Application of Multi Sensor Fusion in Attitude Measurement of Crawler Mountain Forest Robot

Bin Liu and Yan Ren
Henan Forestry Vocational College, 2 Zhongzhou East Road, Luoyang, China
Email: 87570637@qq.com

Abstract. Due to the complex terrain of the special robots in mountain forests application environment and the roughness of the road, it is difficult to solve the problem of the measurement of robot's attitude, especially the real-time dynamic solution. In this paper, an attitude measurement system based on gyroscope, accelerometer and three-axis magnetometer multi-sensor fusion is proposed, and adds the complementary filtering algorithm to the attitude solution, the real-time dynamic attitude measurement of the robot is improved obviously.

1. Introduction
In the process of attitude control and attitude information calculation, the forestry tracked robot adopts gyroscope and accelerometer as the key sensor to obtain the attitude information. When the gyroscope is used alone, the result of attitude calculation will appear the integral drift over the time, meanwhile, the accelerometer is very sensitive to non-gravitational acceleration, which often leads to the failure of the sensor combination to obtain accurate dynamic inclination through the calculation of the component of gravity acceleration on three axes. In particular, the forest tracked robot will produce the centripetal acceleration and other non-gravitational acceleration components in dramatic shift, especially in the severe motion vector, the result of the calculations will be abnormal, the error it caused can not be accepted.

This paper presents an attitude measurement system based on gyroscope based on the above problems, and the complementary filtering technique is added to the attitude resolving algorithm, so that the measurement accuracy and real-time property of the real-time dynamic attitude measurement of the robot are obviously improved.

2. System Hardware Components
This system uses STM32F103 as the main control chip, using the timer, interrupt and serial port and other resources in the processor, and through the I2C bus to communicate with each sensor.

In this system, the MPU6050 chip is used to provide the acceleration component of gravity acceleration on three orthogonal axes, The MPU6050 is a motion sensor chip from InvenSense's highly integrated 3-axis accelerometer, 3-axis gyroscope, and DMP (Digital Motion Processor) digital motion processor. The MPU6050 features a 16-bit ADC to digitize the gyro and accelerometer outputs.

The HMC5883L chip is used to provide the magnetic field information in this system, which is used to calculate the steering angle of the vehicle. HMC5883L is produced by Honeywell company, a three axis magneto resistive sensor, integrated circuit includes an amplifier, automatic degaussing drive, calibration, the compass precision control to 1~2°.

The block diagram of the system is shown in figure 1:
3. Algorithm Research

Three axis acceleration sensor can be used to determine the attitude of the sensor in the whole range. Assuming that gravity is the sole factor of the source of acceleration, θ exists only exist in the xOy plane, and ϕ is the angle between the z-axis and the gravity vector. As shown in figure 2.

Using the basic trigonometric identities as shown in equations (1), (2), (3). Calculations Determine the angle between each axis of the gyroscope and the reference position individually for 3-axis tilt detection. The direction in which the x-axis and y-axis of the device are in the horizontal plane (0g field) is usually be selected as the reference position and the z-axis is perpendicular to the horizontal plane (1g field). Among them, θ represents the angle between the horizontal plane and the x-axis of the accelerometer, and ψ represents the angle between the horizontal plane and the y-axis of the accelerometer. Φ represents the angle between the horizontal plane and the z-axis of the accelerometer.
\[
\lambda = \tan^{-1}\left(\frac{-A_{X,OUT}}{\sqrt{A_{Y,OUT}^2 + A_{Z,OUT}^2}}\right)
\]
(1)

\[
\gamma = \tan^{-1}\left(\frac{A_{Y,OUT}}{\sqrt{A_{X,OUT}^2 + A_{Z,OUT}^2}}\right)
\]
(2)

\[
\psi = \tan^{-1}\left(\frac{\sqrt{A_{X,OUT}^2 + A_{Y,OUT}^2}}{A_{Z,OUT}}\right)
\]
(3)

Assuming that the error caused by the X axis of the micro accelerometer is caused by the change of the ambient temperature of the device, then the equation (3) becomes:

\[
\lambda_i = \tan^{-1}\left(\frac{-\left(A_{X,OUT} + \Delta a_x\right)}{\sqrt{A_{Y,OUT}^2 + A_{Z,OUT}^2}}\right)
\]
(4)

In the formula, \(\Delta a_x\) — Error on X axis of accelerometer.

