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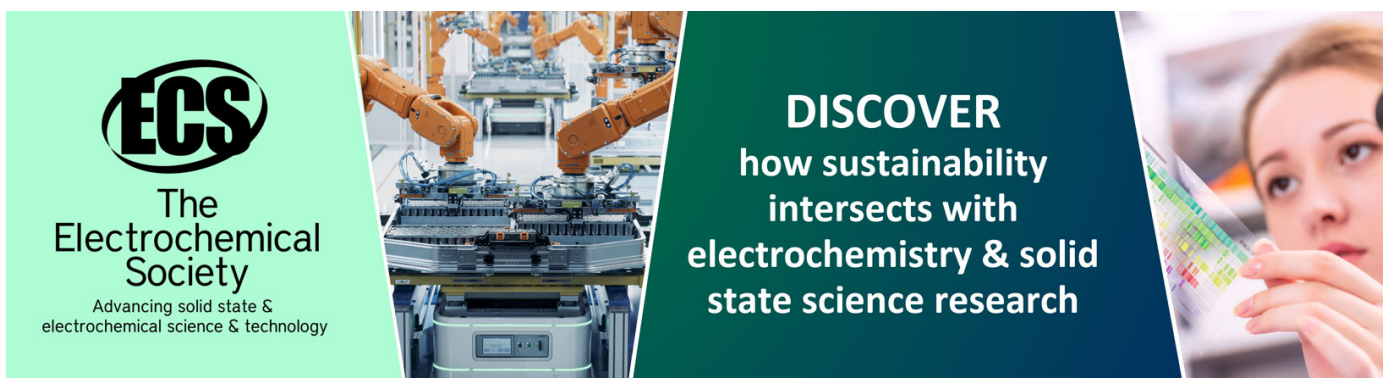
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Real-time Vehicle Pose Measurement Technology based on Multi-sensor Information Fusion

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Abstract. To achieve vehicle unmanned driving, it is necessary to obtain the exact position and posture of the vehicle in real time. To get accuracy position and attitude information, multiple different sensors will be used.However, it's difficult to deal with the collected information and to integrate the relevant data.This article first introduces the method of obtaining measurement data when using encoder, inertial navigation system and GPS alone.Secondly, using the INS/GPS loose combination system to design a multi-sensor information fusion method.In order to verify the accuracy of the method, a multi-body dynamics simulation model was established and a test bench was built.The simulation and experimental results show that the proposed method can well fuse multi-sensor data and accurately obtain the real-time position and attitude of the vehicle body.

1. Introduction

Unmanned vehicles and related technologies research has been widely concerned by scholars. Among them, it is very important to accurately obtain the real-time pose of the vehicle. Encoders, inertial navigation devices, and GPS sensors are commonly used to obtain real-time poses and attitudes of vehicles. How to deal with the data obtained by related sensors and how to ensure the accuracy of the fusion data are the difficulties of current research, which needs to be focused on.

Relevant scholars have done some research on this aspect. Zhang uses a vision sensor in combination with lidar for positioning, while improving pose estimation based on a lidar odometer [1]. Li designed the vehicle integrated navigation system based on GPS, INS and encoder [2]. Zhang completed the combined navigation of strapdown inertial navigation and encoder measurement information by designing kalman filter [3]. Tan proposed an adaptive filtering algorithm for GPS/INS integrated navigation. The improved neural network algorithm weakens the influence of observed gross errors [4]. Li proposed a multipath effect dynamic elimination algorithm for GPS/INS tightly coupled integrated navigation system [5].

This paper first introduces the encoder, inertial navigation system (INS) and GPS method separately on how to obtain the vehicle body pose information. Then, an algorithm for multi-sensor information fusion is proposed. After that, a dynamic model was built in the Recurdyn software for simulation. Finally, build a test bench and verify the accuracy of the algorithm through two experiments.

