

A HYBRID OPTO-INERTIAL TRACKING SYSTEM PROTOTYPE

Faisal Kalim

Supervisor: Benjamin Busam

Partners: IFL & FRAMOS

5.30.2017

Project Outline



➤ Motivation

- Different Tracking Solutions
- Each have pros and cons
- Hybrid solution for overcoming limitations

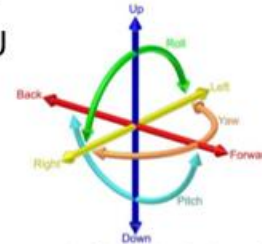
➤ Problem Statement

- To develop a software prototype that fuses the data streams of both an inertial measurement unit (IMU) and an optical tracking system (OTS)



6 degrees of freedom

IMU



- Accelerometer: Left-Right, Back-Forward, Up-Down
- Gyroscope: Pitch, Roll, Yaw

Project Outline



- Requirements and Specifications
 - **Tracking**
 - Tracking of device based on IMU data
 - Data Fusion
 - **Evaluation**
 - Compare results of IMU based tracking to OTS
 - **GUI**
 - Display individual + hybrid pose values

Tasks



- IMU interfacing with computer
- Calibration of IMU
- Kalman filtering
- Orientation Estimation
- Hybrid Orientation Estimation
- Position Estimation



Calibration of Accelerometer

➤ Calibration Model

$$\begin{pmatrix} A_x \\ A_y \\ A_z \end{pmatrix} = \begin{pmatrix} 1 & M_{xy} & M_{xz} \\ M_{yx} & 1 & M_{yz} \\ M_{zx} & M_{zy} & 1 \end{pmatrix} * \begin{pmatrix} S_x \\ S_y \\ S_z \end{pmatrix} * \begin{pmatrix} V_x & B_x \\ V_y & B_y \\ V_z & B_z \end{pmatrix}$$

➤ Calibration Method

- Measurements in different static position
- Net acceleration in static condition equals g
- Gauss-Newton nonlinear optimization

➤ Results

$$\begin{matrix} \text{➤ } M = & \begin{pmatrix} 0.9992 & -0.0012 & 0.0090 \\ -0.0012 & 0.9976 & -0.0195 \\ 0.0090 & -0.0195 & 0.9971 \end{pmatrix} & B = & \begin{pmatrix} -0.0266 \\ 0.0095 \\ 0.0218 \end{pmatrix} \end{matrix}$$



