Attitude Estimation Using Madgwick Filter

1st Venkateshkrishna
Masters in Robotics
Worcester Polytechnic Institute
Worcester, MA 01609
vparsuram@wpi.edu

2nd Athithya, Lalith
Masters in Robotics
Worcester Polytechnic Institute
Worcester, MA 01609
lnavaneethakrishnan@wpi.edu

3rd Gampa, Varun
Masters in Robotics
Worcester Polytechnic Institute
Worcester, MA 01609
vgampa@wpi.edu

***Abstract*—This project implements a Madgwick filter and a complimentary filter to estimate the orientation of a 6-DOF IMU. The orientation estimated using the filters are compared with the ground truth orientation obtained from a vicon motion capture system. The results show that the Madgwick filter is better at estimating the orientation than the complimentary filter.**

I. Introduction

The aim of this project is to implement a Madgwick filter and a complimentary filter to estimate the orientation using gyroscope and accelerometer data obtained from a 6-DOF IMU. The esimated orientation is compared with the ground truth orientation obtained from a vicon motion capture system. Orientations from individual sensors are also compared with the ground truth orientation.

II. Pre-Processing Gyroscope Data

The raw values are obtained from the gyroscope are converted to the physical units (rads^{-1}) using

$$\widetilde{\omega} = \frac{3300}{1023} \times \frac{\pi}{180} \times 0.3 \times (\omega - b_g) \tag{1}$$

where $\widetilde{\omega}$ represents the the value of ω in physical units and b_g is the bias of the gyroscope. b_g is calculated as the average of the first 200 samples.

III. Pre-Processing Accelerometer Data

The raw values of obtained from the accelerometer are converted to the physical units (ms^{-2}) using

$$\widetilde{a}_x = (a_x \times s_x + b_{a,x}) \times g \tag{2}$$

where $\widetilde{a}_x$ represents the the value of a_x in physical units and $b_{a,x}$ is the bias of the and s_x is the scale factor of the accelerometer and g is the acceleration due to gravity. $\widetilde{a}_y$ and $\widetilde{a}_z$ were calculated similarly.

IV. Attitude estimation using Madgwick Filter

A. Gyroscope data processing

We use the pre-processed gyroscope data and use the current estimate of the orientation to calculate the rate of change of the orientation. This is done by

$$\overset{I}{W}\dot{\mathbf{q}}_{\omega,t+1} = \frac{1}{2}\overset{I}{W}\hat{\mathbf{q}}_{est,t} \otimes [0, {}^{I}\omega_{t+1}]^T \tag{3}$$

This gives the update angular velocity from the gyroscope data. For t =0 we use the initial orientation from the vicon system. The update angular velocity is then used to update the orientation using the equation.

B. Accelerometer data processing

Here we use the pre-processed accelerometer data to calculate the orientation. First we assume that the acceleration of the IMU is much lesser than the acceleration due to gravity. Next to calculate the orientation we turn the problem into an opitmization problem of the form:

$$\min_{{}^{I}_{W}\hat{q} \in \mathcal{R}^4} f({}^{I}{}_{W}\hat{\mathbf{q}}_{est,t}, {}^{W}\hat{g}, {}^{I}\hat{a}) \tag{4}$$

To do this gradient descent is followed. The gradient is calculated using the equation

$$\nabla f = J^T({}^{I}{}_{W}\hat{\mathbf{q}}_{est,t}, {}^{W}\hat{g}) f({}^{I}{}_{W}\hat{\mathbf{q}}_{est,t}, {}^{W}\hat{g}, {}^{I}\hat{a}_{t+1}) \tag{5}$$

where J is the Jacobian matrix of the function f. The Jacobian matrix is calculated using the equation

$$J = \begin{bmatrix} -2q_3 & 2q_4 & -2q_1 & 2q_2 \\ 2q_2 & 2q_1 & 2q_4 & 2q_3 \\ 0 & -4q_2 & -4q_3 & 0 \end{bmatrix} \tag{6}$$

and the function f is calculated using the equation

$$f({}^{I}{}_{W}\hat{\mathbf{q}}_{est,t}, {}^{W}\hat{g}, {}^{I}\hat{a}_{t+1}) = \begin{bmatrix} 2(q_2q_4 - q_1q_3) - a_x \\ 2(q_1q_2 + q_3q_4) - a_y \\ 2(0.5 - q_2^2 - q_3^2) - a_z \end{bmatrix} \tag{7}$$

Using the gradient the orientation increment is calculated using the equation

$${}^{I}{}_{W}\hat{\dot{\mathbf{q}}}_{\nabla,t+1} = -\beta \frac{\nabla f({}^{I}{}_{W}\hat{\mathbf{q}}_{est,t}, {}^{W}\hat{g}, {}^{I}\hat{a}_{t+1})}{||\nabla f({}^{I}{}_{W}\hat{\mathbf{q}}_{est,t}, {}^{W}\hat{g}, {}^{I}\hat{a}_{t+1})||} \tag{8}$$

where β is a constant that was chosen based on how much trust we have in the accelerometer data. This was chosen to be 0.1.

C. Combinining the orientation increment from the gyroscope and accelerometer

Now that we have calculated the orientation increment from the gyroscope and accelerometer we combine them to get the final orientation increment using the equation

$$ {}^{I}_{W}\dot{\hat{\mathbf{q}}}_{est,t+1} = {}^{I}_{W}\dot{\hat{\mathbf{q}}}_{\omega,t+1} + {}^{I}_{W}\dot{\hat{\mathbf{q}}}_{\nabla,t+1} \tag{9} $$

Finally we use the orientation increment to update the orientation using the equation

$$ {}^{I}_{W}\hat{\mathbf{q}}_{est,t+1} = {}^{I}_{W}\hat{\mathbf{q}}_{est,t} + {}^{I}_{W}\dot{\hat{\mathbf{q}}}_{est,t+1}\Delta t \tag{10} $$

V. Results

The plots for the 6 training data sets are shown in Figs. 1, 2, 3, 4, 5, 6. Each plot has three subplots corresponding to roll, pitch, and yaw respectively. There are 5 legends in each subplot for the orientation computed from gyroscope, accelerometer, complementary filter, vicon data, and Madgwick filter.

