

LOCALIZATION OF PIPELINE ROBOTS ON THE BASE OF INERTIAL NAVIGATION

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Keywords: pipeline robot, large diameter pipe, local navigation, gyroscope, Kalman filter.

Abstract. A new approach to localization of a pipeline robot in large-diameter pipes based on the method of inertial navigation is Proposed. This navigation system can expand functions, including communication with the computer and optimization of the human-computer interface. The robot's trajectory is modeled in the Matlab environment.

ЛОКАЛИЗАЦИЯ ТРУБОПРОВОДНЫХ РОБОТОВ НА ОСНОВЕ ИНЕРЦИАЛЬНОЙ НАВИГАЦИИ

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Ключевые слова: трубопроводный робот, локальная навигация, гироскоп, фильтр Калмана.

Аннотация. Предложен новый подход к локализации трубопроводного робота в трубах большого диаметра на основе метода инерциальной навигации. Данная система навигации может расширить функций, включая связь с компьютером и оптимизацию интерфейса взаимодействия человека и компьютера. Траектория движения робота моделируется в среде Matlab.

Introduction

As early as the middle of the last century, large pipelines represented by oil and gas pipelines were widely used worldwide. It is not only used in the transportation of petroleum, gas and natural gas, but also widely used in urban drainage and industrial production [1]. Pipeline transportation provides people with great convenience and brings some problems: with the aging of the pipeline and the corrosive effect of the substances transported on the pipeline, the pipeline will appear cracks, corrosion and damage [2]. In order to avoid economic losses, environmental pollution, personal safety, etc., the inspection work, maintenance work and cleaning maintenance work inside the pipeline should be carried out regularly.

The traditional detection methods are mostly manual, which has a large workload, poor efficiency, poor effect and high cost. Therefore, the pipeline inspection robot become popular. The advantages of inspection speed, easy operation, accurate judgment, and low cost of pipeline robots push the research of pipeline inspection robots to the hot topic of domestic and foreign research [3]. The mobile robot in the pipe is a whole system that works in the pipeline and integrates a variety of pipeline detection devices, sensors and working devices, and performs the work in the pipeline under the remote control of the staff or the control of the robot's own system.

This paper focus on the most important part of pipeline robot - navigation. Navigation system not only can locate the robot position, but also obtain the location of flaws. The author of this paper proposed and implemented a new, more efficient, convenient and economical approach to navigating a pipeline robot in

large diameter pipes only by using a gyroscope. With this approach, we can get the position and the posture of climbing robot.

Action of robot

The path of robot movement is shown in the Fig. 1. If the pipe is unfolded into a rectangle, the robot will move S-shaped on this rectangle.

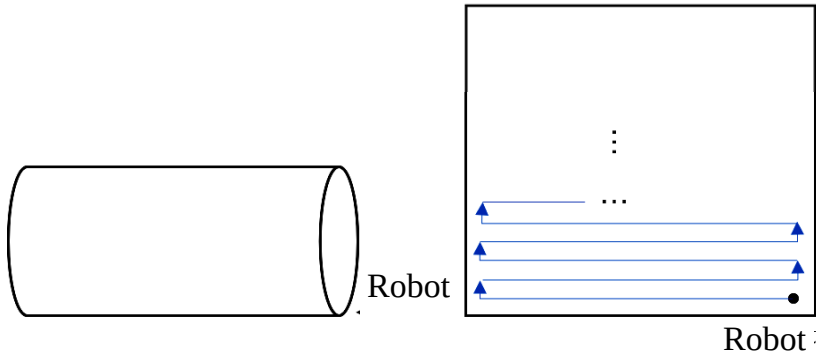


Fig. 1

The robot climbs into pipe from one side, heading towards the pipeline direction. When it come to an end, the robot turns its head in the opposite direction. By only moving one side of track and make U-turn. The robot repeats these movement until the pipe have been all detected.

Principle of location

The sketch map of the location system is as shown in Fig. 2. Four parts of system determine the location of the robot.

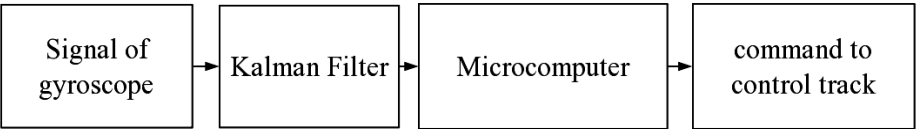


Fig. 2

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.

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.

Microcomputer. Microcomputer is the most important component of navigation system. We got the signal of gyroscope first. These signals processed by

microcomputer and get the position and orientation information of the robot. And then, by controlling the roll angle of the robot, to make the robot move according to predetermined trace.

Command to control track. If we know the trace of robot is not according to the predetermined trace. Under the calculation of microcomputer, control signals are obtained to control the track, so that the robot returns to the correct trajectory.

