IMU Attitude Estimation using Complementary Filter

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***Abstract*—The project 0 aims to estimate the three dimensional orientation of the IMU by reading the acceleration and the gyroscope values provided by it. A complementary filter is implemented to fuse the values from the accelerometer and the gyroscope to obtain the orientation. The orientation is then compared with the ground truth from the vicon motion capture system.**

I. Introduction

The data from a six degree IMU is provided, 3-axis gyroscope and 3-axis accelerometer. The orientation of the IMU recorded from the VICON motion capture is also provided. The data for each correspondence is provided in a .mat file. The IMU data follows the following structure:

$$[a_x a_y a_z w_z w_x w_y]$$

The VICON data meanwhile stores the timestamps ts and the orientation in a 3x3 Rotation matrix denoting **Z-Y-X** euler angles for N time instances. The parameter values for the IMU are also provided in a 2x3 vector containing the Scale and Bias values.

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II. Unit Conversions

The values obtained from the IMU are not in the physical values and need to be converted using appropriate formula. The acceleration data from the IMU is converted to ms^{-1} using the formula given below:

$$\bar{a}_x = \frac{a_x + b_{a,x}}{s_x}$$

where $\bar{a}$ is the value of acceleration in physical units the b and s are the bias and scale factors for the accelerometer obtained from the IMU parameters file.

The gyroscope values form the IMU are converted to the physical units ω to $rads^{-1}$ using the following formulation:

$$\bar{\omega} = \frac{3300}{1023} x \frac{\Pi}{180} x (\omega - b_g)$$

where $\bar{\omega}$ is the ω in physical units and b is calculated as the average of the first few hundred sample values.

The alignment of the IMU and Vicon timestamps is not present. I am not using any interpolation or slerp to align the time stamps. Rather the closest timestamps are used to calculate the initial state.

III. Orientation from Gyroscope Values

The IMU provides us with 3-axis gyroscope values $\omega_z, \omega_x, \omega_y$. The orientation of the IMU can be obtained by performing simple integration. The first value of the orientation is assumed to be known, i.e., taken from the vicon data. The vicon data is converted from rotation matrix to euler angles for this.

$$\theta_{t+1} = \theta_t + \omega_t \Delta\ t$$

where $\Delta\ t$ is the difference between two timestamps recorded by the IMU. The plots of the orientation from the gyro values from the IMU are then plotted.

IV. Orientation From Accelerometer Values

The orientation of the IMU can b eobtained from the accelerometer values of the IMU using the following formulas:

$$\text{Roll},\ \phi = \tan^{-1}\left(\frac{a_y}{\sqrt{a_x^2 + a_z^2}}\right)$$

$$\text{Pitch},\ \theta = \tan^{-1}\left(\frac{-a_x}{\sqrt{a_y^2 + a_z^2}}\right)$$

$$\text{Yaw},\ \psi = \tan^{-1}\left(\frac{\sqrt{a_x^2 + a_y^2}}{a_z}\right)$$

V. Complementary Filter

A Complementary Filter is a simple filter used to fuse values from two different sensor data values. This provides a more accurate measurement of the orientation. The accelerometer is noisy at the beginning but provides a stable long term measurement while gyroscope values are accurate in the beginning and drift away as time increases.

The euler angles obtained from the accelerometer values are passed through a low pass filter:

$$\hat{\theta}_{at+1} = (1-\alpha)\theta_{at} + \alpha\tilde{\theta}_{at+1}$$

The euler angles obtained from the gyroscope values are passed through a high pass filter :

$$\hat{\theta}_{g_{t+1}} = (1-\alpha)\hat{\theta}_{g_t} + (1-\alpha)(\theta_{g_{t+1}} - \theta_{g_t})$$

The values of α used in the high pass and the low pass filter is taken as 0.5 .

The filtered values are then multiplied with the fusion factor and then added together to get an estimate of the orientation of the IMU.

$$\hat{\theta} = (1 - \alpha)\hat{\theta}_{at} + (\alpha)(\theta_g$$

where θ is the orientation from the complementary filter, θ_a is the values from accelerometer after low pass filter and (θ_g) is the value from the gyroscope after high pass filter.

The fusion factor (α) is taken as 0.2.

VI. Results

Theh legend is provided at the left most corner of the figures. The complementary filter is represented as "cf" in the graphs.

