Pedestrian dead reckoning

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1 IMU calibration analysis

The commercial IMU sensors could potentially have quite a few systemic and random errors in them. Using a simple calibration experiment, it is possible to eliminate the two most common ones - bias and scale factor. Bias error is a constant value that shifts the IMU measurements and the scale factor adjusts the slope of the measurement line. A simple experiment of measuring the stationary values of the IMU along all directions are noted for different orientations of the coordinate system. Only the readings along the axis through which the gravity force acts is used for the calibration. The values generated when the axis is facing towards and away from the ground is used to calculate the bias and scale factor.

	Bias - Acc	Scale Factor - Acc
X	0.0021817	-0.000327044
Y	0.0169198	-0.000656106
Z	-0.0043685	0.000124924

(a) Bias and Scale factor of Acceleration

	Bias - Gyro	Scale Factor - Gyro
X	-0.004215	-0.993074083
Y	0.001228541	-0.985698374
Z	-0.001368177	-0.971665299

(b) Bias and Scale factor of angular velocity

Figure 1: Final Calibration values

2 Trajectory plot and drift estimation

The most critical step in converting IMU data into trajectory is to construct the transformation matrix. We applied three methods:

1. **Euler angle:** We multiply the angular velocity obtained by the IMU and the time interval (time stamp) to obtain the Euler angle(pitch, roll, yaw) for each time interval. These Euler angles are then used to form the rotation matrix, thereby converting the acceleration from the body frame to the local frame. The initial trajectory drift is 79.95 m and the calibrated trajectory drift is 52.47 m.

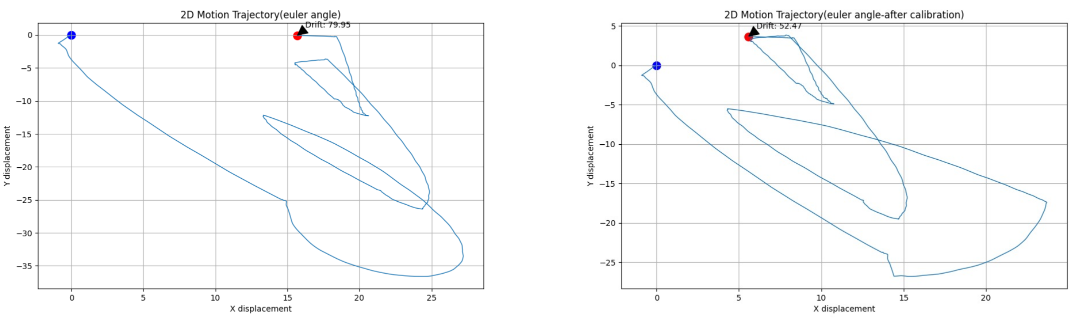

Figure 2: Trajectory plot(Euler angle)

2. **Direction cosines:** Also using angular velocity, we iteratively construct the transform matrix based on the previous transform matrix. The core formula is based on the Formulas 5.74-5.88 in *Fundamentals of Inertial Navigation, Satellite-based Positioning and their Integration*[1]. The initial trajectory drift is 15.03 m and the calibrated trajectory drift is 11.24 m.

3. **Quaternion:** We extract the 'orientation' information directly from the IMU as the quaternion and convert it into a transformation matrix according to Formula 5.93 in *Fundamentals of Inertial Navigation, Satellite-based Positioning and their Integration*[1]. The most effective way of parameterizing the transformation matrix is to use the quaternion method. The initial trajectory drift is 15.00 m and the calibrated trajectory drift is 11.52 m.

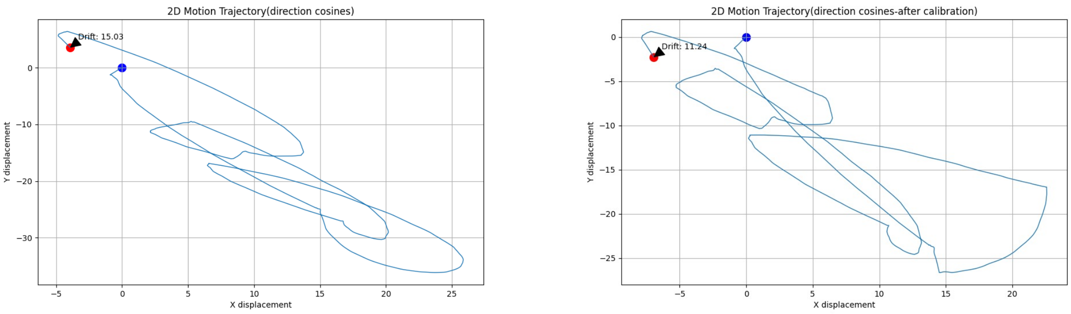

Figure 3: Trajectory plot(Direction cosines)

