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# Simulation Research on Attitude and Position Solution of Multi-rotor UAV Based on Virtual Multi-sensor

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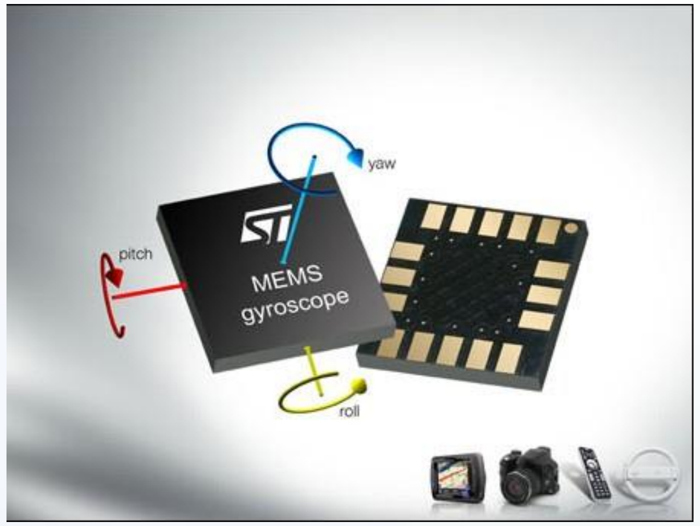
# Part 01

## Introduction

# Background

With the development of MEMS technology and computer technology, the measurement of small aircraft attitude generally adopts a low-cost **strap-down inertial measurement unit** (IMU), which is mainly composed of **a low-cost gyroscope**, **an acceleration sensor** and **an electronic compass**. The MEMS gyroscope has temperature drift characteristics, and the acceleration sensor is affected by the vibration of the aircraft during flight. The electronic compass is a magnetoresistive sensor that is easily interfered by external magnetic fields.



MEMS gyroscope

MEMS accelerometer


electronic compass

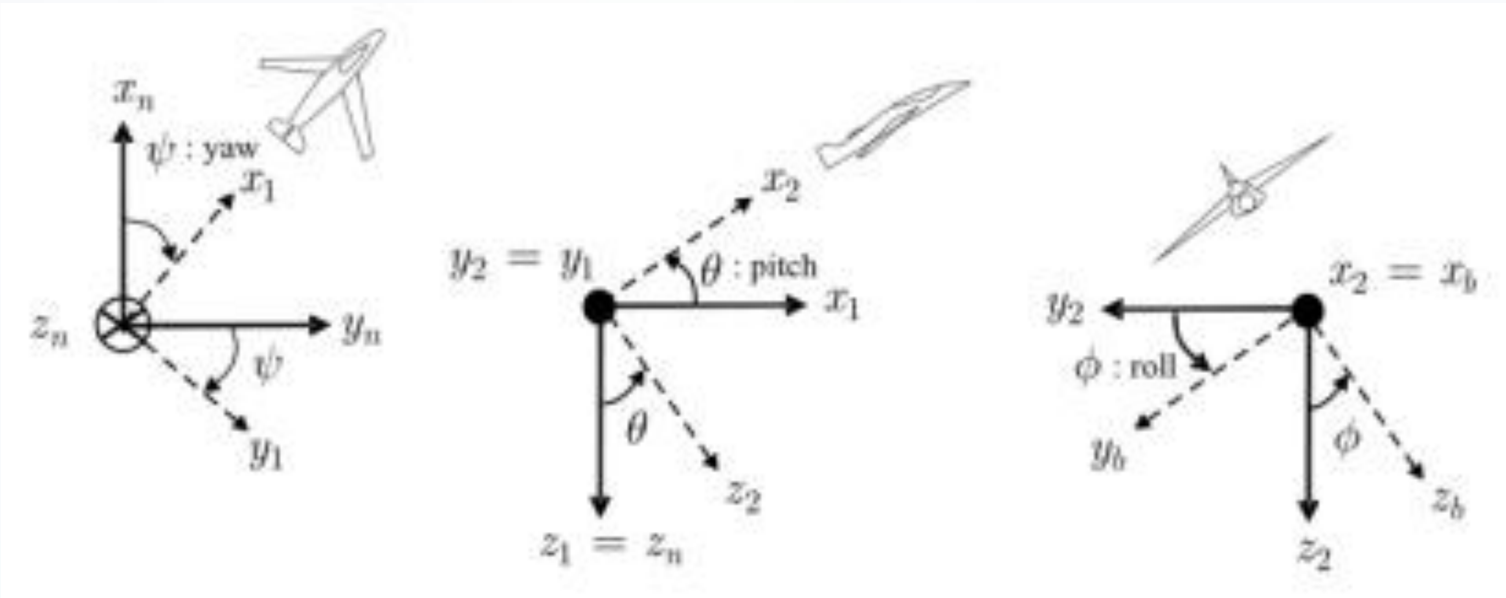
Therefore, how to integrate the data of IMU multi-sensor, and filter out external interference, and obtain high reliability and high-precision attitude data is very challenging. This paper will explore the working principle of the multi-rotor UAV airborne sensor, the attitude and position calculation and simulation based on sensor data fusion.

# Part 02

# Euler Angle Attitude Description System Principle Model

# Euler Angle

**Euler angle** is a very intuitive method, which is widely used in the attitude control of UAV. It consists of three sets of angular parameters that uniquely determine the position of the rotating object. The inertial reference coordinate system undergoes three basic rotations around a fixed point to obtain the body coordinate system. In these three rotations, the rotation axis is a certain coordinate axis of the coordinate system to be rotated, and the rotation angle is the Euler angle.