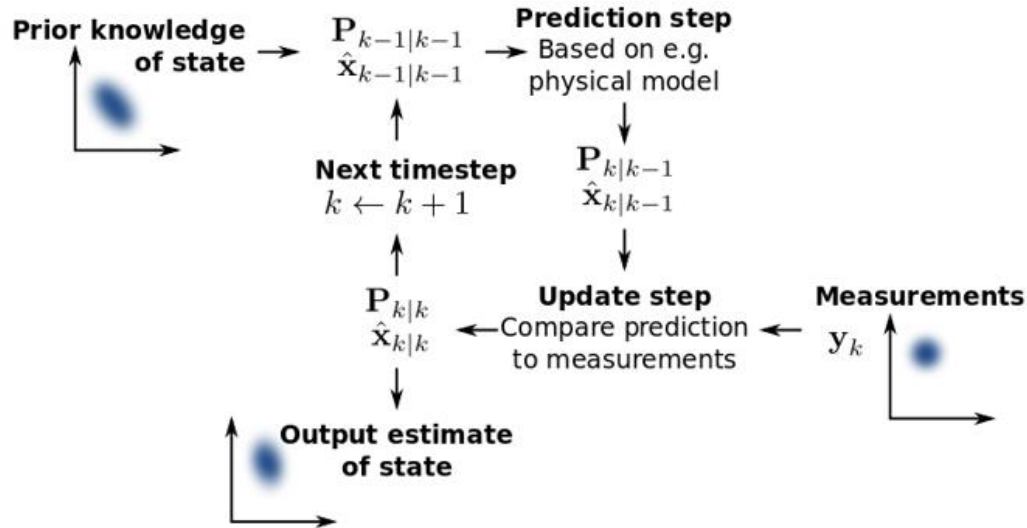
Kalman Filtering

- State Vector
- Process Model
- Measurement Model
- Kalman Filter Cycle

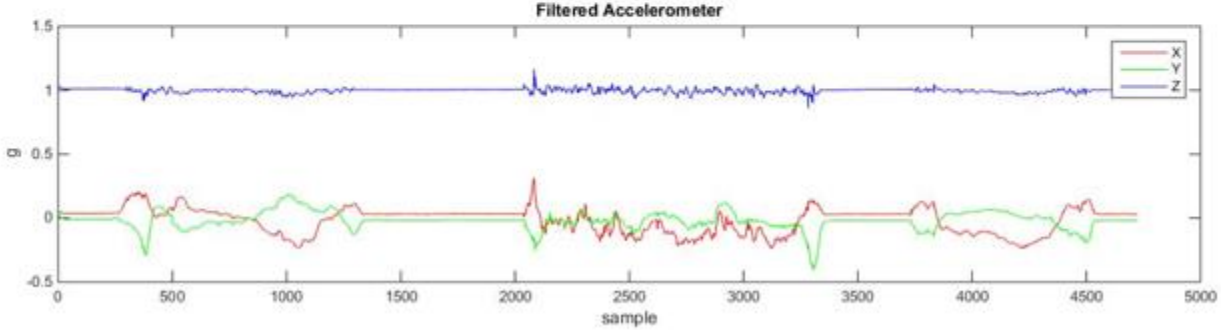
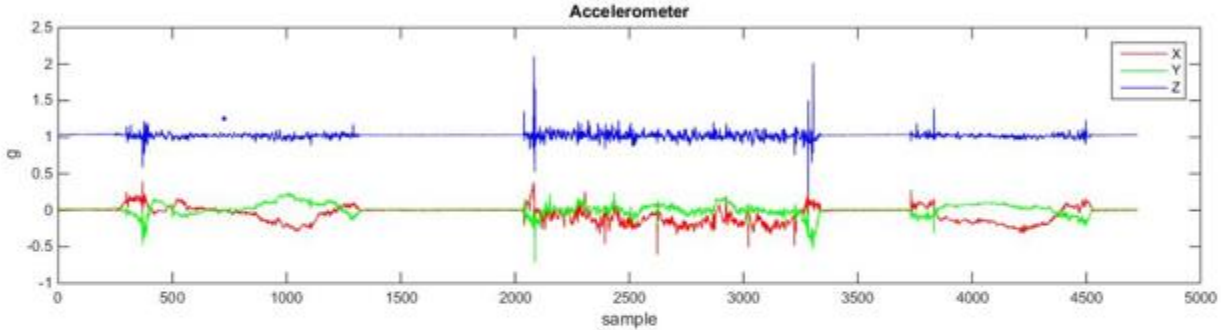
$$\mathbf{x} = (x, y, z, \dot{x}, \dot{y}, \dot{z}, \ddot{x}, \ddot{y}, \ddot{z})^T$$

