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Research on Location Method of Pipe Climbing Robot based on Gyroscope

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***Abstract* - This paper introduced a location method of pipe climbing robot, this robot working in a big pipe that used to desalinate sea water. Traditional method on flaw detection of big sea desalination pipe is by human, This paper provide a new idea on location of the flaw detection robot. Using the fuse of multiple sensor information, the position and posture of climbing robot can be obtained. Gyroscope and the motor encoder can provide sufficient message to locate the robot. Also, with the moving of robot, some errors caused by slide of the robot track and the reading of sensors will happen. These errors can be eliminated by kalman filter. The practicable of this method has been proved by simulation of motion trajectory. Errors could also happened with the improper arrangement of pipeline, but this method is to calculate the subtraction of the sensor reading on two state. So we do not need to consider these errors, it doesn't affect the outcome at any arrangement of pipeline.**

Index Terms - robot localization, kalman filtering, gyroscope.

I. Introduction

A. System

With the development of machinery, electronics and control technology, Robots are increasingly used and becoming more and more versatile. As an important branch of robots, The climbing robot has its special working environment [1]. The radius of pipe that used to desalinate sea water is more than 5 meters. Look into the pipe in one side, the pipe divided into four part by a square. The erosion of sea water can cause some damages like rust and crack. When the pipe need flaw detected, workers go in the pipe to detect flaws. This robot can replace the stuff to detect the pipe. Therefore, The location technology of the robot not only can locate the robot position, but also obtain the location of flaws. Robot localization is the most basic problem in the field of robot research [2]. In this research, not only the robot need to detect damages, but also need to know where damages are. Therefore, the importance of accurate location technology tell its own tale [3].This paper presents a simple and feasible location system, which can directly get the position and the posture of climbing robot. With mpu-6050 as the main chip, gyroscope motion sensor is the first six axis motion data processing component in the world, which eliminate the problem of out-sync of time. It conserve more space. Mpu-6050 model can also output 9 axis or 6 axis data at real-time with fusion movement data processing function set. At the same time, it can reduce the power require to calculate data.

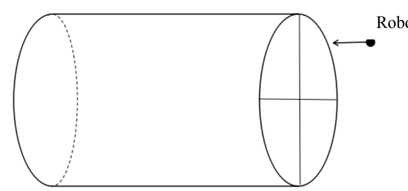

Fig. 1 Entrance of the robot to the pipe

B. The action of robot

The pipe is divided into four parts on average and separated from each other. The robot climb into pipe from one side, heading towards the pipeline direction. When it come to an end, the robot turn round along the semicircle which radius is the robots width. And then start its second route to detect the pipe. The robot repeat this circle until the quarter of the pipe all have been detected. The process of robot movement is shown in the Fig.1. In this paper, we only focus on the location method, so we can ignore the detection of damage on the pipe.

When the robot need to turn round, it can move only left motor or right motor, make the robot turn round only use left track or right track, Fig.2 has shown the diagram of the motion of pipe climbing robot, the robot left track go along with the circle with the arrow direction. When it get to the black dot, the movement of turn round finish.

With the pipe climbing robot go in different section of the pipe, the adsorption structure of the robot can provide different force to make sure the robot can adsorb on the pipe steady. But different strange can make different friction, and then provide different resistance. If we look from one side of the pipe, we can obtain the position of the robot by the reading of gyroscope. According to the position , we can adjust the adsorption strength to make robot adsorb steady. The moving distance can be measured by motor encoder accurately.

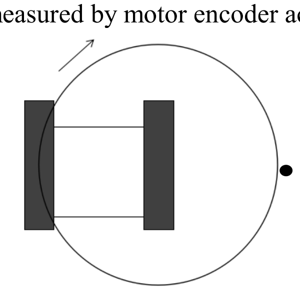

Fig. 2 process when the robot turn round

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II. Principle of Location

A. System diagram

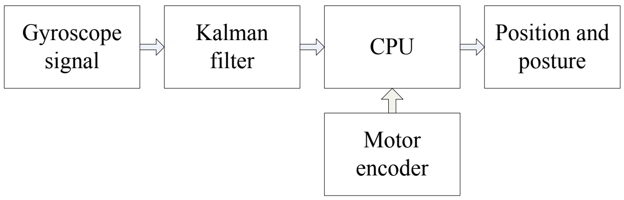

Fig. 3 The location system of Pipe-climbing robot

The sketch map of the location system is as shown in Fig.3.Three parts of system determine the location of the robot.

