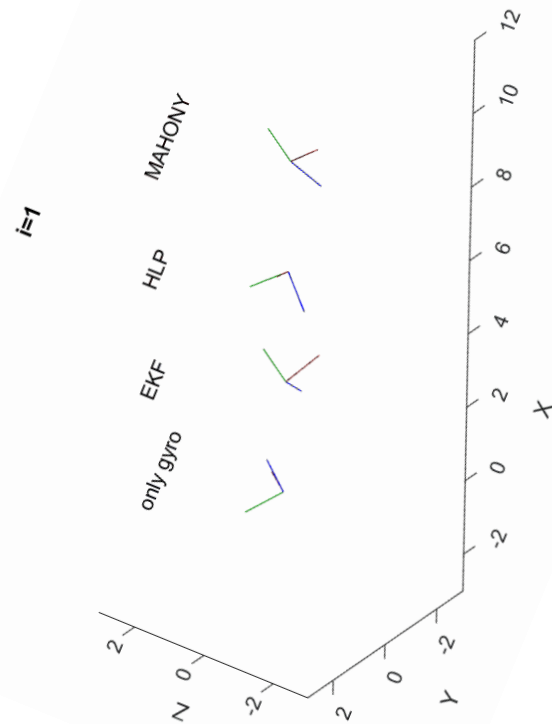
Experiment Result

Violent orientation changing without calibration



Experiment Result

Violent orientation changing with calibration



Conclusion and Future Work

Conclusion

- Calibration use in this project can get a better result in mild rotation changing case
- If the orientation changing rapidly, orientation tracking could be less accuracy while calibration for system error could be less effective.

Future work

- Dynamic calibration for gyro and accelerometer
- Explore the more calibration method
- Compare more different calibration methods and justify their difference (pros and cons)
- Explore the state of the art sensor fusion algorithms
- Compare new fusion algorithm with classic algorithm

References

- [1] Tedaldi, David, Alberto Pretto, and Emanuele Menegatti. "A robust and easy to implement method for IMU calibration without external equipments." *2014 IEEE International Conference on Robotics and Automation (ICRA)*. IEEE, 2014.
- [2] Sabatelli, Simone, et al. "A double-stage Kalman filter for orientation tracking with an integrated processor in 9-D IMU." *IEEE Transactions on Instrumentation and Measurement* 62.3 (2012): 590-598.
- [3] Mahony, Robert, Tarek Hamel, and Jean-Michel Pflimlin. "Nonlinear complementary filters on the special orthogonal group." *IEEE Transactions on automatic control* 53.5 (2008): 1203-1218.
- [4] Shike Shen: 9 Axis IMU Calibration [<https://blog.csdn.net/shenshikexmu/article/details/80013444>]

Thank you!

Any Questions?