$$\mathbf{x}_k = A\mathbf{x}_{k-1} + B\mathbf{u}_k + \mathbf{w}_{k-1}$$

$$\mathbf{z}_k = H\mathbf{x}_k + \mathbf{v}_k$$



Project Results



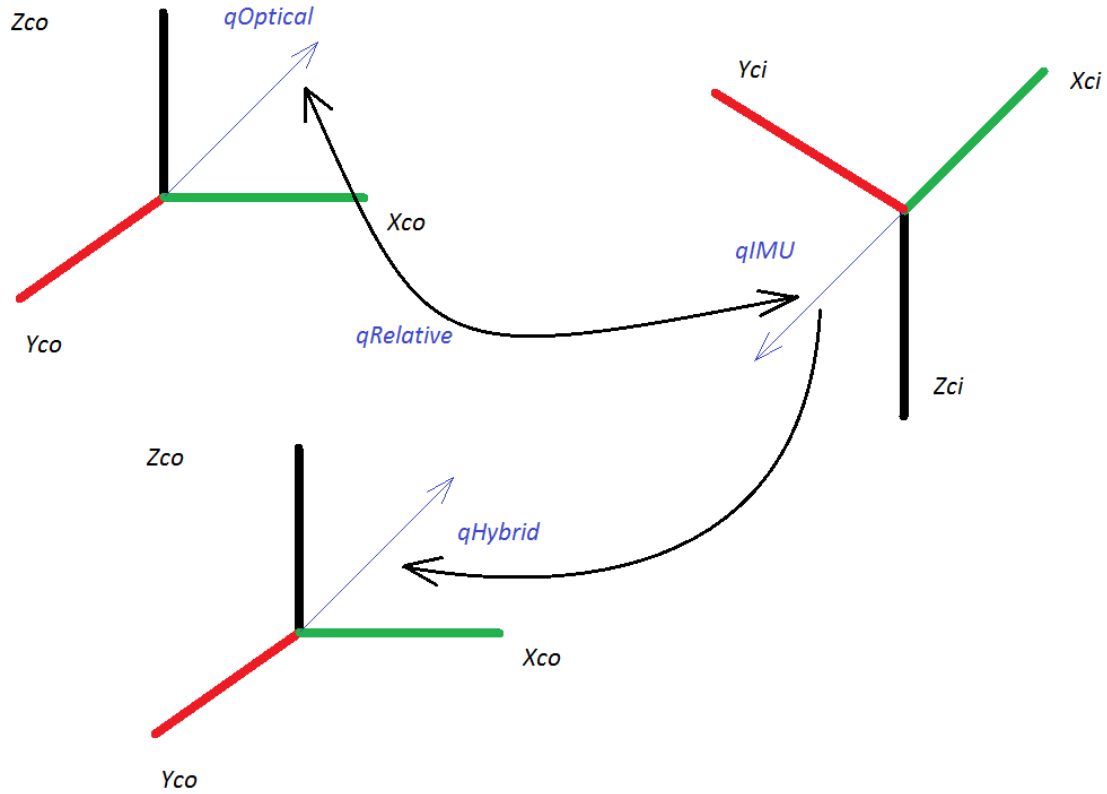


Orientation Estimation

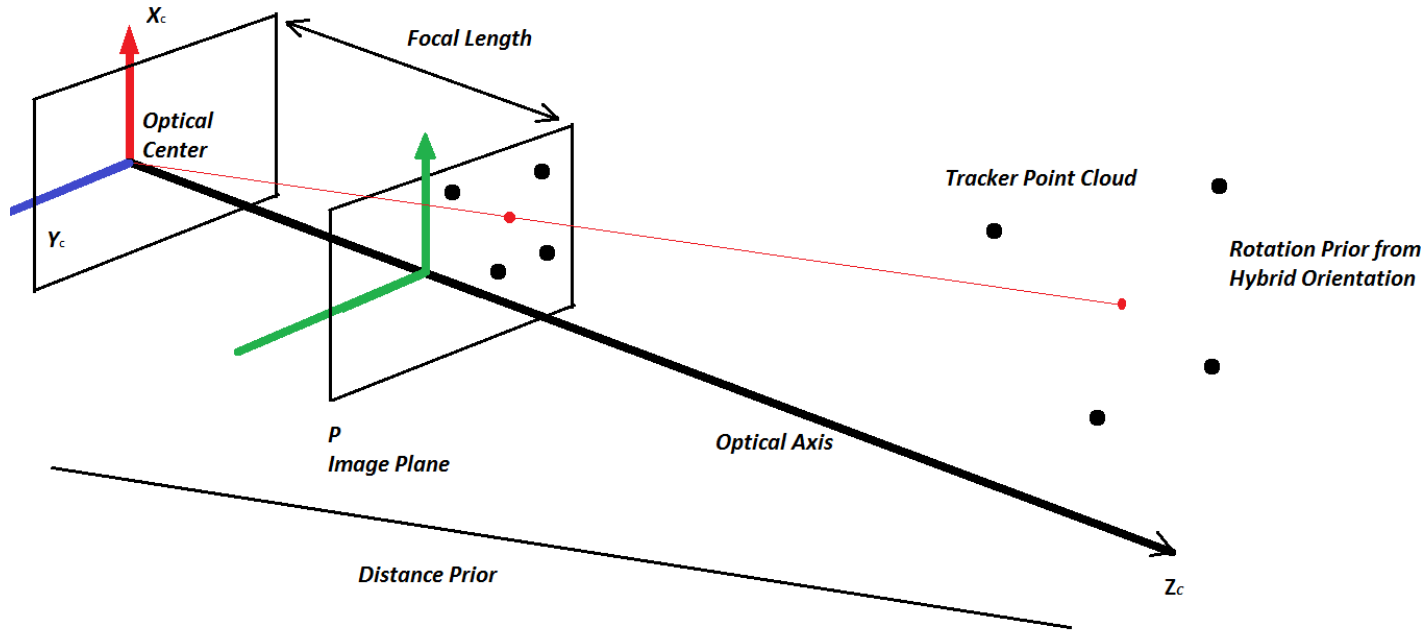
- Based on Mahony AHRS opensource algorithm.
- Calculates quaternion derivative of angular velocities, and then integrates it to find orientation at give instance.
- Also takes into account accelerometer values, to compensate for gyroscope drift.
- Calculates orientation in Earth's Frame of reference.
- Can Take into account magnetic sensor values as well