1) Gyroscope signal

Mobile robots are commonly used location sensors are as follow: speedometer, camera, ultrasonic ranging, infrared, microwave or laser radar, gyroscope, compass, speed or accelerometer and so on. Gyroscope can obtain the location data of the robot only depending on the motion of the robot. It has the advantage of small influence of external environment and strong anti-interference compared with other sensors. And the most important thing is that this kind of sensor is cost-effective.

2) Kalman filter

Kalman filter is an optimal real-time recursive data processing algorithm. It makes data more accurate by introducing a gain K at every state moment which multiply the detected data of gyroscope to obtain the correction of the next state.

3) Motor encoder

Motor encoder can read how many steps did the motor go and we can get the distance by multiply the step size of the motor. This reading combine with the reading of gyroscope can obtain the position and posture of the robot.

B. Location principle of the robot

The main control mode of this kind of robot is manually, operating stuff control the robot beside the pipe. So the location system only need to ensure that the robot is going straightly as the operator thinking when he operate the robot to move. The robot has been controlled to go straight along the pipeline or perpendicular to the pipeline, combining with the angle that gyroscope read and the distance that motor encoder has work out, the location and the posture can be obtained. The angle of the gyroscope can be read as shown in Fig.4.

If the pipeline is improper, the angle A will still be angle A, it will not change with the pipeline change, we can still use this method to obtain the position of the robot on the lateral view of the pipe. Therefore, we can ignore the errors caused by improper arrangement of the pipe.

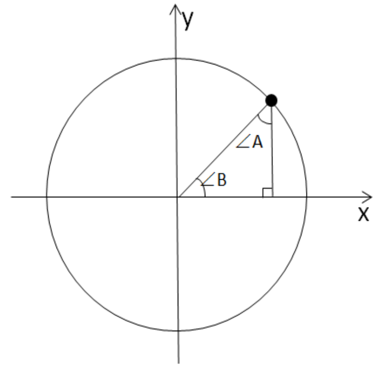

Fig. 4 The principle of get the angle from gyroscope

If we look this pipe from one side, we can see the sight as Fig.4 shown, The black pot in the figure represent of the robot position. The gyroscope can read the angle between the head of the robot and the vertical direction. If we know angle A, we also know angle B, and we know the robot on which position on this circle. The motor encoder tell us how long the robot have moved, combine these two information, the location and posture can be calculated.

III. Error and Error Eliminate

A. Errors

1) Improper arrangement of the pipeline

If the pipe position is not appropriate, the angle that the gyroscope read is still angle A, so this problem can be avoid.

2) Improper initial direction of the robot

If the robot moves in a direction that different from the pipeline, the robot will move along its direction. In this case, because the pipe has a certain radian, the robot position on the lateral section of the pipe will change accordingly. And this change can make the data of gyroscope change. The location system will know the robot has deviate from the track. The system can send a message to tell the modified system to make the robot back to its route.

As can be shown in Fig.5, the robot move from A to B, we can see the robot on front view and lateral view separately, the value that gyroscope read is apparently different between A and B. So the system can read this kind of error and compensate this kind of error. This error can be compensated until the value of gyroscope is same as the initial value.

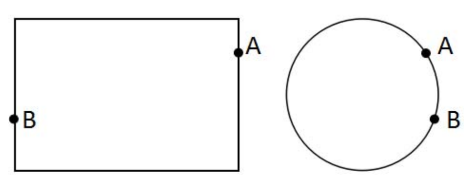

Fig. 5 The incorrect route cause by improper direction

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3) Gyroscope observed error

The attitude Angle of the robot in the uniform linear motion has been accumulated and accumulated to a large error in a certain period of time. This is caused by the zero-value error and random drift error of the gyroscope. Correction is needed if we want to obtain the accurate linear motion, make the location error controlled in an acceptable range. So, the Kalman filter has been introduced.