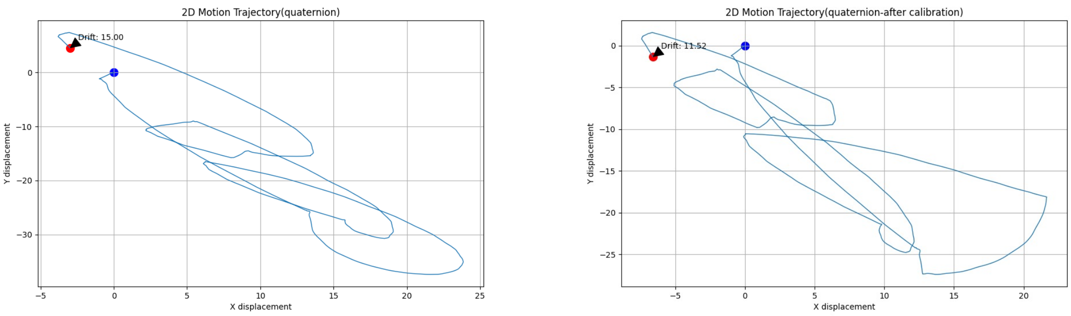

Figure 4: Trajectory plot(Quaternion)

3 Brief discussion

It can be observed from the results that the Euler angle method produces the largest drift value. This is mainly because the rotation represented by Euler angles has nonlinear characteristics and is susceptible to gimbal lock. On the other hand, quaternions and directional cosine matrices (DCM) provide relatively close results, and the directional cosine matrix is more suitable when dealing with complex geometric and dynamic calculations, although it is more computationally intensive. In contrast, the quaternion method is the most efficient processing method of the three.

We did another experiment, which processed the three-axis accelerations and subtracted the average values respectively to reduce the influence of gravity. The trajectory plot was greatly improved, but it is obvious that this is not the core of improving accuracy, just a trick.

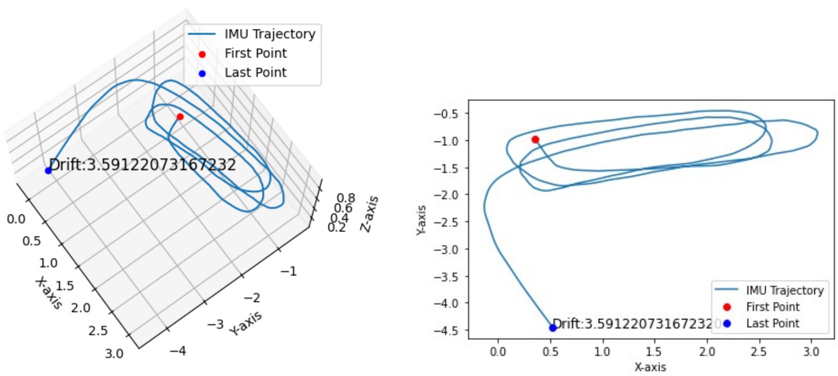

Figure 5: Trajectory plot(Quaternion)

But no matter which method is used, the trajectory that appears is difficult to be consistent with the perfect three-circles we imagined. Considering that the IMU estimates position and attitude by integrating the data twice, any small measurement error (such as the gravity component) will continue to amplify with the integration, and any sensor will inevitably be affected by noise, which also aggravate the error to some extent.

As for how to improve the quality of the trajectory, we can consider multi-sensor fusion, filtering such as Kalman, using more advanced algorithms such as SLAM and using high-precision IMU. This is also the direction of our next research.

References

[1] Aboelmagd Noureldin, Tashfeen B Karamat, and Jacques Georgy. *Fundamentals of inertial navigation, satellite-based positioning and their integration*. Springer Science & Business Media, 2012.