Euler Angle And Coordinate System Conversion Diagram

The UAV flight control system generally adopts the sequence of **Z-Y-X**, that is, first around the Z axis, then around the Y axis, and then around the X axis, and finally reaches a certain posture.

# Euler Angle

$$\vec{r}_n = C_b^n \vec{r}_b = \begin{bmatrix} c_{11} & c_{12} & c_{13} \\ c_{21} & c_{22} & c_{23} \\ c_{31} & c_{32} & c_{33} \end{bmatrix} \vec{r}_b \qquad (2\text{-}1)$$

**It is called the direction cosine matrix from the body coordinate system to the inertial reference coordinate system.**

$$C_n^b = C_x(\phi) C_y(\theta) C_z(\psi) = \begin{bmatrix} \cos\theta\cos\psi & \cos\theta\sin\psi & -\sin\theta \\ \sin\phi\sin\theta\cos\psi - \cos\phi\sin\psi & \sin\phi\sin\theta\sin\psi + \cos\phi\cos\psi & \sin\phi\cos\theta \\ \cos\phi\sin\theta\cos\psi + \sin\phi\sin\psi & \cos\phi\sin\theta\sin\psi - \sin\phi\cos\psi & \cos\phi\cos\theta \end{bmatrix} \qquad (2\text{-}2)$$

**the inertial reference coordinate system→the body coordinate system**

$$C_b^n = (C_n^b)^{-1} = (C_n^b)^{\mathrm{T}} \qquad (2\text{-}3)$$

**the body coordinate system→the inertial reference coordinate system**

**from equations (2-1) and (2-3):**

$$\begin{cases} \tan\psi = \dfrac{c_{21}}{c_{11}} \\ \sin\theta = -c_{31} \\ \tan\phi = \dfrac{c_{32}}{c_{33}} \end{cases} \qquad (2\text{-}4) \quad \Rightarrow \quad \begin{cases} \psi = \arctan\dfrac{c_{21}}{c_{11}} \\ \theta = \arctan(-c_{31}) \\ \phi = \arctan\dfrac{c_{32}}{c_{33}} \end{cases} \qquad (2\text{-}5)$$

**It should be noted that when $\theta = \pm\pi/2$ or $c_{11} = c_{21} = 0$, the Euler angle solution will be singular, that is the gimbal deadlock problem.**

# Part 03

## Sensor Analysis

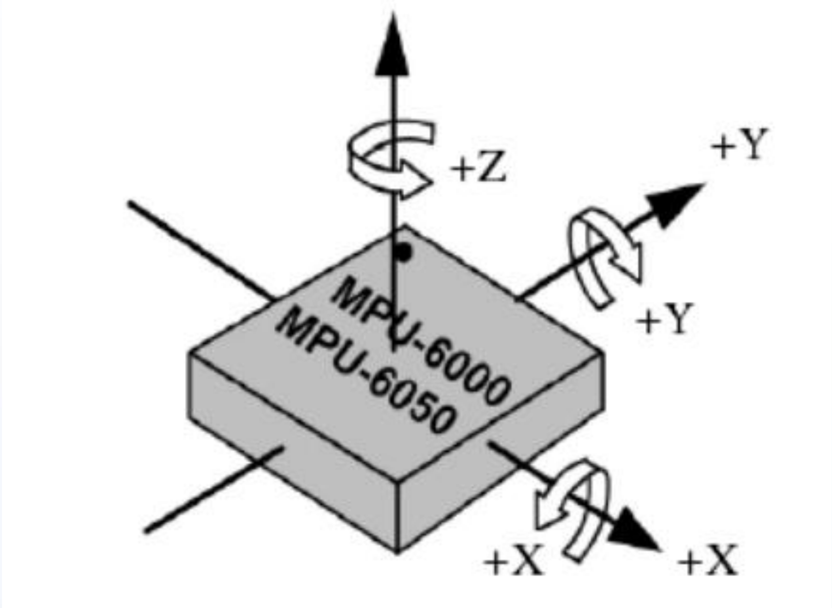
# Sensors

The sensors of the multi-rotor drone are like the senses of the human body, and they can be used to sense their posture and position. Sensor information can be used to make state estimates, and the more information, the more accurate the state quantity estimate. Usually, the multi-rotor unmanned opportunity is equipped with sensors such as :

- MEMS three-axis accelerometer
- MEMS three-axis gyroscope
- GPS
- magnetometer
- barometer