B. Kalman filter algorithm

Almost all area of research, where data is needed, where we face the question of "measurement" and “estimation”. We hope we can be able to estimate and predict the data on the basis of accurate measurement data. The optimal estimation theory provides the theoretical basis and realization algorithm of random system information processing [4].

Kalman filter is the most important part of control engineering and control theory, from the Angle of stochastic process, the linear and nonlinear kalman filtering is studied for now. They usually has two state space expression: continuous and discrete. The state space expression of discrete filter is different from the state space expression of continuous kalman filter, the discrete model introduces the state noise parameters. And the different values of related parameters can form dynamic model. At present, kalman filtering equation of discrete linear system also be deduced, which plays an important role in solving the filtering problem of continuous kalman filter state space system [5]. It is an optimal real-time recursive data processing algorithm. It makes data more accurate by introducing a gain K at every state moment which multiply the detected data of gyroscope to obtain the correction of the next state.It can predict the real value from a set of discrete measurements with noise[6]. If process noise and observation noise of a stochastic linear system are Gaussian noise, kalman filter works well [7].

Kalman filter is essentially a constant prediction and correction of observed values.

1) prediction

The kalman filter model predicts the state at the k moment according to the correction of moment k-1.Use the following formula to predict.

$$\overline{x}_k = A_k x_{k-1} + B_k u_k + W_{k-1} \quad . \quad (1)$$

$$\overline{P}_k = A_k P_{k-1} A_k^T + Q \quad . \quad (2)$$

x_{k-1} is the estimated value after correction at k-1 moment, $\overline{x}_k$ is the predict value at the moment k, A_k is the state transformation matrix from moment k-1 to moment k, u_k is the control vector, which determined by the movement of robot, B_k is the input affecting the control vector, W_{k-1} is process noise, P_{k-1} is the covariance matrix after correction at k-1 moment, $\overline{P}_k$ is the predicted covariance matrix at k moment, Q is the covariance matrix of process noise.And then we can revise the data.

2) Correction

Use the observed value Z_k and Kalman gain K_k at k moment to correct the State predictive value $\overline{x}_k$ and the predicted covariance matrix $\overline{P}_k$.

$$z_k = H_k x_k + v_k \quad . \quad (3)$$

$$K_k = \frac{\overline{P}_k H^T}{H\overline{P}_k H^T + R_k} \quad . \quad (4)$$

H_k is measurement matrix, v_k is observe noise, R_k is covariance matrix of v_k, then we can revise the predicted values of state and covariance matrix.

$$x_k = \overline{x}_k + K_k(z_k - H_k \overline{x}_k) \quad . \quad (5)$$

$$P_k = (I - K_k H_k)\overline{P}_k \quad . \quad (6)$$

Until now, we can obtain the optimal value of moment k state, after that, we can bring the optimal value of state value and covariance to the next moment.

Use of kalman filter can eliminate the most observe error and make the sensor data more convincing.It can also make our location system have a better credibility. It makes data more accurate by introducing a gain K at every state moment which multiply the detected data of gyroscope to obtain the correction of the next state [8].

Fig.6 has shown the process of the Kalman filter, using the Kalman filter to eliminate the most noise of the observe signal, and read a more accurate position of the pipe climbing robot.

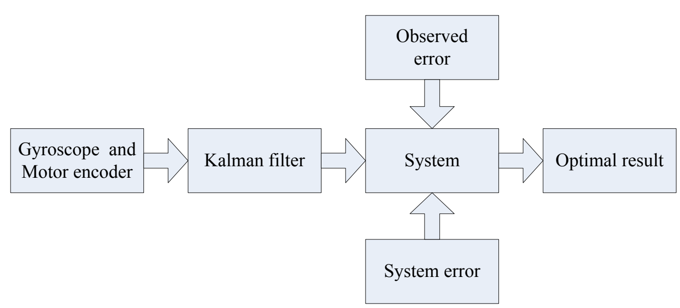

Fig. 6 The process of Kalman filter

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C. Application of Kalman filter

1)At the beginning, order k=1, set up the initial reading of the gyroscope which is x_{k-1} and the covariance matrix P_{k-1}.

2)According to the movement type of the robot to predict the possible reading of the gyroscope at the moment $\bar{x}_k$.