Furthermore, **Test** data was released 24hrs before the submission deadline of this project. The same code was tested on it as well and the following results are seen:

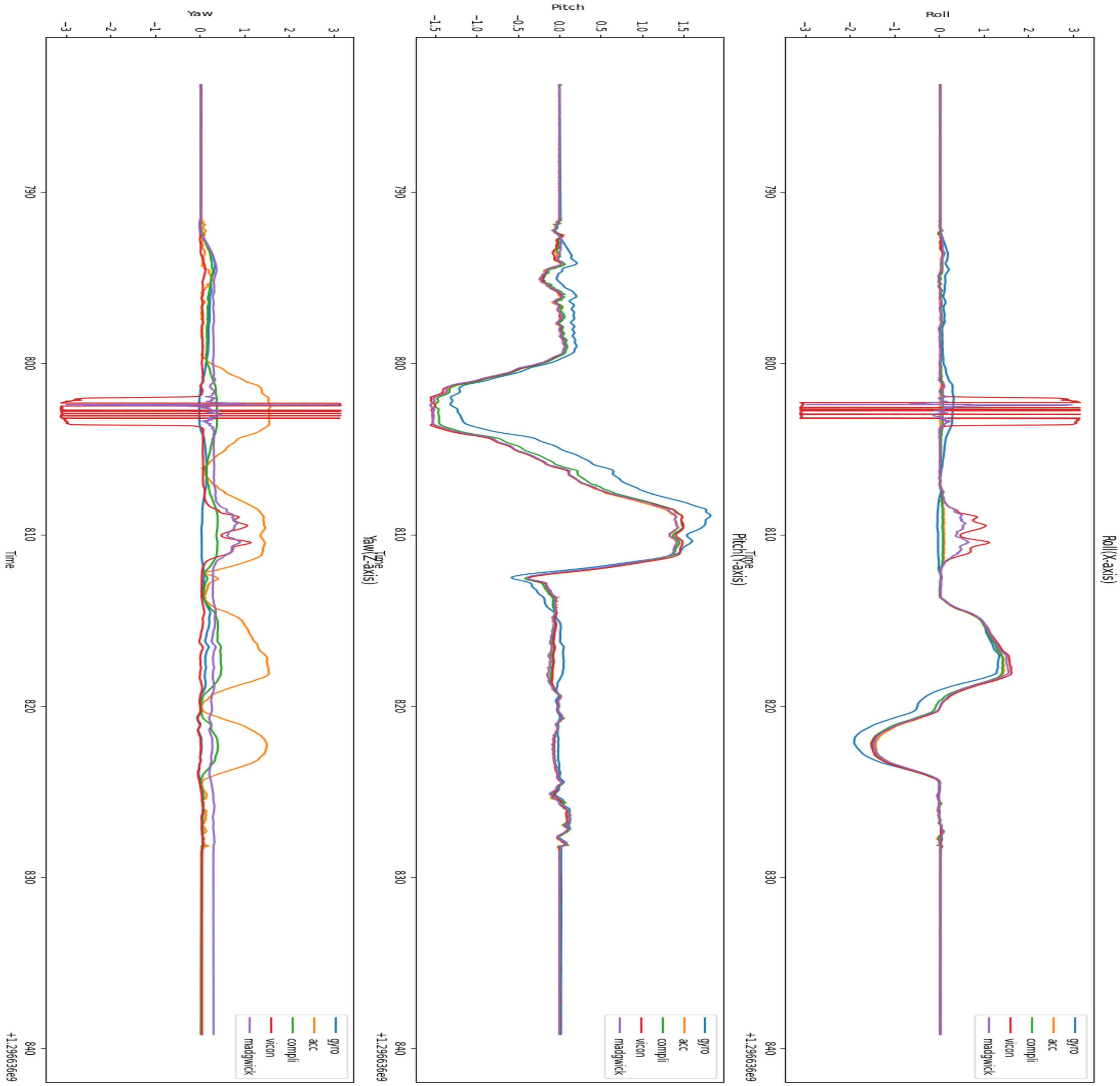