…

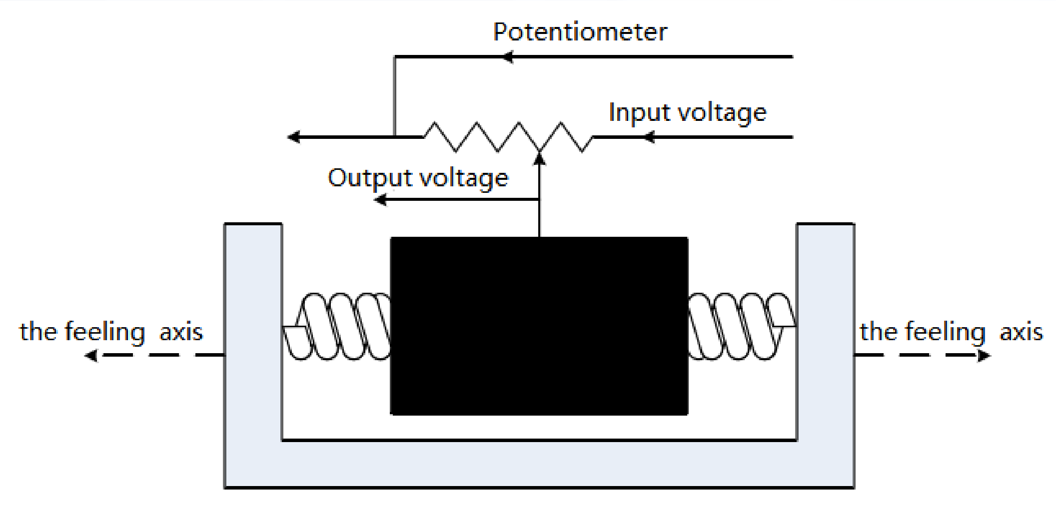
# 1.MEMS gyroscope




Gyro principle

**the MEMS gyroscope** is a **Coriolis-based** sensor that detects the angular velocity of rotation. At present, in the multi-rotor UAV flight control system, **the gyroscope calibration method** is usually adopted to keep the aircraft in a simple state, measure the output value of the gyroscope multiple times and find the average value, and use this value as the zero point of the gyroscope. The drift value can be removed from the measurement in the future measurement.

# 2.MEMS accelerometer

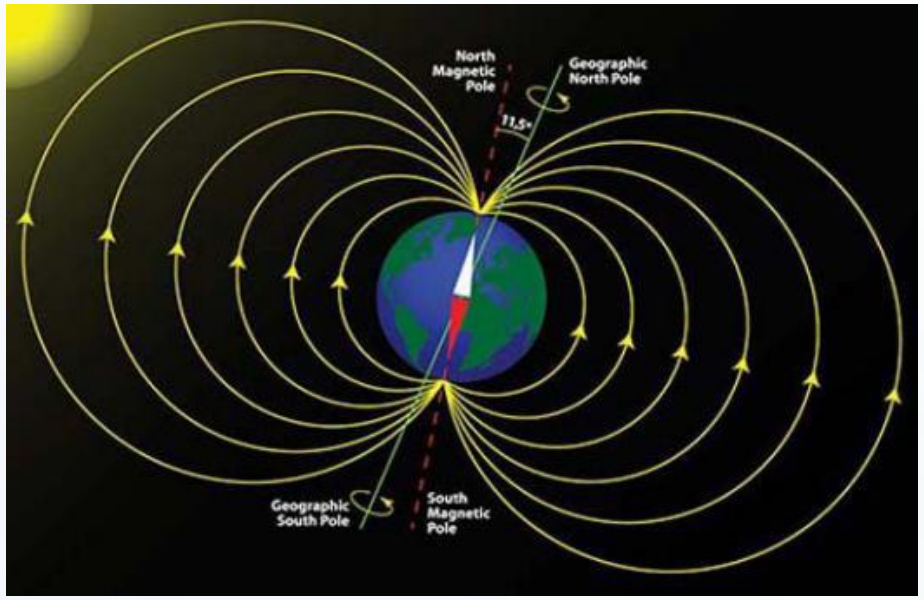



Accelerometer principle

The sensitive mass compresses the spring under the action of the inertial force to deform, and **the displacement** is converted into **an electrical signal** by the displacement sensor, and the motion acceleration is indirectly measured by measuring the electrical signal. Accelerometer calibration in multi-rotor UAV flight control systems typically uses a **six-sided calibration**.

Accelerometers cannot distinguish between gravitational acceleration and motion acceleration and are easily affected by body vibration.

# 3.MEMS magnetometer

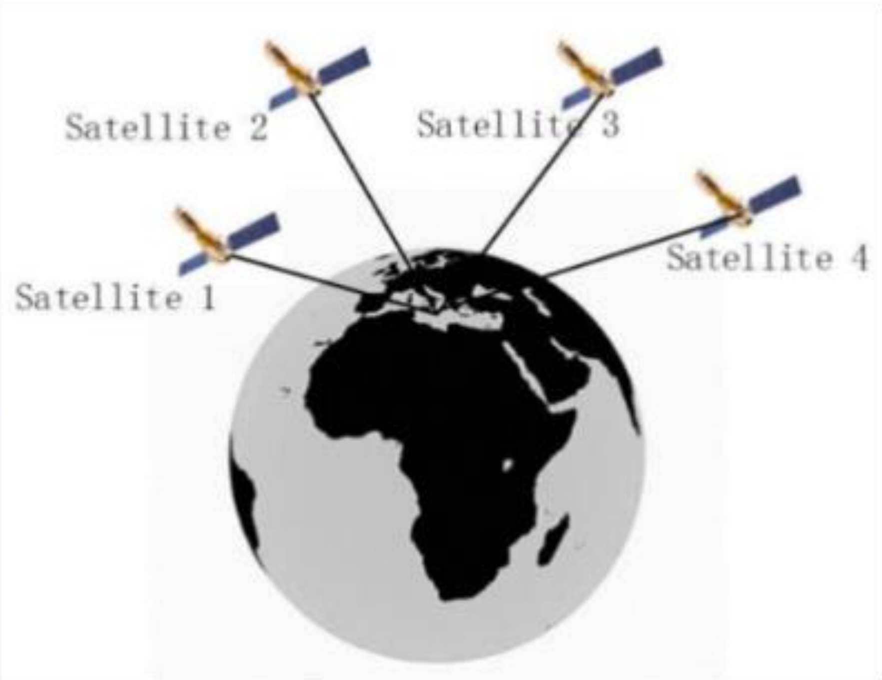



Earth's magnetic field and the Earth's rotation axis

The magnetometer can measure **the three-dimensional geomagnetic intensity** through the earth so that the magnetic field component of the earth's magnetic field on the horizontal plane can be used to obtain **the deflection orientation of the aircraft relative to the earth's magnetic field**. However, the magnetometer is extremely susceptible to interference.