2. Sensor data acquisition

2.1 Encoder

This article uses four encoders, which fixed to the four wheels of the vehicle separately. By solving the data measured by the four encoders, the pose change of the vehicle body coordinate system in the ground coordinate system (odom system) can be obtained. Schematic diagram of vehicle kinematics modelling is shown in figure 1. O_{base} is the origin of the car body coordinate system, L is the distance between the front and rear wheels of the car body, and W is the distance between the left and right wheels of the vehicle body.
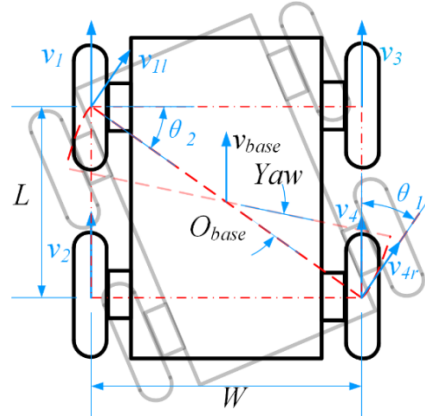

Figure 1. Kinematic model

The model is a four-wheeled all-wheel drive slip motion model in which the speeds of the left two wheels are equal and the speeds of the right two wheels are the same, i.e. $v_1 = v_2, v_3 = v_4$. Through kinematic analysis, the linear velocity v_{base} and angular velocity $\dot{Yaw}$ of the vehicle motion can be solved by the tire speed, such as equation (1).

$$\begin{cases} v_{base} = \dfrac{v_1 + v_4}{2} \\ \overset{g}{Y\dot{a}w} = \dfrac{W \times (v_4 - v_1)}{W^2 + L^2} \end{cases} \tag{1}$$

2.2 Inertial navigation system

The INS is directly attached to the vehicle body, and the measured amount can be regarded as the change of the vehicle body in the odom coordinate system. The data measured by the three gyroscopes is the projection of the angular velocity of the vehicle body in the odom coordinate system, and the data output by the three accelerometers is the projection of the vehicle body acceleration in the odom coordinate system. The data output by the system is shown in table 1.

Table1. Inertial navigation system output.

Parameter	Unit	Parameter	Unit	Parameter	Unit
Rolling angle(R)	°	Angular velocity(X)	°/s	Acceleration(X)	g
Pitch angle(P)	°	Angular velocity(Y)	°/s	Acceleration(Y)	g
Yaw angle(Y)	°	Angular velocity(Z)	°/s	Acceleration(Z)	g

2.3Global positioning system

Need to get the measured value of GPS in UTM coordinates, then convert to odom coordinate system. The initial position of the car body in the UTM coordinate system is x_{UTM_0}、 y_{UTM_0}、 z_{UTM_0}. After the vehicle starts to drive, use equation 2 to convert the measured value of the GPS to the real-time pose of the vehicle in the odom coordinate system.

$$\begin{bmatrix} x_{base} \\ y_{base} \\ z_{base} \\ 1 \end{bmatrix} = T^{-1} \begin{bmatrix} x_{UTM_0} \\ y_{UTM_0} \\ z_{UTM_0} \\ 1 \end{bmatrix} \tag{2}$$

Where T is the pose transformation matrix, α、 β、 γ are the initial attitudes of the vehicle body in the UTM coordinate system, which are the rolling, pitch and heading angles respectively.

$$T = \begin{bmatrix} c_\beta c_\gamma & s_\alpha s_\beta c_\gamma - c_\alpha s_\gamma & c_\alpha s_\beta c_\gamma + s_\beta s_\gamma & x_{UTM_0} \\ c_\beta s_\gamma & s_\alpha s_\beta s_\gamma + c_\alpha c_\gamma & c_\alpha s_\beta s_\gamma - s_\alpha c_\gamma & y_{UTM_0} \\ -s_\beta & s_\alpha c_\beta & c_\alpha s_\beta & z_{UTM_0} \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3}$$

3. Fusion of multi-sensor measurement information

In the process of obtaining data, various factors may cause errors in the measurement results, such as the environment, the instrument state and personnel. Therefore, it is important to find the best estimate of the parameters and make a reasonable evaluation. In this paper, the extended kalman filter (EKF) is used to filtering noise and processing error on the measured data of these sensors.