The McLaughlin series substituted into the arc tangent function.

\[
\lambda'_i = \sum_{n=0}^{\infty} (-1)^n \frac{1}{2n+1} \left(\frac{-\left(A_{X,OUT} + \Delta a_x\right)}{\sqrt{A_{Y,OUT}^2 + A_{Z,OUT}^2}}\right)^{2n+1} (-1 \leq \Delta a_x \leq 1)
\]
(5)

The error caused by acceleration error is

\[
\Delta \lambda = \lambda_i - \lambda'_i
\]
(6)

When the error caused by the offset and the error caused by the sensitivity mismatch superimposed, the detection error angle will become quite large, probably completely beyond the acceptable range of angle detection applications. To reduce this kind of error, It should be calibrated imbalance and sensitivity of the transmitted signal according to a three-axis magnetometer and the inclination angle calculated using the calibrated output acceleration Three axis magnetometer output change equation (7) as follows:

\[
A_{OUT}[g] = A_{OFF} + \left(Gain \times A_{ACTUAL}\right)
\]
(7)

In the formula, \(A_{OFF}\) — Offset error, the unit is g; \(Gain\) — the gain of acceleration, the ideal value is 1; \(A_{ACTUAL}\) — the true acceleration and the target value of the accelerometer, the unit is g.

When the target axis is measured, the orthogonal axes are in the 0g field, so the method is helpful to minimize the cross shaft sensitivity. Using these values, the offset can be subtracted first from the acceleration measurement, then the results obtained will be divided by the gain compensation value, the rapid change of the angle signal by a very small weight coefficient, to reduce the impact of the mutation signal on the whole, with the previous posture results of the first order complementary filter solution, resulting in calibration of the post-compensation data.

\[
angle(k) = angle(k - 1) \times 0.97 + \theta_{acc}(k) \times 0.03
\]
(8)
In the formula, $\text{angle}(k)$ is the first $k$ complementary angle filtering; $\text{angle}(k-1)$ is the $k$-1 times complementary angle filtering; $\text{theta}_{\text{acc}}(k)$ is the $k$-th complementary angle obtained by the accelerometer sampling calculation.

4. The Results of the Experiment

The actual vehicle test site selection conditions for the rugged mountain road, no more than 25 degrees in any direction. The experimental platform is a special type of forestry special robot developed by Henan forestry Career Academy. Before the experiment, all the sensor is calibrated, the measurement is carried out in four kinds of conditions, these four kinds of tests is possible to keep running in the robot were 18, 30, 40km/h left turn and 30km/h right turn traveling.

The test shall be carried out in both left and right directions. The test shall be carried out at least three times in each direction. At the beginning of each test, the body shall be in the middle of the runway and the whole test procedure shall be recorded.

Figure 3 shows the results of a test tracked robot using only a gyro and an accelerometer to calculate the cornering inclination before the output is corrected and in different vehicle conditions.

![Figure 3](image)

Figure 3. Single sensor solution robot attitude angle

Figure 4 shows the results of the test tracked robots using a single accelerometer to calculate the roll angle in different vehicle conditions. In figure 4-1c shows the maximum lateral angle of 35.7921 degrees, the minimum solution of the roll angle is 19.7307 degrees, and the changing trend and the actual situation there is a big gap, it is concluded that it is not advisable to calculate the roll angle by using the acceleration alone.
The output of the tracked robot under different test condition in the accelerometer calibration using first-order complementary filtering solution side angle results as shown in Figure 4-2, In figure 4-2c the maximum roll angle is 25.4436 degrees, the minimum solution of the roll angle is 7.552 degrees, the corrected calculation results are more close to the real condition. And the algorithm is stable, even if the initial value is not set properly, the solution can still converge to the true value.

5. Conclusions and Expectations
In this paper, a novel data fusion algorithm for dynamic attitude measurement of forestry crawler robot is presented, the output of the meter three axis gyroscope and accelerometer data were corrected by using three axis magnetic field, the use of complementary filtering technique will be the three data fusion, so as to calculate the dynamic posture of robot. According to the test and data off-line simulation analysis of tracked robots, the complementary filtering method has the application and popularization value in the tracked robot manipulation and stability test system.

6. References
[1] Khan A. Real-Time Cross-Layer Routing Protocol for Ad Hoc Wireless Sensor Networks[J]. Intech Open, 2014:26-33.
[2] Austin F. Automated Maneuvering Decisions for Air-to-Air Combat [M].AIAA , 87-2393,659-670.
[3] JB Bullock, EJ Krakiwsky. Analysis of the use of digital road maps in vehicle navigation. Position Location & Navigation Symposium.
[4] Proc.of IEEE Symposium 2000 (AS-SPCC), Lake Louise, Albert, Canada, 2000.
[5] Parkinson B W, O'Connor M L, Elkaim G H, et al. Method and system for automatic control of vehicles based on carrier phase differential GPS: US, US6052647[P]. 2000.
[6] FB Zhan, CE Noon. Shortest Path Algorithms: An Evaluation using Real Road Networks. Transportation Science