Fig. 1. Roll Pitch Yaw angles for data set 1

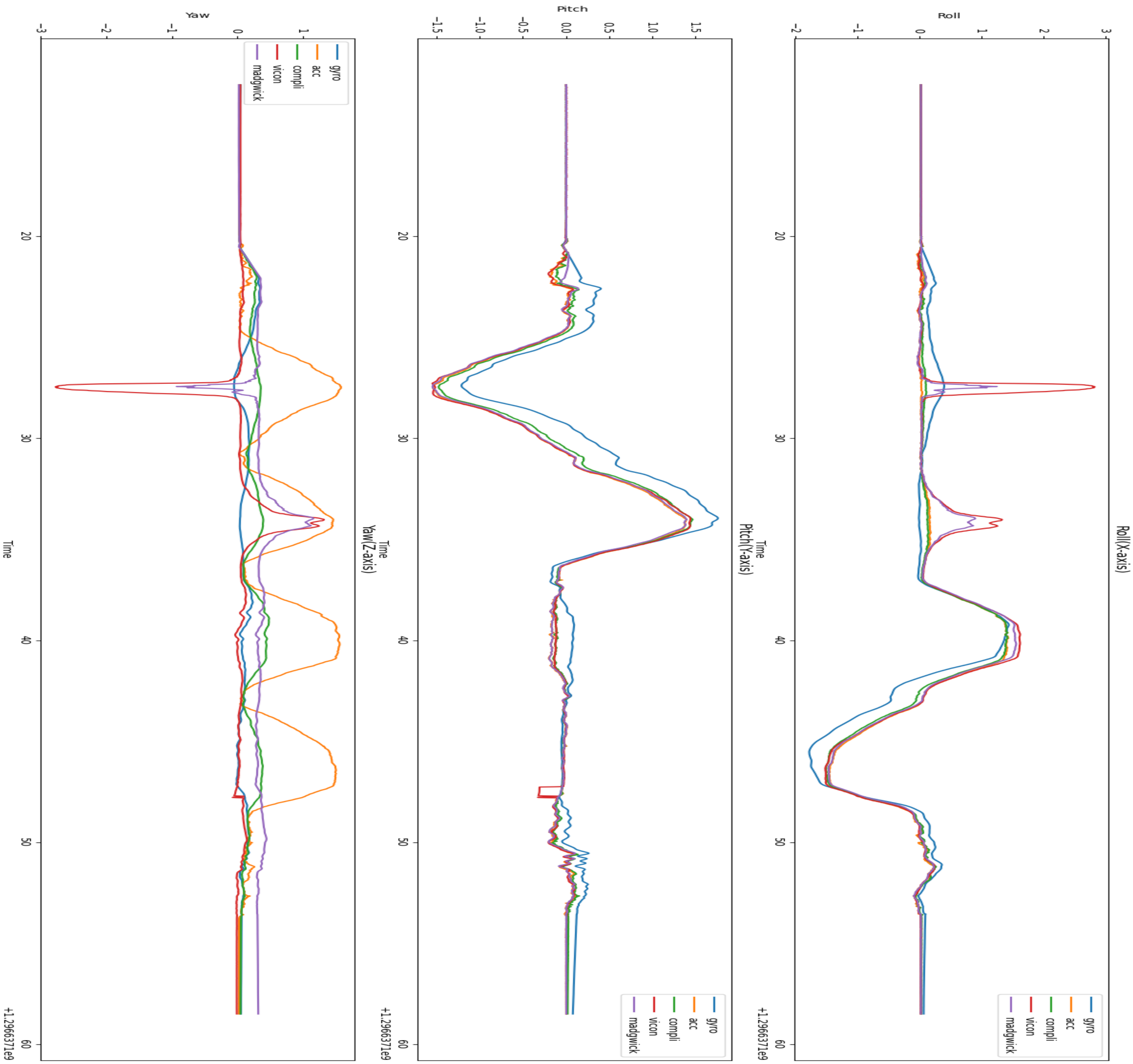

Fig. 2. Roll Pitch Yaw angles for data set 2

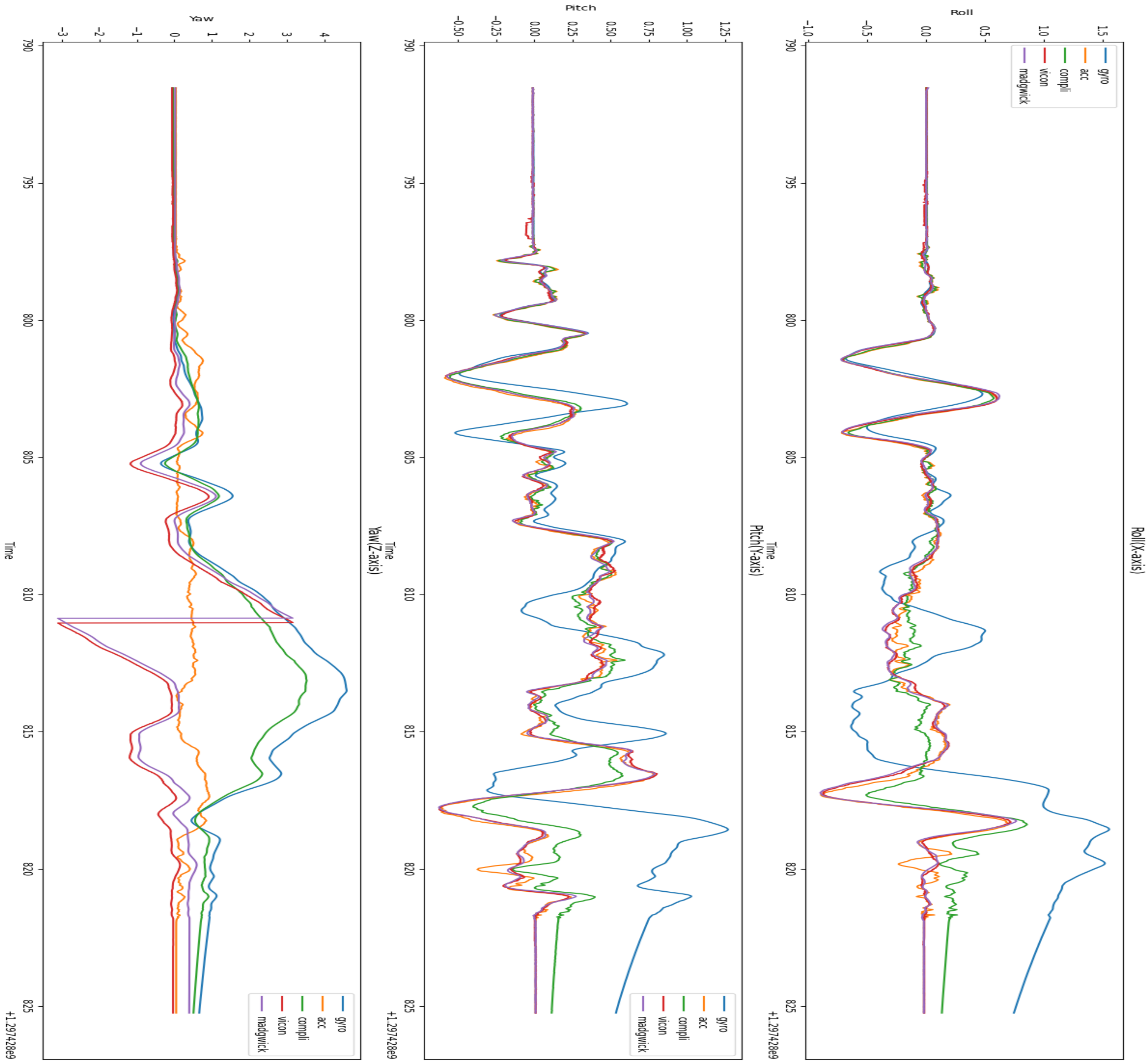

Fig. 3. Roll Pitch Yaw angles for data set 3

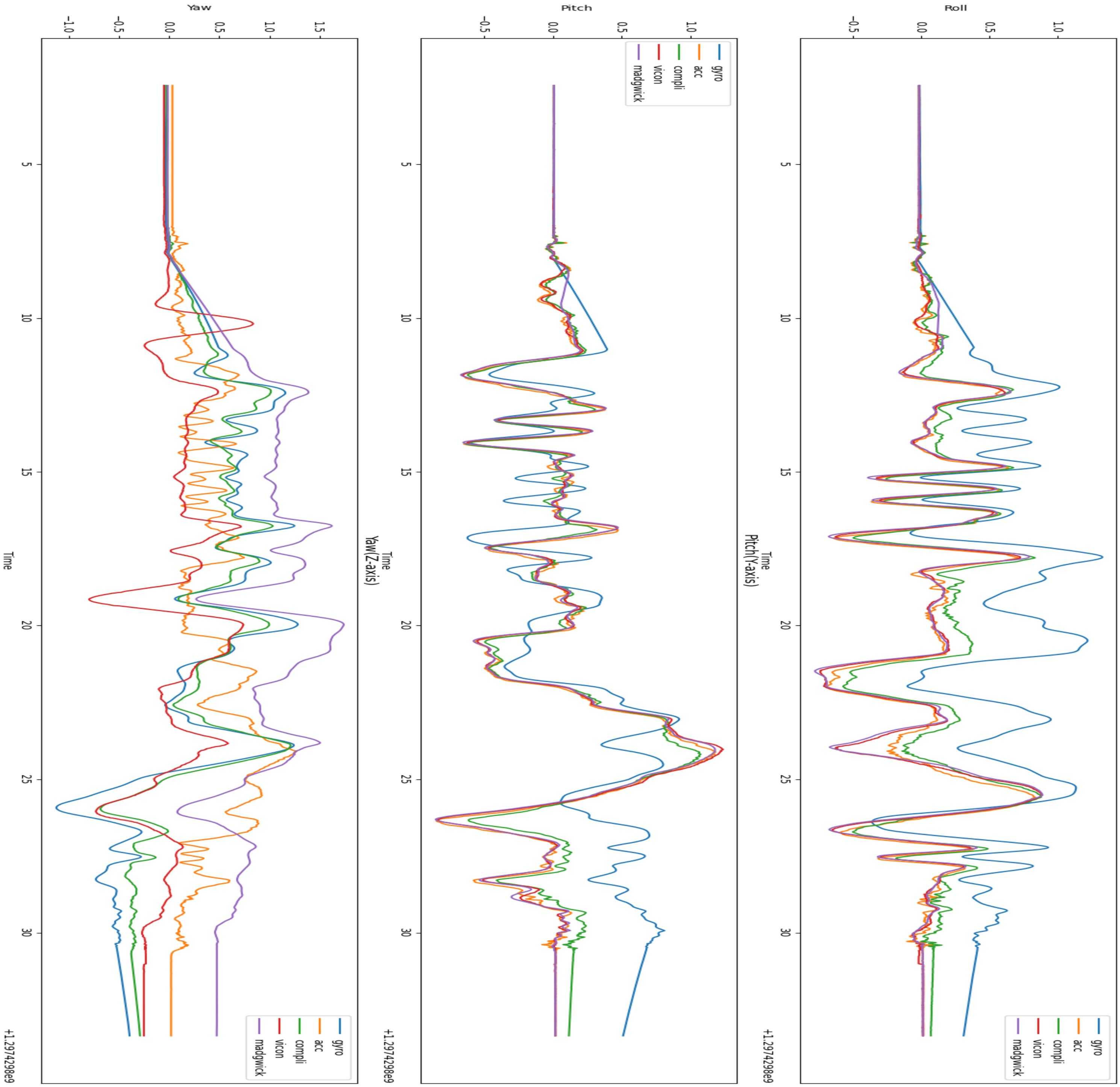