This system refers to the INS/GPS loose combination system to fuse multi-sensor information. When a short-term positioning is required, it only needs to be based on the encoder and the inertial navigation system. Subtract the filtered value from the original data separately, and fused after obtaining their respective confidence levels. When long-term accurate positioning is required, the GPS navigation information must be combined to eliminate cumulative error of the encoder and the INS.
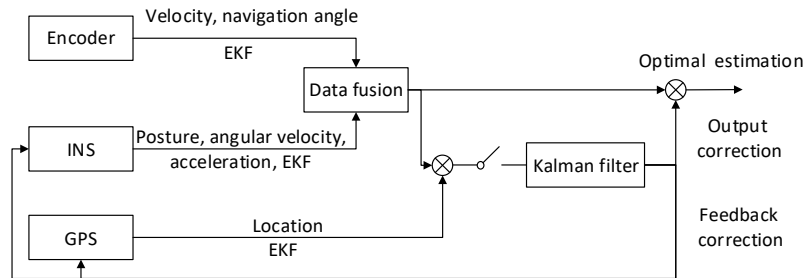

Figure 2.Principle of integrated navigation system

The principle of the integrated navigation system is shown in figure 2. The attitude value is the fusion output value of the INS and the encoder. The position value is the difference between the position information of the encoder and the INS output and the GPS value, and the error amount is estimated by filtering. The output correction is to correct the navigation parameters of the output by the estimated value of the INS error. Feedback correction is to use the estimated value of INS error to correct the corresponding navigation parameters. The configuration of the sensor parameters is shown in table 2. 1 stands for true, indicating that the parameter can be used by the sensor.

Table 2.Sensor parameter configuration

	x	y	z	R	P	Y	$\dot{x}$	$\dot{y}$	$\dot{z}$	$\dot{R}$	$\dot{P}$	$\dot{Y}$	$\ddot{x}$	$\ddot{y}$	$\ddot{z}$
						Parameters（0 = false, 1 = true）									
Encoder	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0
IMU	0	0	0	1	1	1	0	0	0	1	1	1	1	1	1
GPS	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0

4. Dynamic simulation

In order to verify the pose information fusion algorithm proposed in this paper, multi-body dynamics simulation should be carried out to compare with the test data.

First, the 3D model of the test bench is imported into the Recurdyn software, and establishing the constraints and drivers.Then, establish the actual road surface and the simulated road surface. When building the actual road surface, the vibration of the vehicle body is generated by fixing the wooden strip on the road surface, as shown in figure 3. When building a simulated pavement, the same model is built according to the actual pavement designed, as shown in figure 5. The sensors used therein include a two-axis tilt sensor, a laser range finder, an encoder, etc.
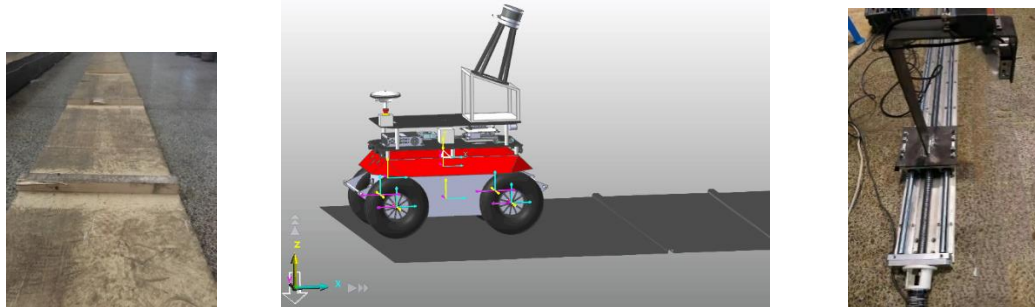

Figure 3. Actual road surfaceFigure 4.Dynamic simulation modelFigure 5. Information collector

The position change of the vehicle coordinate system is obtained by simulation as shown in figure 6. X is the distance travelled by the vehicle, and z is the displacement change of the vertical direction of the vehicle body. The pitch angle transformation is shown in figure 7.
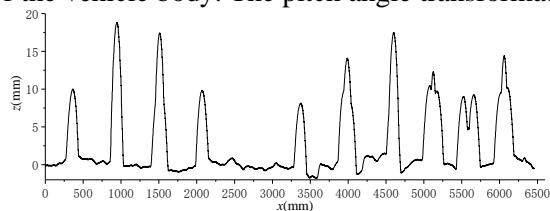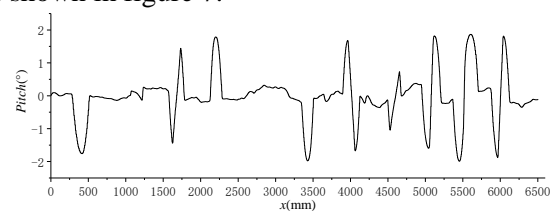

