Research on Zero-speed Detector Based on INS / Wheel speed and Vehicle gear

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Abstract. The zero-speed detector is required for the correction of the positioning error and the initial static alignment of the autonomous vehicle. The zero-speed detector that only depends on the INS (Inertial Navigation System) has zero-speed misjudgment. The performance of the detector after the fusion of wheel speed has been improved, but the wheel speed is still not integrated in scenarios such as long periods of stationary, emergency stop and reverse. Because the wheel speed signal only outputs the vehicle speed when the vehicle reaches a certain speed, there is a long initial alignment time, and the wheel speed is not fused in the complex driving process. This paper proposes a Vehicle gear information added to the INS / wheel speed fusion zero speed detector to achieve a 10s increase in the initial alignment time, the effect of wheel speed fusion has been improved, and thus the zero speed accuracy of detection.

1. Introduction
The Inertial Navigation System (INS) is a three-dimensional dead reckoning system, which is carried on the Inertial Navigation Unit (IMU). The attitude of INS is obtained by CPU calculating the angular rate and accelerometer of IMU module. However, the INS system error will accumulate with time through continuous integration in the long-time operation of inertial devices, so it can not meet the high positioning accuracy in the long-time operation [1].

Zero speed correction technology is the most practical constraint method to overcome the divergence of accumulated error of INS positioning and attitude determination system. It consists of two parts: zero speed interval detection and zero speed update. Among them, zero speed detection is the basis of zero speed update. In addition, the zero speed detection information can be used as the reference of INS relative to the geostationary, and the velocity, attitude and IMU error of INS can be calibrated by quasi-static alignment [2].

Domestic scholars began to integrate wheel speed and INS to improve the positioning accuracy, but there is a prominent problem that the wheel speed can not be integrated. The wheel speed signal can only output the speed when the vehicle reaches a certain speed, especially when the vehicle stops for a long time, stops in an emergency, reverses and so on, which is easy to occur that the wheel speed of the vehicle can not be integrated with INS realizes fusion, which is called "dead zone". It is the existence of this dead zone that leads to the problem of location delay misjudgment when fusion only depends on wheel speed, thus reducing the performance of zero speed detector and increasing the cumulative error of INS system [3]. Therefore, this paper proposes to integrate the vehicle's gear into the integrated...
positioning system, which reduces the delay misjudgment caused by the "dead zone" phenomenon, and thus reduces the output error of INS system.

2. Main Body

2.1. Sensor model

The automatic driving vehicle is divided into four gears: P, R, D and N. P is the parking gear, R is the reverse gear, D is the forward gear and N is the neutral gear. Both P and N speeds are 0. There is a corresponding speed range of corresponding gear in the forward gear. The gear information can be directly fed back and output by the gear detector, and the output is digital. The output of IMU and wheel speed detection is analog quantity, which needs modeling and analysis.

Set the observation value of IMU and wheel speed detector at k time as :

\[ y_k = [y_k^d, y_k^a, y_k^w, y_k^{wss}]^T \]  

(1)

\( y_k^d \) is the gear observation value, \( y_k^a \) is the acceleration observation value, \( y_k^w \) is the gyroscope observation value, \( y_k^{wss} \) wheel speed observation value.

The IMU and wheel speed sensors are described as follows:

\[ y_k = s_k + v_k \]  

(2)

Among them:

\[ s_k = [s_k^d, s_k^a, s_k^w, s_k^{wss}] \]  

(3)

\[ v_k = [v_k^d, v_k^a, v_k^w, v_k^{wss}] \]  

(4)

Where, \( s_k^d, s_k^a, s_k^w, s_k^{wss} \) respectively represent the true values of accelerometer, gyroscope and wheel speed sensor; \( v_k^d, v_k^a, v_k^w, v_k^{wss} \) respectively represent the measurement noise of accelerometer, gyroscope and wheel speed sensor [4]. It is assumed that the noise terms of accelerometer, gyroscope and wheel speed sensor are Gaussian white noise with independent distribution, that is, the covariance matrix is:

\[ C = E(v_k v_k^T) = \begin{bmatrix} \sigma_{a}^2 l_4 & 0 & 0 & 0 \\ 0 & \sigma_{a}^2 l_4 & 0 & 0 \\ 0 & 0 & \sigma_{w}^2 l_4 & 0 \\ 0 & 0 & 0 & \sigma_{wss}^2 l_4 \end{bmatrix} \]  

(5)

In the formula, \( \sigma_{a}^2 l_4, \sigma_{a}^2 l_4, \sigma_{a}^2 l_4, \sigma_{a}^2 l_4 \) respectively represent the noise variance values of gear, accelerometer, gyroscope and wheel speed sensor.