Fig. 4. Roll Pitch Yaw angles for data set 4

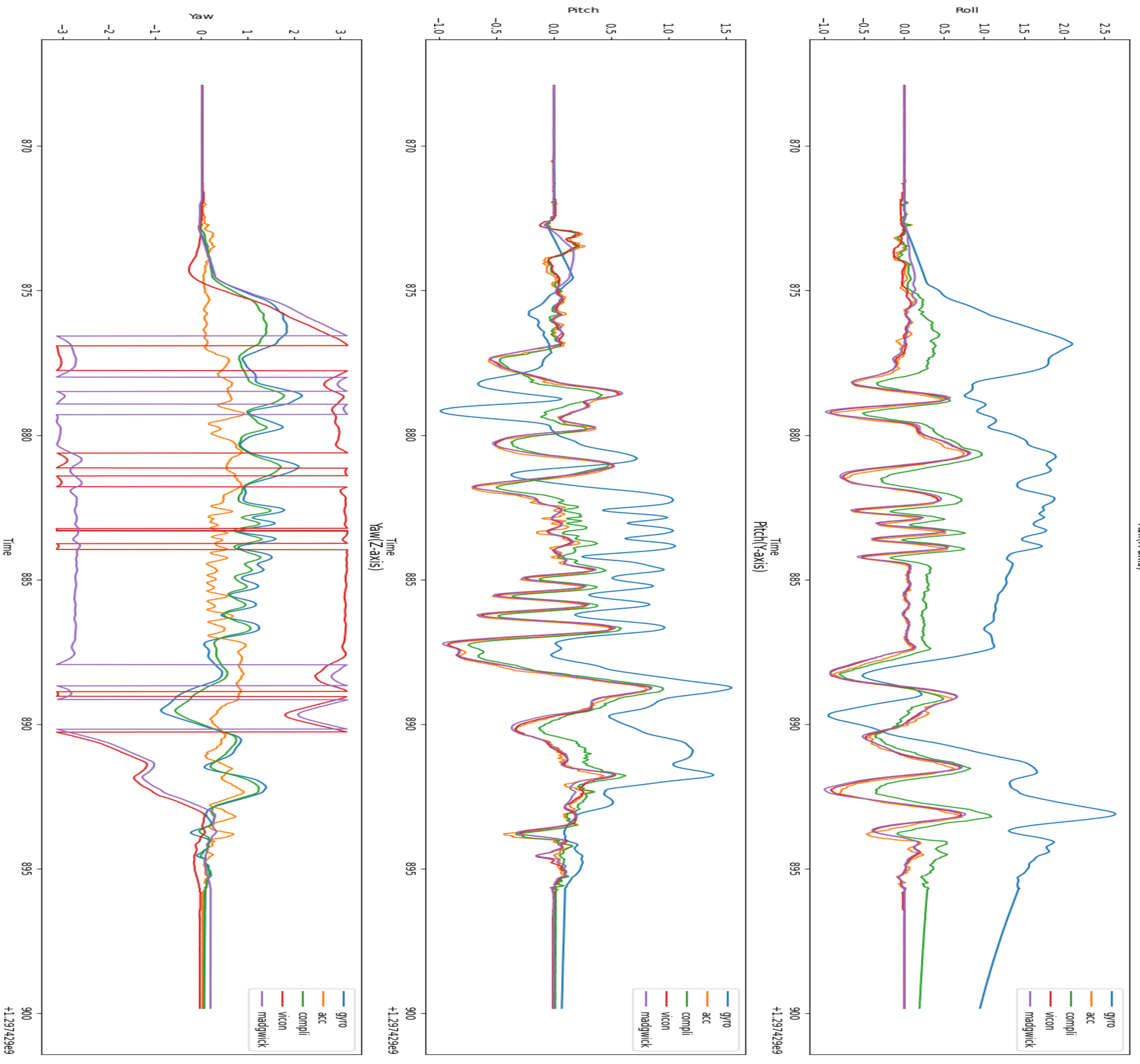

Fig. 5. Roll Pitch Yaw angles for data set 5

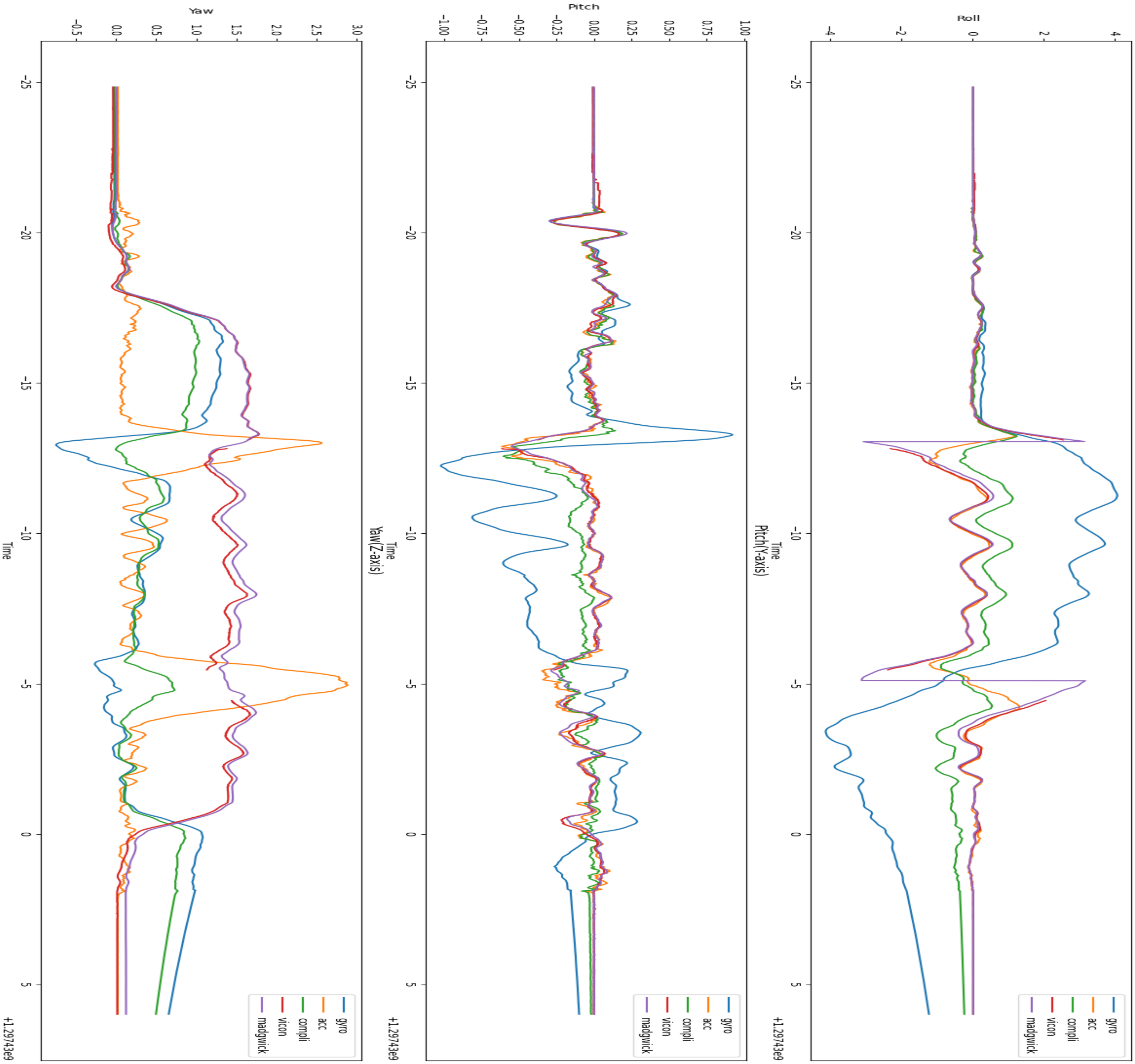

Fig. 6. Roll Pitch Yaw angles for data set 6