At present, in the multi-rotor flight control system, the magnetic declination of the current position can be obtained by **using the latitude and longitude to perform the difference fitting by the look-up table method**.

# 4. GPS




GPS positioning principle

The principle of GPS positioning is to use t**he instantaneous position** of the GPS satellite as a known quantity to measure the distance between the known position satellite and the user receiver. Then, by synthesizing the measurement data of multiple satellites, the specific position of the user receiver can be determined.

The GPS positioning needs to calculate the **four unknowns**, that is, the three-axis coordinates and the clock difference of the user receiver in real time. And need to be synchronously received at least **four satellites**'s observation information.

# Part 04

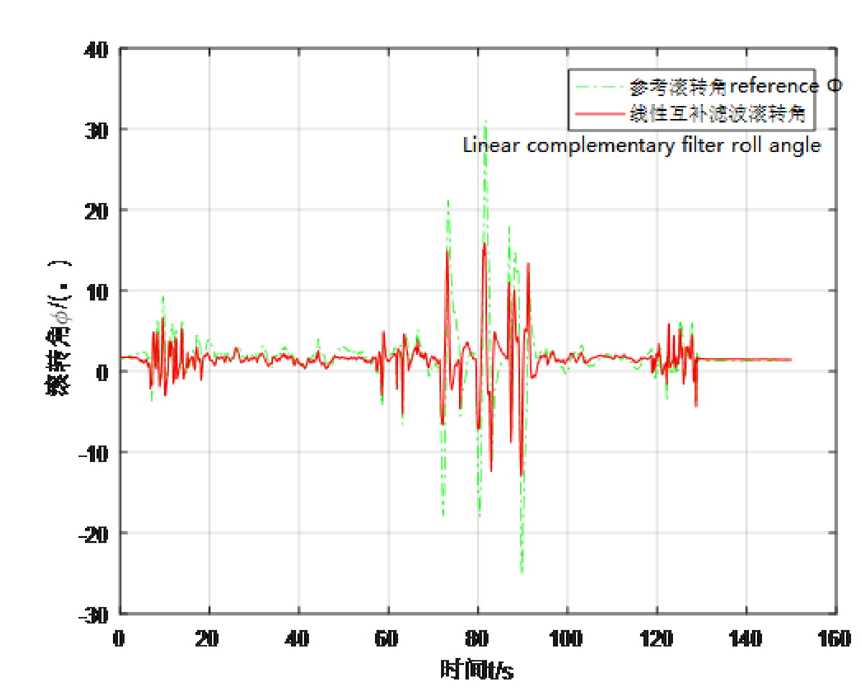
# Multi-rotor Aircraft Attitude Calculation And Simulation

# Attitude solution based on linear complementary filter

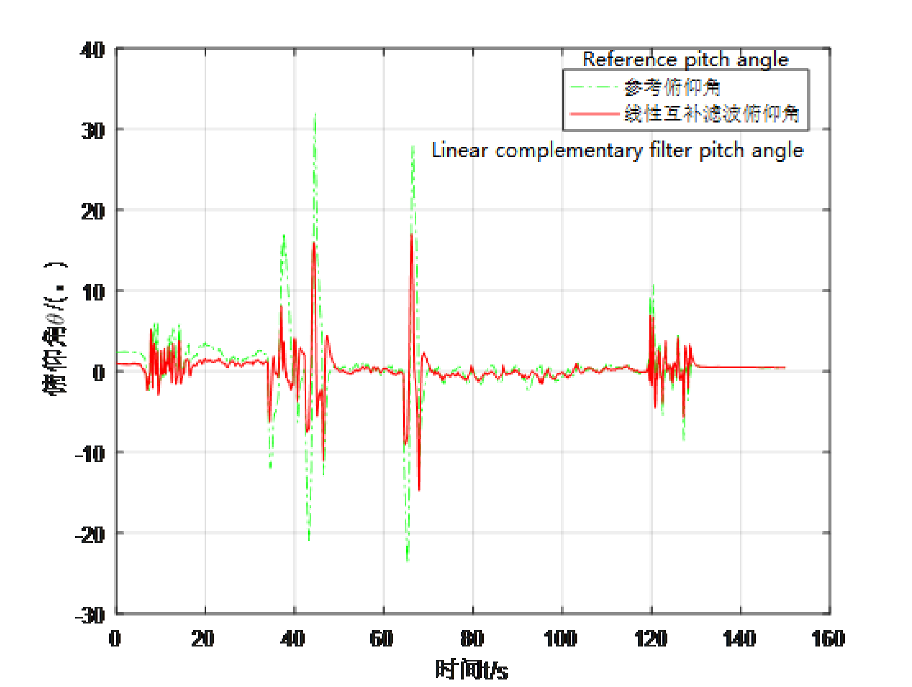
The basic idea of **the linear complementary filter** is to filter out the high-frequency noise measured by the accelerometer with a low-pass filter, and filter out the constant drift of the gyroscope with a high-pass filter.

Taking the pitching angle θ as an example, the form of linear complementary filter is deduced in detail.Similarly, a linear complementary filter with a roll angle and a yaw angle can be obtained separately.