Figure 6. Simulated position change

Figure 7. Simulated pitch angle change

5. Experimental verification

When the system does not need long-term positioning, the INS and the encoder will not generate a large cumulative error, so the positioning can be completed only by the INS and the encoder. When it is necessary to continuously establish a three-dimensional model of the road surface for a long time, it is necessary to integrate GPS information to reduce the cumulative error of the INS and the encoder. In the experimental part of this chapter, the two tests will be carried out separately.

Firstly, verify the data fusion of the INS and the encoder, and the test bench can be built indoors.

When carrying out the test, the control speed is consistent with the simulation speed, both being 0.5m/s. Operating control node, and each sensor data acquisition node. Using the integrated navigation

node ekf_localization_node in robot_localization to fusion data. The vehicle position change is shown in Fig.9, the pitch angle changes is shown in figure 10.
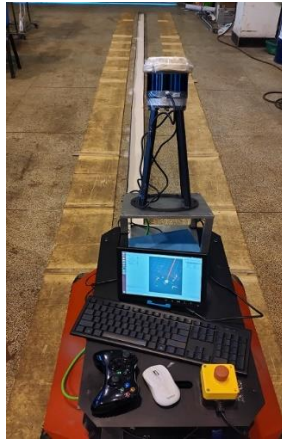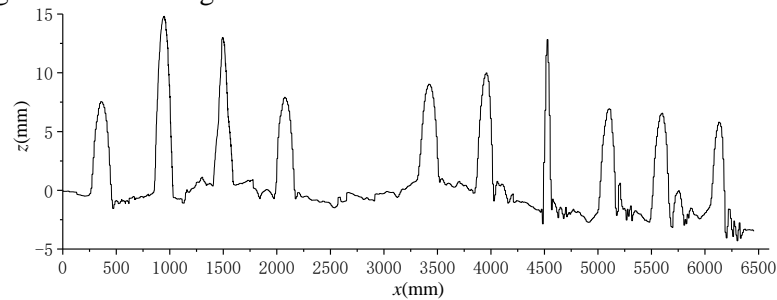