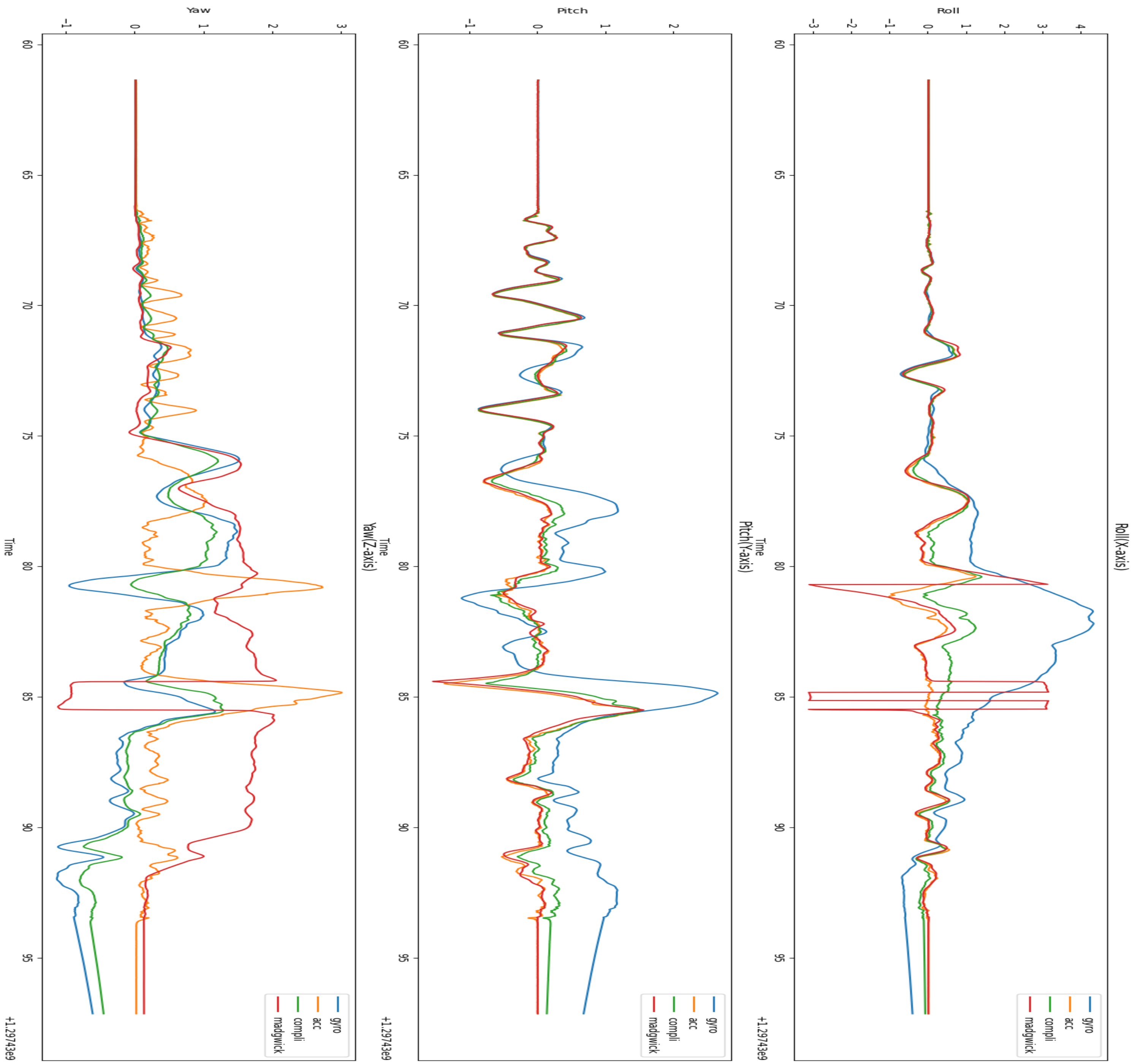

Fig. 7. Roll Pitch Yaw angles for test set 1

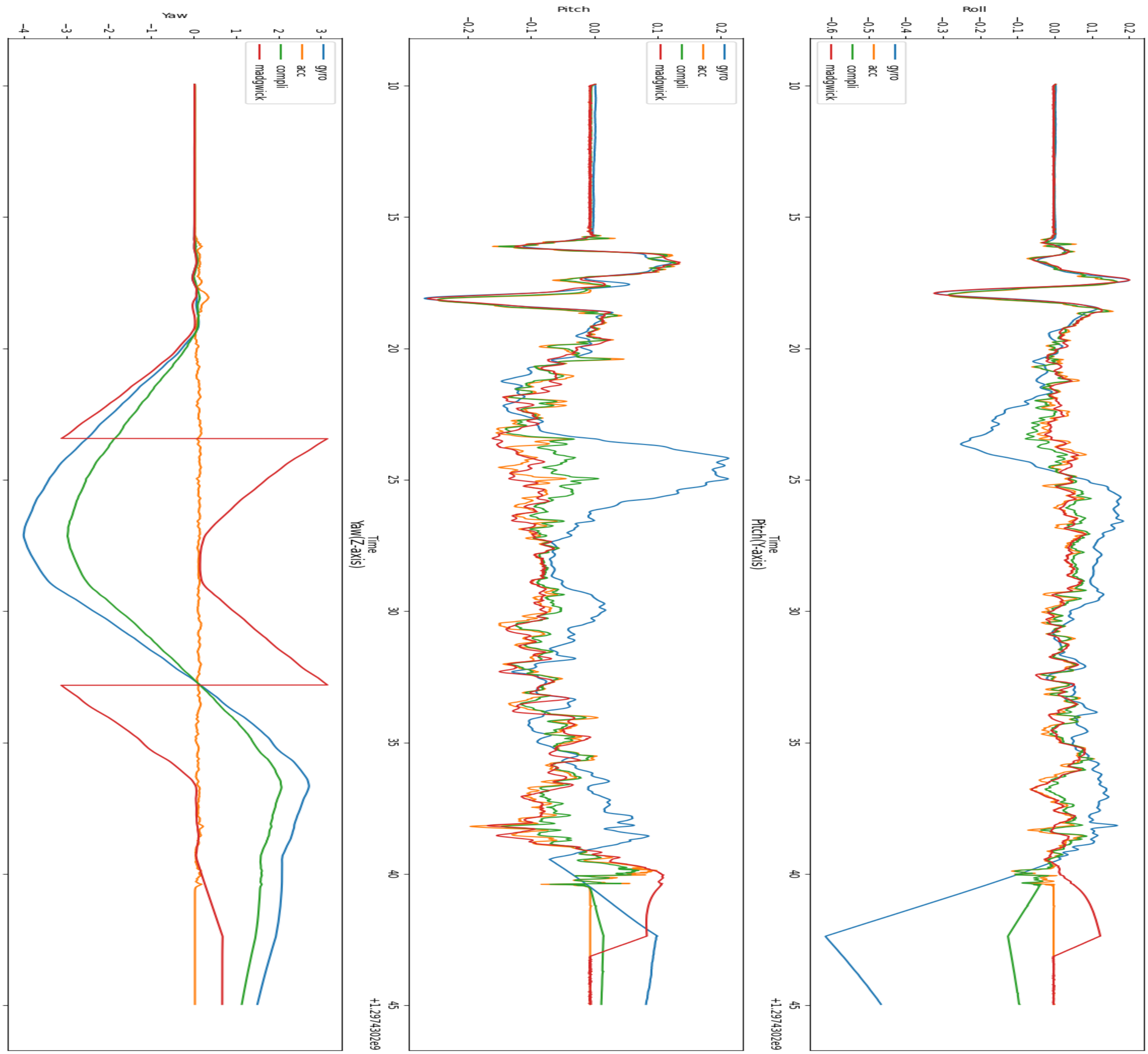

Fig. 8. Roll Pitch Yaw angles for test set 2

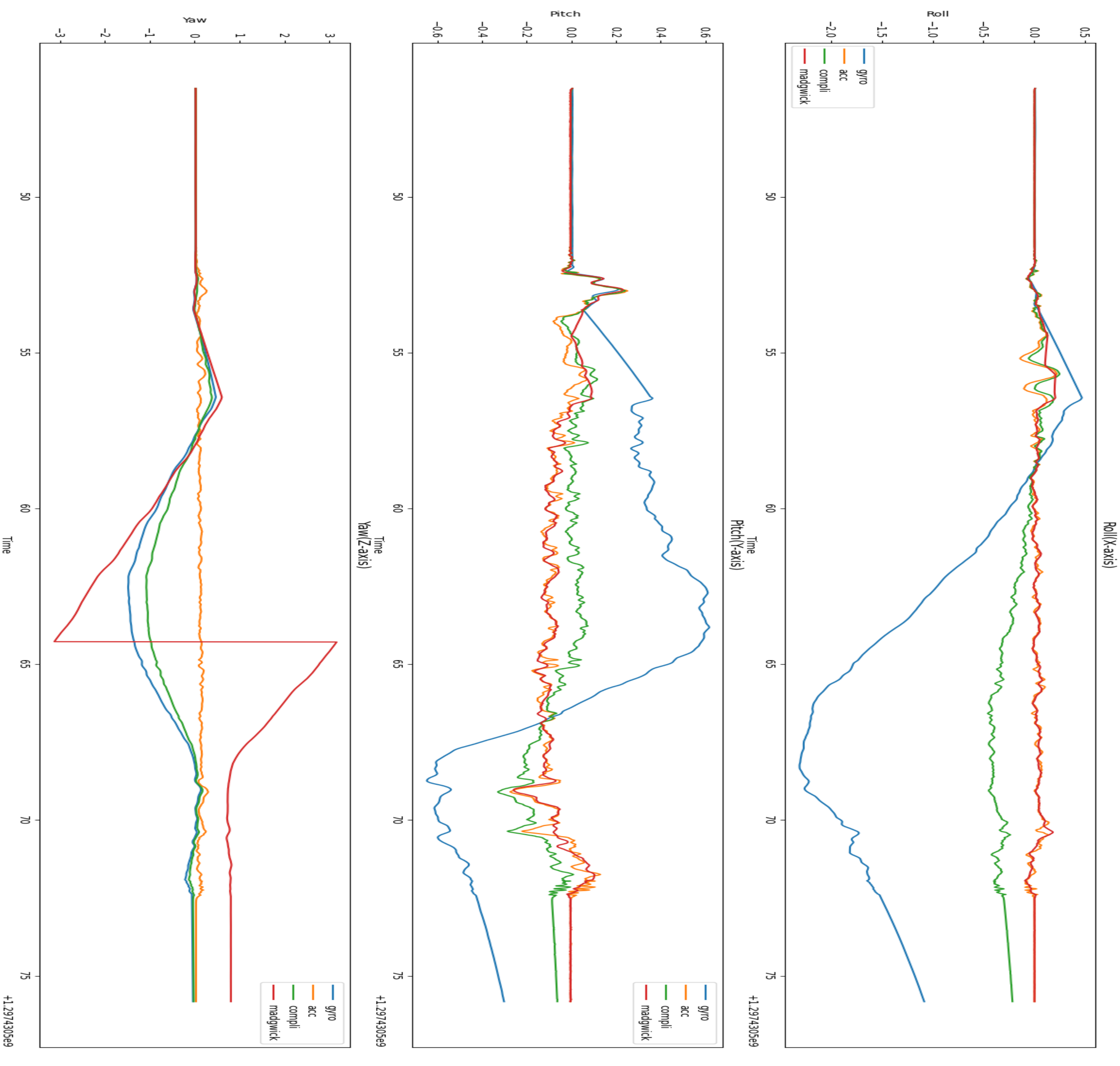

Fig. 9. Roll Pitch Yaw angles for test set 3