2.2. Design of zero speed detection algorithm

The detection zero speed detection can be used as a binary hypothesis testing problem, and the definition hypothesis is as follows:

\[ H_0: \text{carrier in motion} \]

\[ H_1: \text{carrier in static state} \]  

(6)

The zero speed detector first detects the gear engaged by the vehicle. In the four gears of P, R, D and N, it detects that the gear is p, and directly determines that the vehicle is \( H_1 \): the carrier is in a static state. At this time, the centralized positioning fixed solution in N for a period of time before the positioning data is used as the reference output [5]. If N gear is detected, the wheel speed state of “t” in the previous
period of time needs to be detected. If all the previous periods are static, the model output fixed solution of P gear is still referenced. If the speed is not 0, the vehicle enters \( H_0 \): the vehicle is in motion state. If R gear is detected, it needs to output feedback to speed direction in advance to reduce time delay. When the vehicle is in gear D, it is necessary to read the 1-5 information output by the vehicle odometer, then limit the speed calculation range, and enter the \( H_0 \): the carrier is in motion. Next, the zero speed detector detects the acceleration of the inertial device. Theoretically, in the static state, the acceleration is only the acceleration of gravity, and there is no other component. The output of gyro and wheel speed detection is 0, so the constraint conditions are:

\[
H_0: \exists k \in \Omega_{rv} \ s_k^d \neq P \ or \ s_k^a \neq g_n \ or \ s_k^w \neq 0 \ or \ s_k^{wss} \neq 0 \\
H_1: \forall \in \Omega_{rv} \ s_k^d = P \ or \ (s_k^a = g_n \ and \ s_k^w = 0 \ and \ s_k^{wss} = 0 )
\]

The verification formula of zero speed detection is:

\[
\ln(Lq_n) = \frac{1}{N} \sum_{k \in \Omega_n} \left( \frac{1}{\sigma^2} \| y_k^d \|^2 + \frac{1}{\sigma^2} \| y_k^a - g \|_{\|y_k^a\|}^2 + \frac{1}{\sigma^w} \| y_k^w \|^2 + \frac{1}{\sigma^{wss}} \| y_k^{wss} \|^2 \right) < y_N
\]

In style, \( y_N = -2(\ln y)/N \) If the IMU and wheel speed meet the above formula, the carrier is judged to be stationary [6].

3. Experimental verification

3.1. Test platform

This paper is equipped with INS system. The Inertial Measurement Unit adopts two gyroscopes scc2100 of Murata company and one integrated sensor scc2230 which integrates accelerometer and z-axis gyro. Thus, there are three gyroscopes and one accelerometer on one IMU module. Three gyroscopes measure the angular velocity of XYZ in three directions respectively, and then calculate the offset angle of the movement. The accelerometer measures the linear acceleration. The wheel speed detection loads the wheel speed data measured on the wheel, and interacts with the vehicle through CAN bus. The test data is compared with the parameters of high-performance optical fiber inertial navigation. During the test, stop at P gear for 20s, stop at N gear for 20s, and reverse at R gear for 10s, then slowly accelerate to 60km / h by engaging D gear, then slowly slow down to 20km / h emergency stop for 10s, then engage N gear by engaging emergency stop for 10s, and then stop at P gear. The real-time value of wheel speed and gear measuring device is detected in the whole process.
3.2. Analysis of test results

![Graph 1](image1.png)

**Figure 1.** There are multiple time periods of non-fusion gears.

![Graph 2](image2.png)

**Figure 2.** The fusion condition is better after the gear is fused.

It can be seen from the comparison of whether to merge the gears. After merging the gears, the IPC update of interprocess communication can be obtained. Without merging the gears, the wheel speed and INS can't be merged in the case of long-time parking and emergency parking. There are three times of tests in total, and there are many data not merged. There are three times after merging the gears, but the time is very short, and the overall fusion effect is good Better than a non-fused gear.

4. Conclusion

This paper analyzes the situation that the wheel speed can not be integrated with INS in the application of integrated navigation, and analyzes the problem that the integration is not good in the case of long-time parking and emergency parking, and the initial calibration time is long. The integrated navigation method of increasing vehicle gear fusion is proposed, which improves the performance of zero speed detection, and then improves the overall positioning accuracy. The conclusion is as follows:

1. The zero speed detector using only IMU has many misjudgments.
2. The zero speed detector only using IMU and wheel speed can not integrate wheel speed sometime, and the initial calibration time is long.
3. The vehicle gear information is integrated into the INS / wheel speed combination zero speed detector, the performance of the zero speed detector is improved, and the output trajectory is improved in accuracy.

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