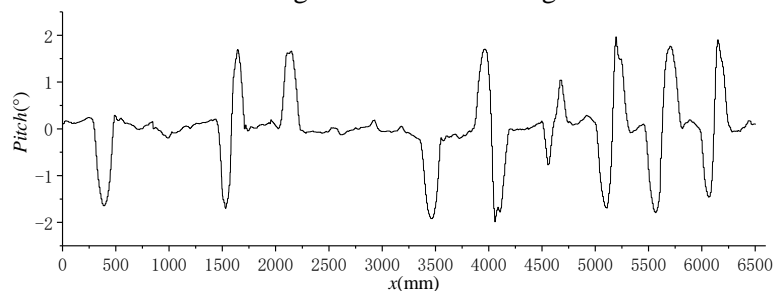Figure 8. Test environment

Figure 9. Position change

Figure 10. Pitch angle change

Compared with the simulation results, the overall trend is basically consistent. Since the simulated pavement is rigid, and the stiffness of the simulation tireis different from the actual, it is reasonable to have a certain error between the results. Comparing the peak of the test data, when the driving distance is less than 5 meters, the real-time pose of the vehicle body is basically accurate, which means that the combined navigation of the encoder and INS designed is feasible in a short time. However, after the driving distance reaches 5 meters, the overall trend of the vertical displacement is continuously reduced. It can be seen that with the increase of time, due to the cumulative error of the sensor, the error of the integrated navigation system is also increasing.
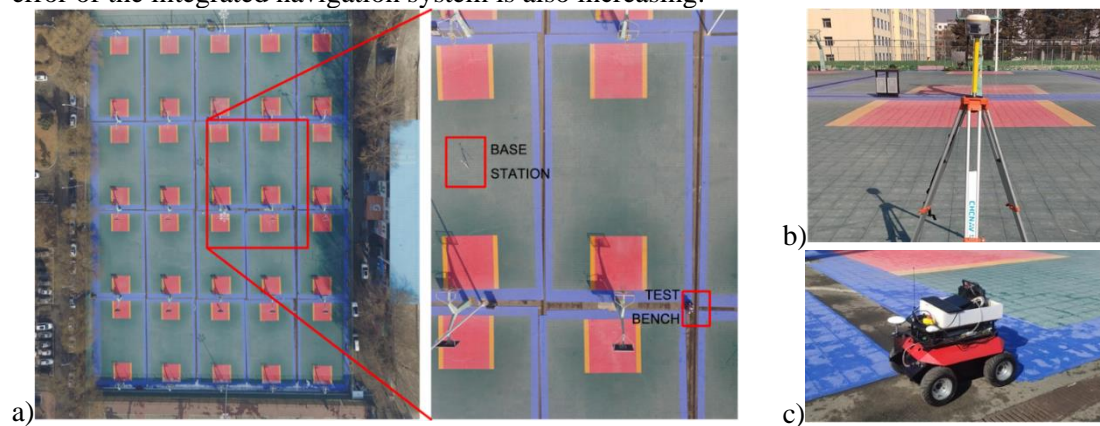

Figure 11. Test environment a) Test site, b) Base station, c) Test bench

So, when the system does need long-term positioning in the process of recognizing the road surface, it is necessary to integrate GPS to accurately sense the real-time pose of the vehicle body, and the test environment needs to be selected outdoors. First, control the vehicle around the playground to collect the measurement data of the encoder, inertial navigation system and GPS, and then view the positioning effect through data fusion. For the sake of clarity, only the two-dimensional coordinate is analysed here. The test environment is shown in figure 11.

In order to facilitate the comparison of the test trajectory with the actual trajectory, the size of the experimental site needs to be quantified. This test uses the standard basketball court, moves around 3 × 2 basketball courts, and is tested twice, as shown in Fig.12 below, the starting point coordinates are (0,0). The red curve in the figure is combined by using both IMU and encoder. The black curve is combined by GPS, IMU and encoder. It can be seen that in a short time, the IMU and the encoder can be used for accurate positioning, but as the cumulative error of the sensor increases, the positioning effect becomes worse with time. After the integration of GPS, the trajectory basically coincides with the actual trajectory, and the error is small.
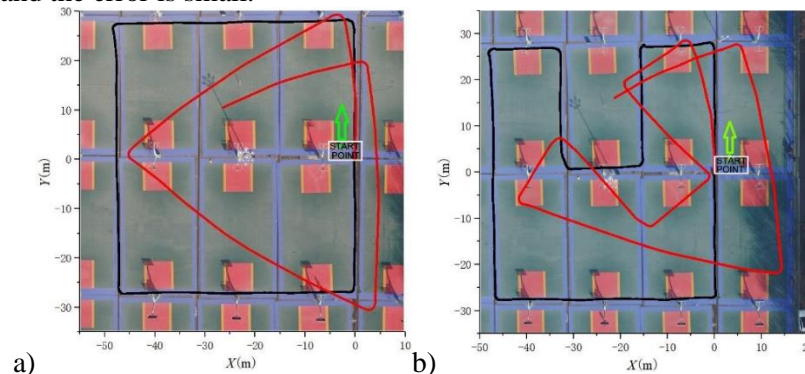

Figure 12. a) The first test result, b) the second test result

6. Conclusion

In this paper, a fusion method of multi-sensor information collection is used to measure the real-time pose of the vehicle. Firstly, the method of obtaining the real-time pose of the vehicle coordinate system by encoder, INS and GPS is introduced separately. Then, based on the information fusion of multiple sensors, an integrated navigation system was proposed. After that, a dynamic simulation model was designed to verify of the pose information fusion algorithm of the system. Finally, the test bench was built and two information fusion tests were carried out. The test results show that the combined navigation method is effective and has high accuracy.

Acknowledgments

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