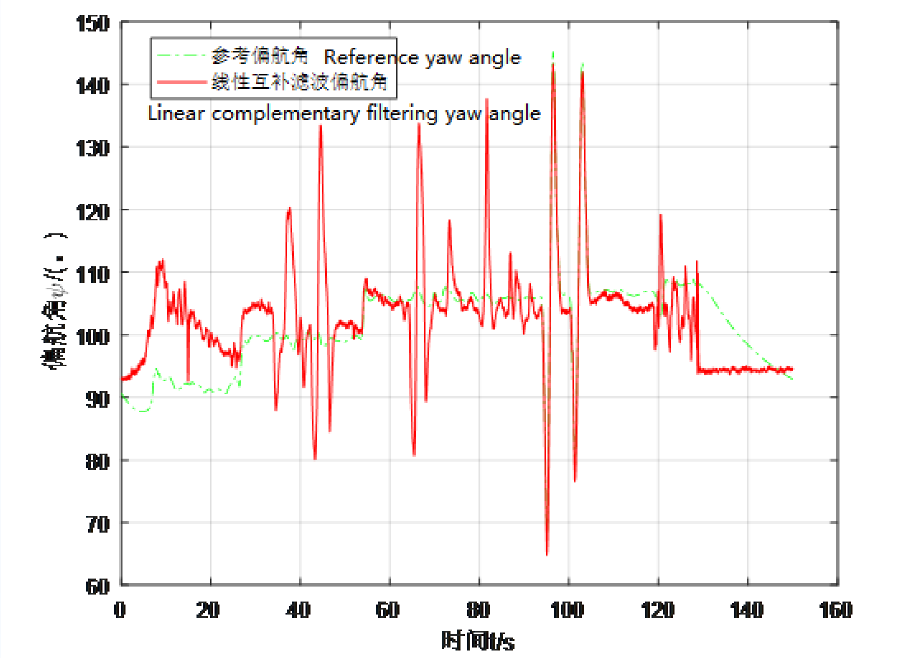
The linear complementary filter can track the actual attitude well under static or high frequency dynamic conditions.




(a) Linear complementary filter roll angle variation diagram




(b) Linear complementary filter pitch angle variation diagram

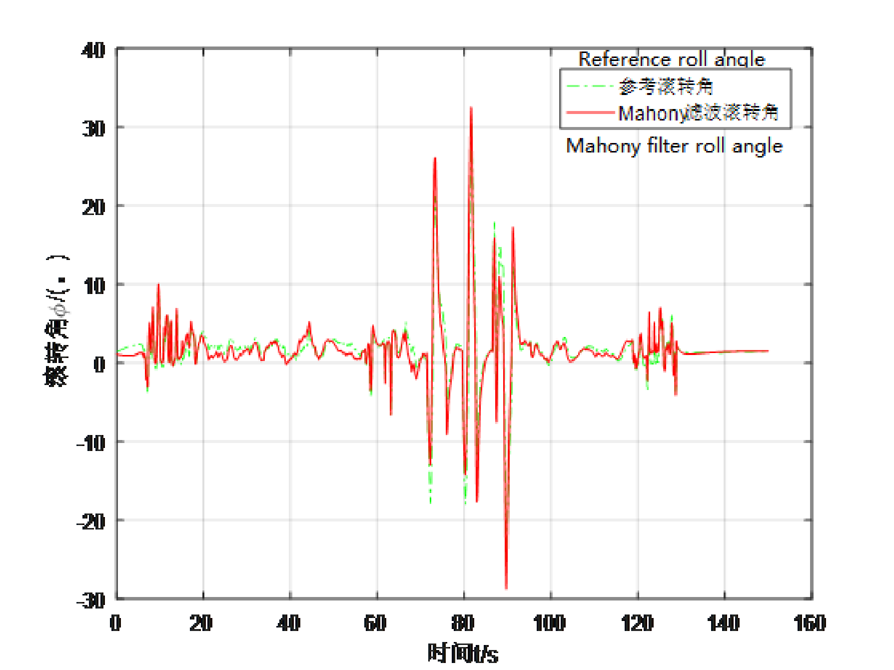



(c) Linear complementary filter yaw angle variation map

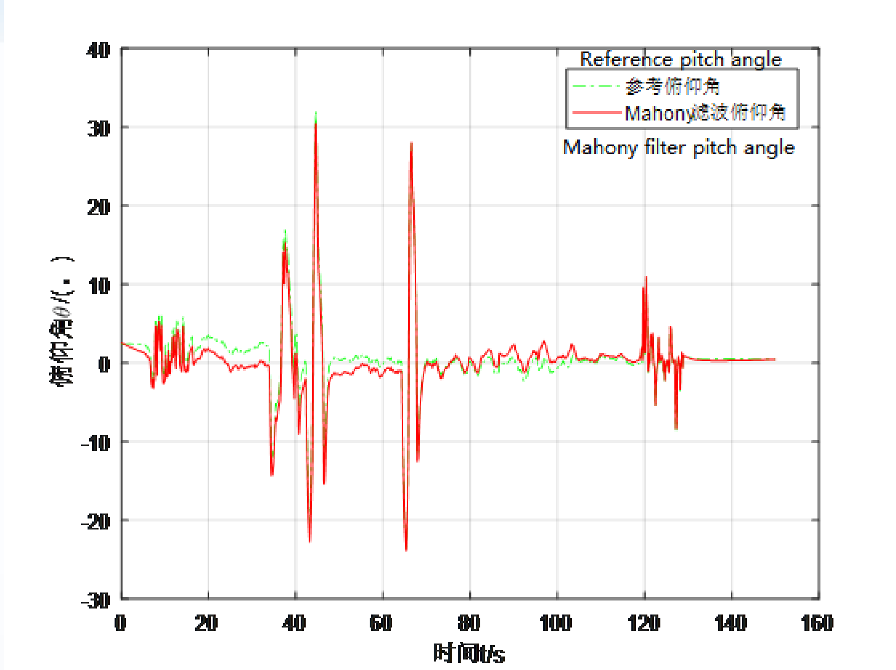
# Attitude solution based on nonlinear complementary filter