Location principle of the robot

We already know the initial position. And with the help of gyroscope, we can obtain angle and angular acceleration of robot. This angle is the roll angle of the robot relative to the horizontal position.

Robot running automatically, operator only need to put the robot on initial point. The robot runs in an S shape on the inner wall of the pipe. The location system needs to ensure that the robot runs in the direction of the central axis of the pipeline. With control the roll angle of robot within a certain range, we can ensure that robot run in right direction.

Since inertial navigation adopts the way of track estimation. To obtain the position of the robot, need the attitude angle of the robot. The gyroscope provides the attitude angle.

Error and error eliminate

If the robot moves in a direction that different from the pipeline or the track slide, the orientation of robot will change. 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 roll angle of robot change. The microcomputer system will know the robot has deviate from the track. The system can send a command information to make the robot back to its route.

As can be shown in Fig. 3, with the movement of robot from A to B, roll angle will change accordingly. We can see the robot on front view and lateral view separately, the value that gyroscope read was apparently different between A and B.

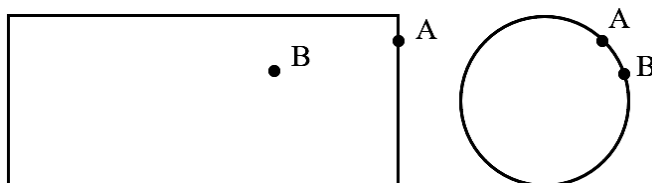


Fig. 3

This error can be compensated by controlling the accordingly track of robot running slower until the value of roll angle is corrected. And then restore the original running speed of this track

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.

Kalman filter algorithm

Kalman filter is the most important part of control engineering and control theory. 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 [4]. If there is measurement Gaussian white noise, Kalman filtering can estimate the state of the dynamic system and update and process the data collected in real time [5].

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

Prediction. The Kalman filter model predicts the state at the k moment according to the correction of moment $k-1$. Using the following formula to predict:

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

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

where x_{k-1} is the estimated value after correction at $k-1$ moment, $\bar{x}_k$ 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, $\bar{P}_k$ is the predicted covariance matrix at k moment, Q is the covariance matrix of process noise. And then we can revise the data.

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

$$z_k = H_k x_k + v_k,$$

$$K_k = \frac{\bar{P}_k H_k^T}{H_k \bar{P}_k H_k^T + R_k},$$

where 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:

$$x_k = \bar{x}_k + K_k (z_k - H_k \bar{x}_k), \quad (3)$$

$$P_k = (I - K_k H_k) \bar{P}_k. \quad (4)$$

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.

Kalman filtering continuously loops through time updates and state updates (Fig. 4), so the optimal estimate can be made for each moment [6].

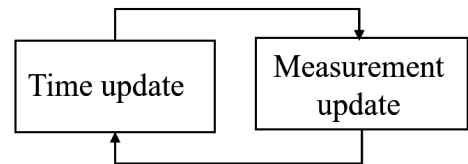


Fig. 4

The cycle from the predicted state to the corrected state to the predicted state, and the posterior estimate of the previous state as the prior estimate of the next state is the working process of the Kalman filter algorithm. The specific process is shown in Fig. 5.

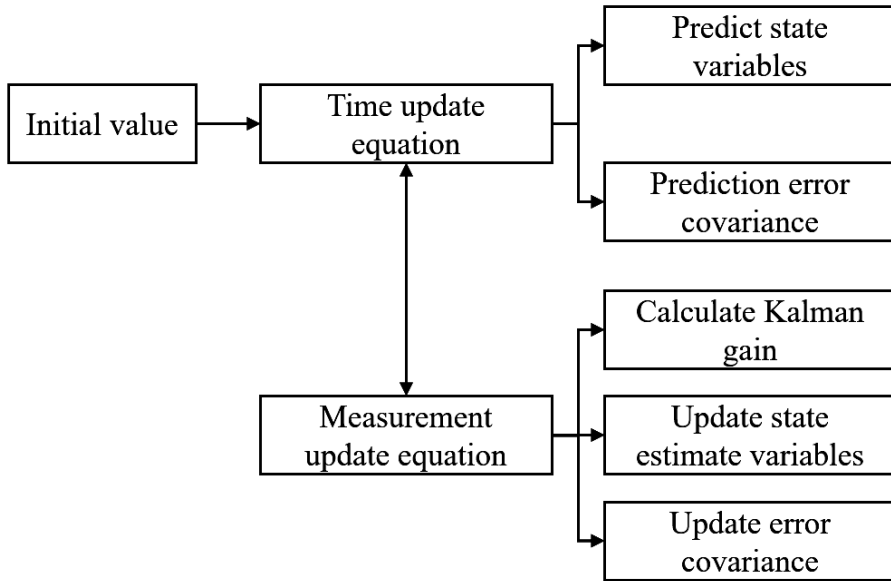


Fig. 5

The Kalman filter algorithm first predicts the value in the next state based on the initial value, then determines the covariance, calculates the Kalman gain, then calculates the optimal estimate based on the predicted and measured values, and finally updates the covariance.