S. O. H. Madgwick, An efficient orientation filter for inertial and inertial/magnetic sensor arrays, Technical report, University of Bristol University, UK, 2010.

Hybrid Orientation Estimation



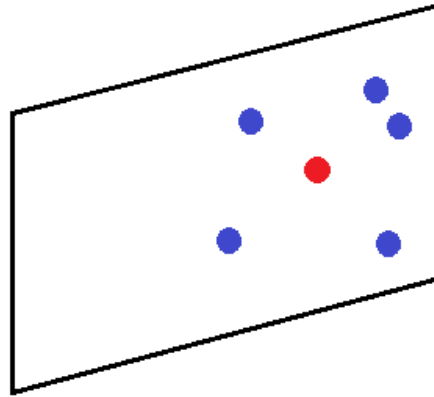
Hybrid Pose Estimation From One Camera



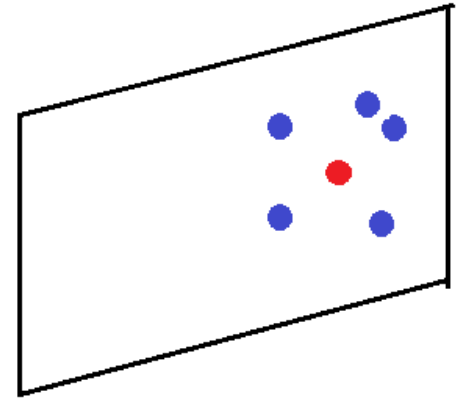
Robust Points Correspondence



- Normalize the point sets
- Sort the points according to distance from center
- find points with highest difference of distances from center.
- Select points which are:
 - 1) Closest to each other and
 - 2) Have farthest difference from each other.



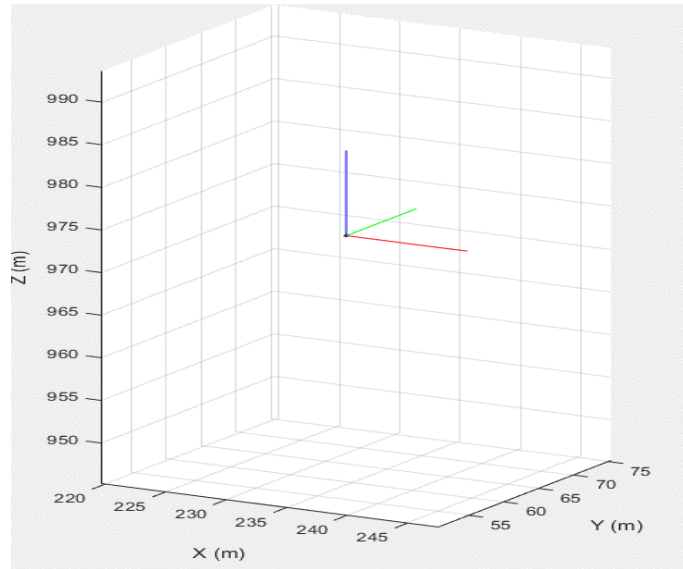
Projected Image



Actual Image

Challenges Faced

- Position estimation is extremely challenging
 - Precise calibration of IMU
 - Navigation grade IMU is more precise
 - How to take into account centripetal acceleration



Grade	Accelerometer Bias Error [mg]	Horizontal Position Error [m]			
		1s	10s	60s	1hr
Navigation	0.025	0.13 mm	12 mm	0.44 m	1.6 km
Tactical	0.3	1.5 mm	150 mm	5.3 m	19 km
Industrial	3	15 mm	1.5 m	53 m	190 km
Automotive	125	620 mm	60 m	2.2 km	7900 km

DEMO