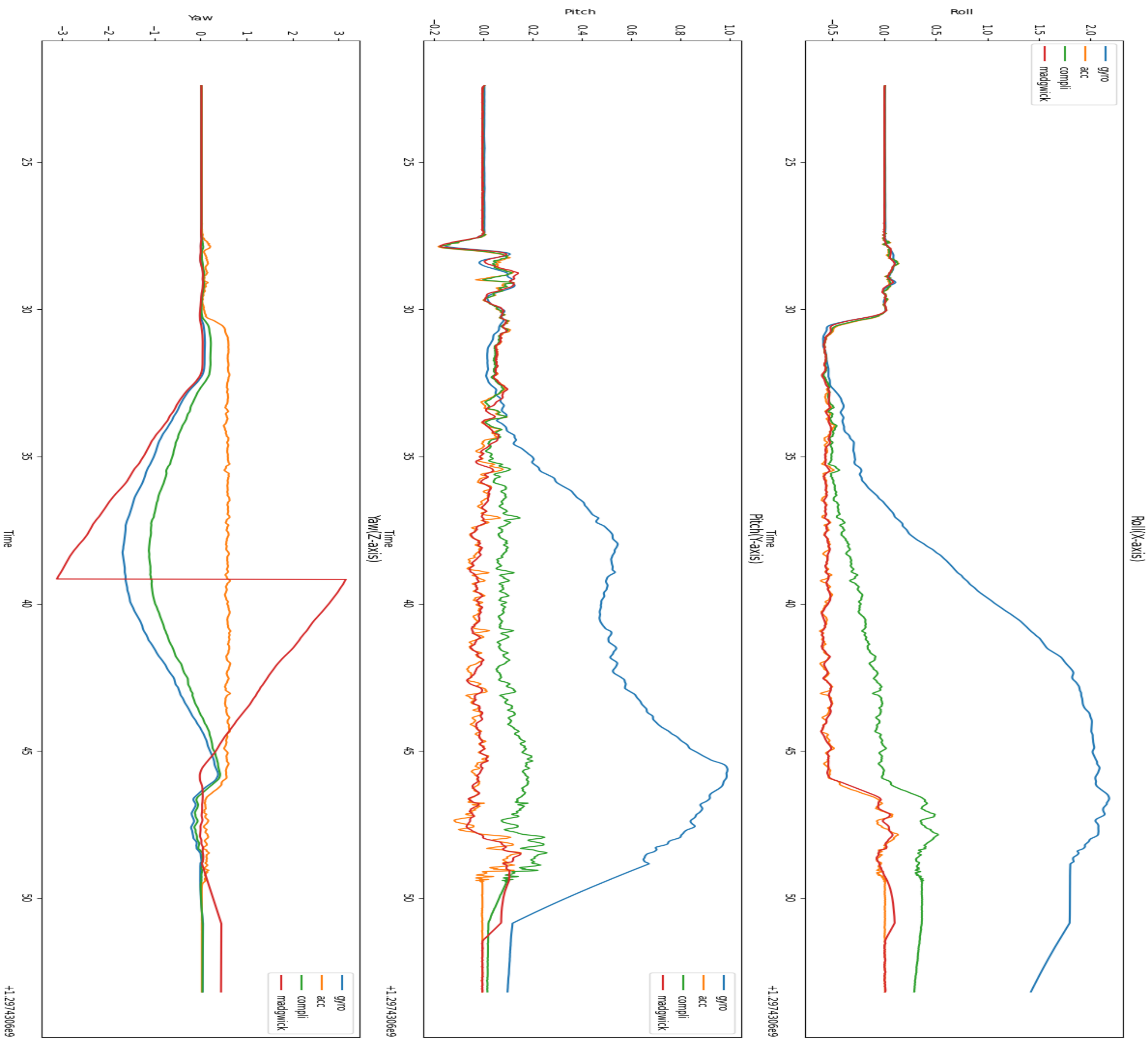

Fig. 10. Roll Pitch Yaw angles for test set 4

VI. VIDEOS

The videos comparing the orientation estimated using the different methods can be found at videos

VII. CONCLUSION

In this project we implemented a Madgwick filter and a complimentary filter to estimate the orientation of a 6-DOF IMU. The orientation estimated using the filters is compared with the ground truth orientation obtained from a vicon motion capture system. The results show that the Madgwick filter is better at estimating the orientation than the independent sensors and the complimentary filter.

REFERENCES

[1] Complementary filter: link
[2] Madgwick filter: link