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 (3) and (4) 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 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.

Simulation of uniform linear motion

The results of simulating uniform robot movement in Matlab are shown in Fig. 6 and 7.

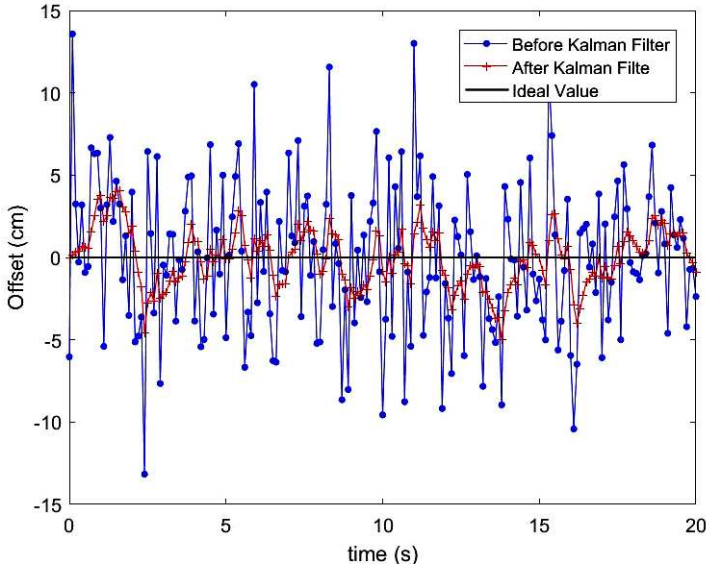


Fig. 6

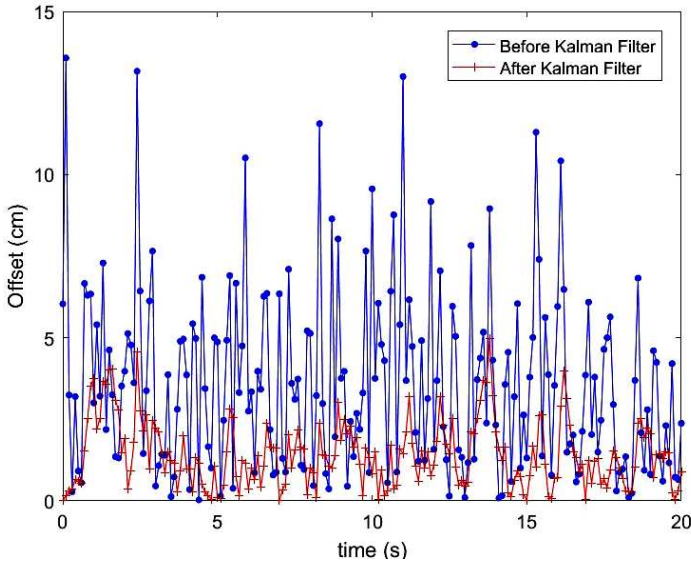


Fig. 7

As shown in Fig. 6, the black straight line in the middle is the ideal trajectory; the dashed-dotted line is the trajectory of the robot drawn by the attitude angle calculated by directly using the data collected by the gyroscope; the cross-hair is the trajectory of the motion after Kalman filtering.

As we can see, errors relative to standard trajectory before and after filtering have been shown in Fig. 7 more clearly. The green line is the error before filtering, red line is the error before filtering. The feasibility of navigation system method of using Kalman filter has been proven.

Conclusion

In this paper, we only talk about location system of robot and not focus on the damage detection system of the pipe. With this system, robot could record its position in the pipeline at any time (not only recording the position of robot, but the position of defection of pipe). This system can be embedded in most dual-track robots running in large-diameter pipelines. This system also can expand more functions, including communication with the computer and optimization of human-computer interaction interface.

References / Список литературы

1. Feng W.Y. Design and research of wireless positioning system for climbing robot. Zhejiang University, 2017.
2. Wang P., Li S.J., Chen Z.H. Research overview of mobile robot positioning method, 2011. P. 911-915.
3. Xu H., Li Z.X., Su Y. Research Status and Prospects of In-pipe Inspection Robot Positioning Technology, Machine tools and hydraulics, 2013.
4. Feng G., Lv M.T. Simulation of Kalman Filtering Based on MATLAB.
5. Wang L.S., Gao X.W., Yin L.J. Maximum Correntropy Criterion Based Robust Kalman Filter, 2018.
6. Cerati G., Elmer P. Kalman filter tracking on parallel architectures, Journal of Physics: Conference Series, 2017.

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