3)Apparently, we can calculate the state change matrix A, and because of the simulation of the robot movement, we can ignore the control vector u_k, W_{k-1}, Q can also be ignored, both of them are valued zero, and then we can use (1), (2), to obtain the prediction of position and the covariance matrix.

4)In the period of correction, H is equal to I, v_k, R_k are zero, according to (5), (6), update the predicted reading and the covariance matrix.

5)Order k=k+1, and back to step 2) until the robot stop moving.

Kalman filter is an optimal real-time recursive data processing algorithm. It makes data more accurate by introducing a gain K at every state moment which multiply the detected data of gyroscope to obtain the correction of the next state. It can predict the real value from a set of discrete measurements with noise [9].

IV. Simulation of the Sensor Values

A. Simulation of uniform linear motion of robot

As shown in Fig.7, The red line is the value of the gyroscope when the robot moving straightly and at a constant speed, The light blue line is the non-deviation value, The blue line is the kalman filtered value.

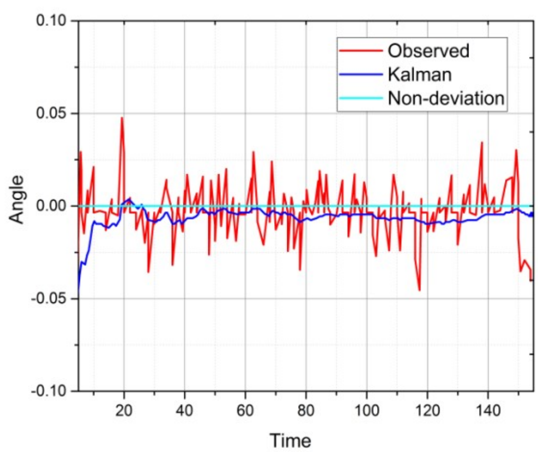

Fig. 7 The simulation of uniform linear motion

As we can see in Fig.7, The result of kalman filter make the error smaller. The error is more acceptable. The blue line is more closer to the nattier blue line compared with the red line.

After eliminate more noise., the observed value of gyroscope can representation the movement of the pipe climbing robot more accurate.

B. Simulation of uniform circular motion

Fig.8 has shown the value of gyroscope sensor when the robot turn round, we can see the kalman filter has a better result than directly observe. Kalman filter makes data more accurate by introducing a gain K at every state moment which multiply the detected data of gyroscope to obtain the correction of the next state.

V. Conclusion

In conclusion, the robot is controlled by human manually, the location system only need to ensure that the robot moving along the pipeline when the people control it to go straight. Combining the method that this paper introduce, the reading of the gyroscope is more close to the actual value, the gyroscope can easily detect the direction that robot goes. The location system will be steady. By using kalman filter, most of the error contained in the value that the gyroscope sensor read has been eliminated, which make the result of location of the pipe climbing robot more accurate.

In this paper, we only talk about location the robot but not focus on the damage of the pipe is because we want to know exact location of the damage, not only the robot location. If we know the location of damages, we can send people to go in the pipe to do repair job. Even we can connect the robot to WIFI or Internet and then we can watch the three dimension picture of this pipe. And reveal the damage location on computer screen.

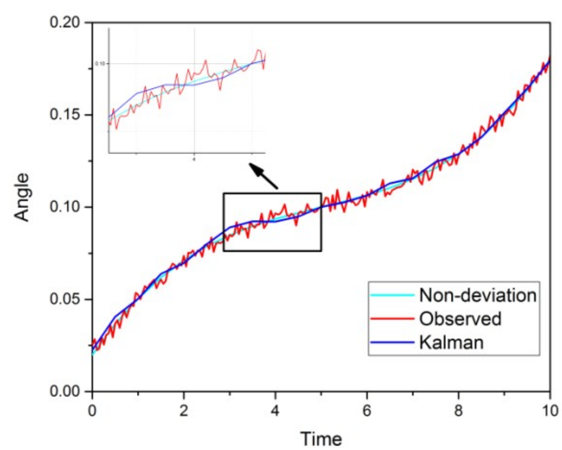

Fig. 8 Simulation of uniform linear motion

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