**The Mahony complementary filter** is a representative one of the nonlinear complementary filters . First, the deviation of the rotation matrix between the two coordinate systems is obtained, and then the rotation matrix is corrected to include the correct posture information, and the corrected attitude angle is obtained.

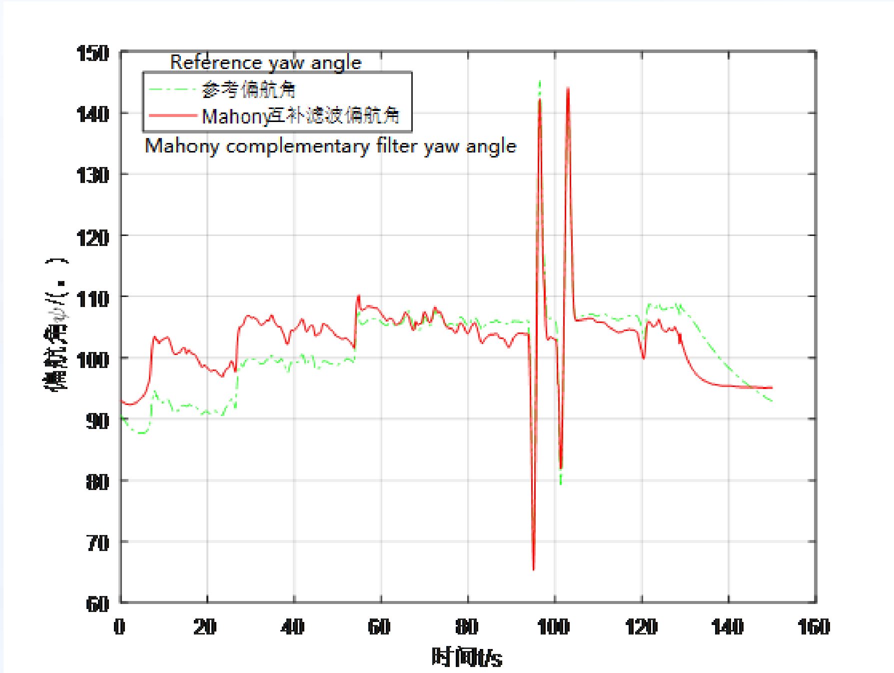
Using the same set of IMU measurement data, using MATLAB simulation verification for Mahony complementary filtering. Take the results are as follows:



(a) Mahony filter roll angle change diagram



(b) Mahony filter pitch angle change diagram



(c) Mahony filter yaw angle change diagram

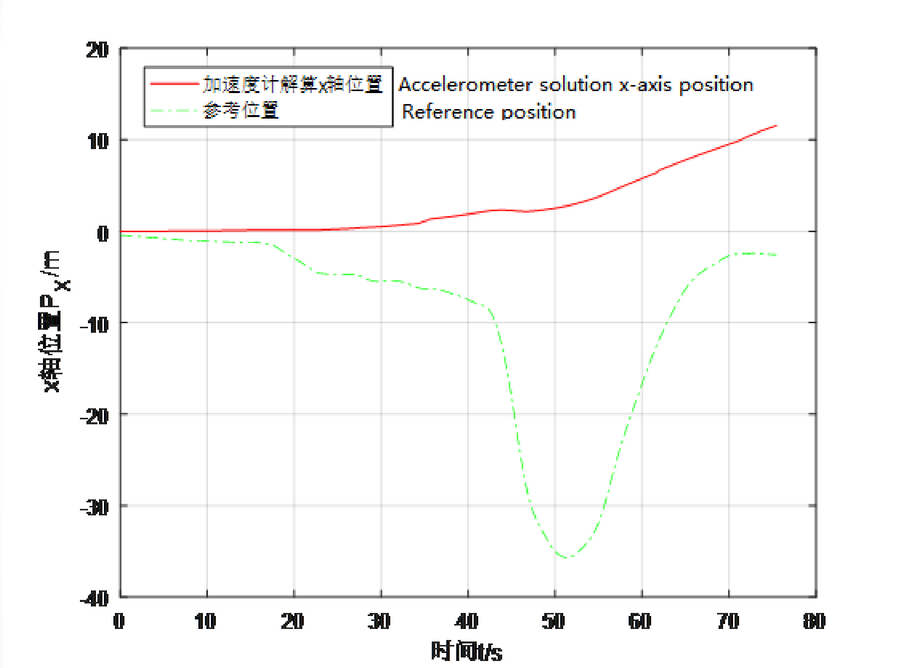
# Part 05

## Location Calculation Based On Kalman Filter

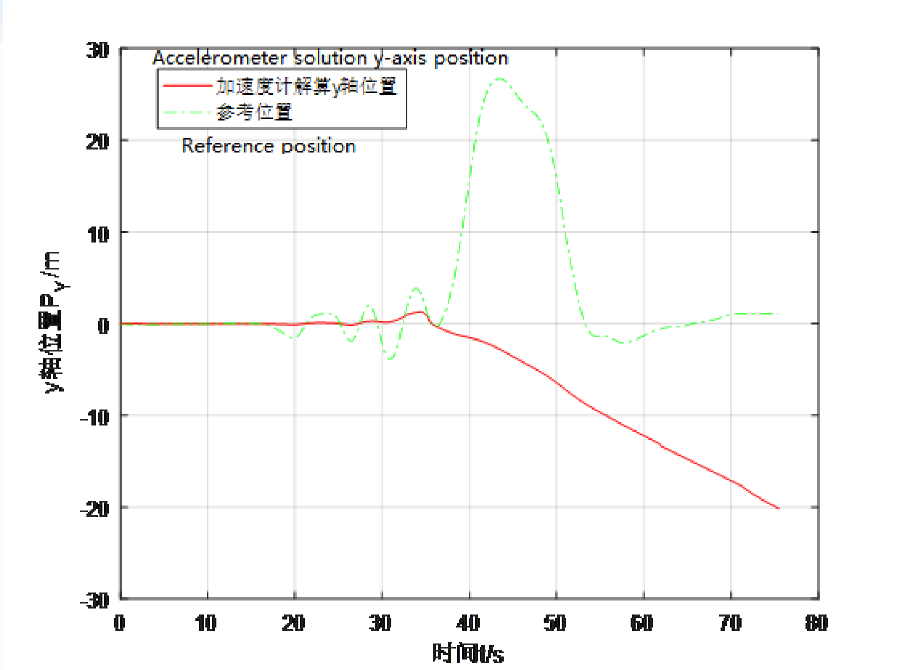
# Location calculation based on Kalman filter

In this section, **the Kalman filter** is used to fuse the position information of each sensor to solve the position information that satisfies the actual flight control. The basic idea is to use the state equation and the recursive method to obtain an optimal estimate of the target quantity based on the previous estimate and the current observation.

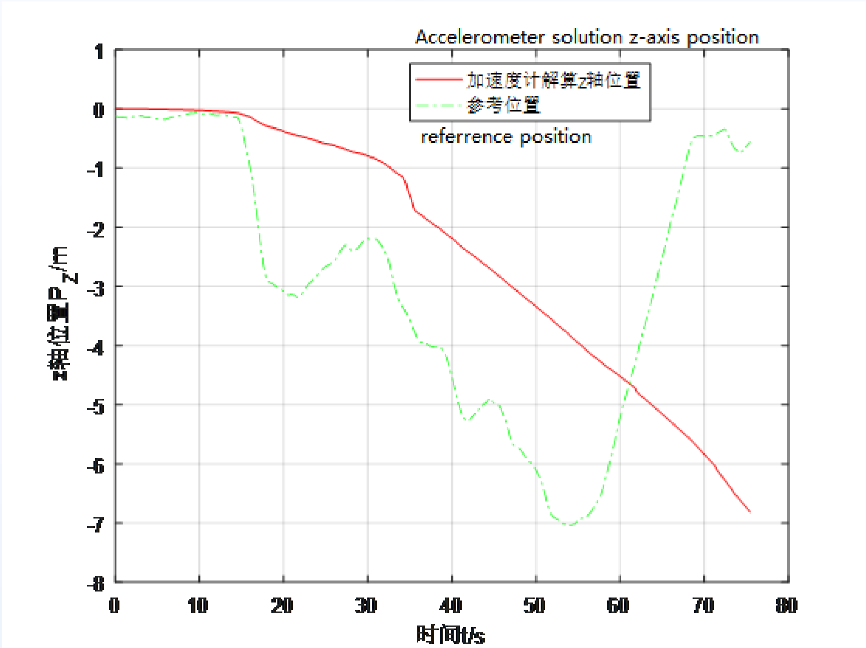
The position solution of the multi-rotor flight control system is to discretize the continuous system first, and then use the discrete Kalman filter equation.




(a) Accelerometer solution X-axis position change diagram




(b) Accelerometer solution Y-axis position change diagram



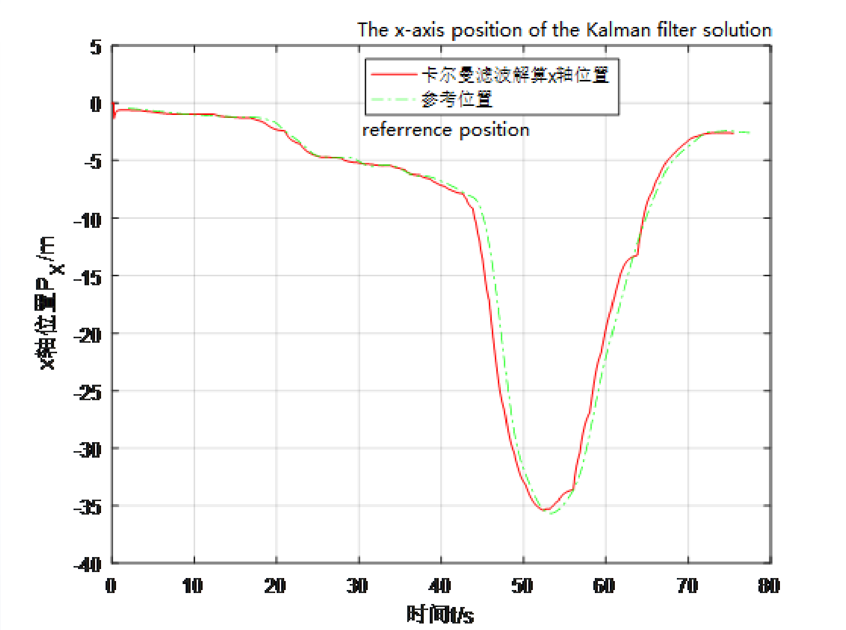

(c) Accelerometer solution Z-axis position change diagram

We can see that only the position solution calculated by the accelerometer measurement information deviates greatly from the actual position.