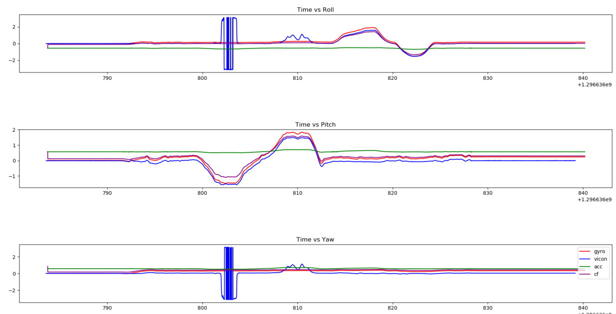

Fig. 1. Data Set 1

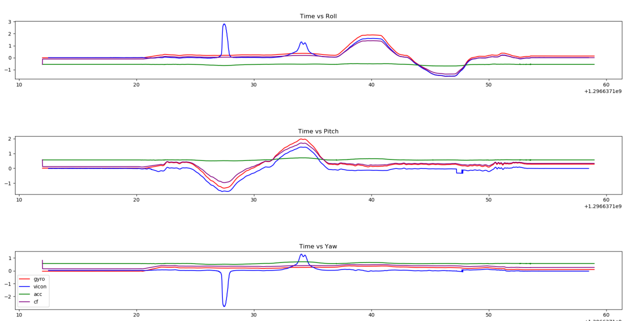

Fig. 2. Data Set 2

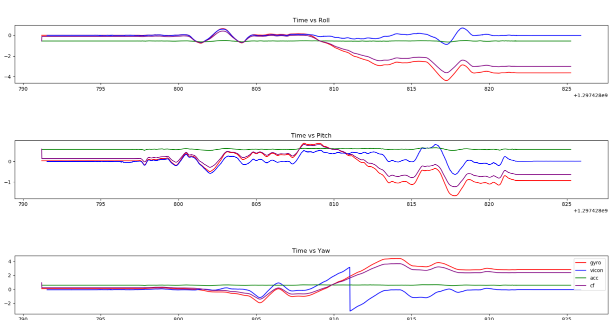

Fig. 3. Data Set 3

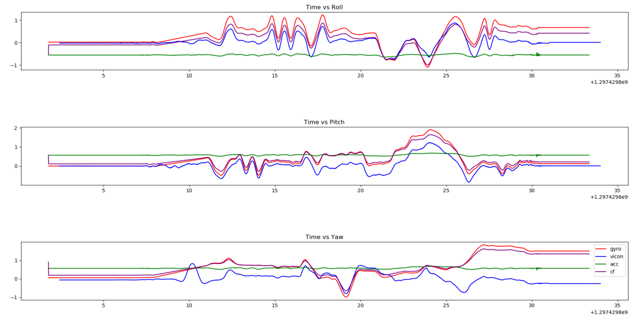

Fig. 4. Data Set 4

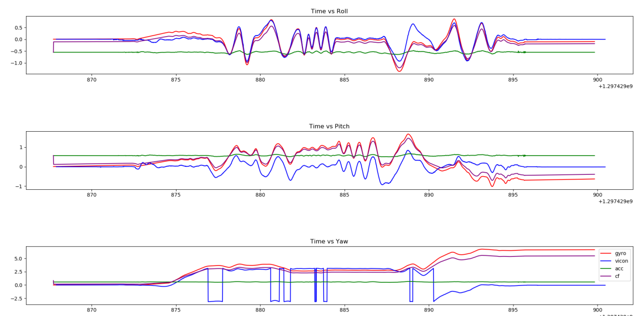

Fig. 5. Data Set 5

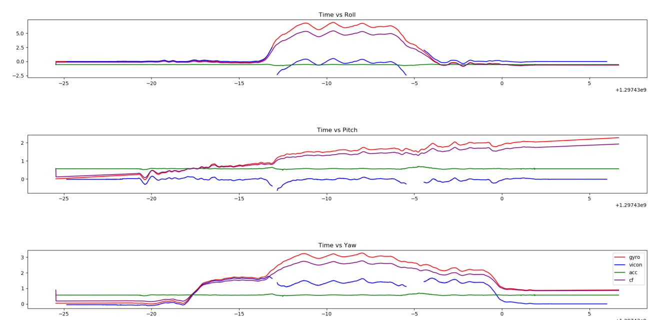

Fig. 6. Data Set 6

The orientations obtained from the accelerometer and gyroscope values of the IMU give a very rough and inaccurate orientation of the IMU compared to the vicon ground truth data. The accelerometer outputs a straight line, while the values read from the gyroscope drift away from the ground truth values. The complementary filter tries filter values from both the observation and gives a better estimate of the orientations.

References

[1] Nitin J. Sanket, Orienation Tracking based Panorama Stitching using Unscented Kalman Filter