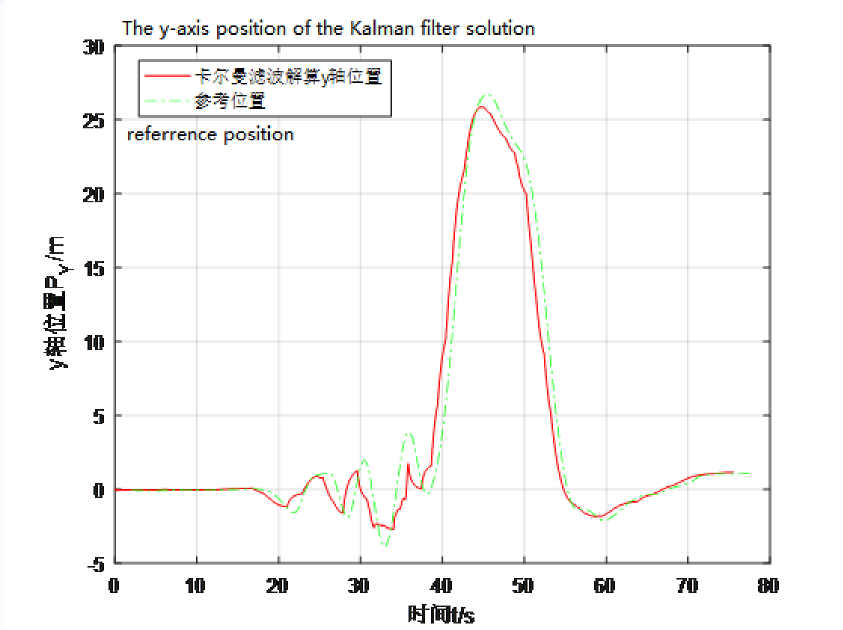
# Location calculation based on Kalman filter

When the GPS and barometer altimeter measurement information is added to correct the accelerometer information, the position calculation simulation results are as follows:

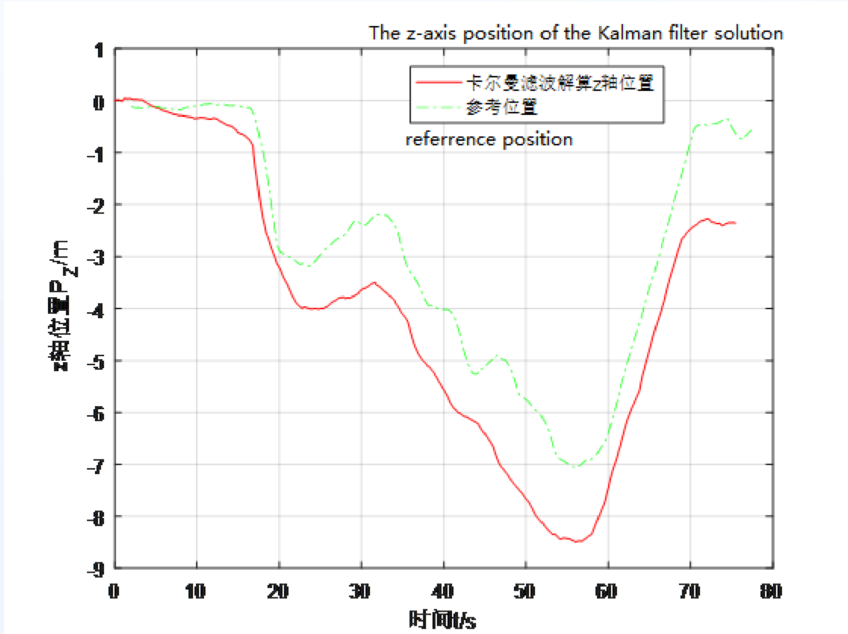
It can be seen that after the measurement information of the Kalman filter fusion accelerometer, GPS and barometric altimeter, the calculated horizontal position is very close to the reference position, and the height position is also obviously corrected.




(a)Kalman filter solves the X-axis position change diagram




(b) Kalman filter solves the Y-axis position change map




(c) Kalman filter solves the Z-axis position change diagram

# Part 06

## Conclusion

# Conclusion

- This paper mainly completed the attitude and position calculation of multi-rotor UAV based on virtual sensors. Firstly, **the measurement principle and calibration method** of various on-board measurement sensors are introduced. Since the attitude and position calculation errors are very large using only single sensor information, the three-axis position solution is based on **complementary filtering** and **Kalman filtering** based methods respectively. Calculate and perform simulation verification.
- The simulation results show that：
- The method of attitude calculation based on complementary filtering has a small amount of code and computation, but the optimization ability is limited because the weight assigned to each sensor is fixed.
- The position calculation method based on Kalman filter can dynamically adjust the weight distribution of the sensors, and can provide accurate real-time attitude and position information for multi-rotor drone flight.

THANKS FOR YOUR GUIDANCE