Study on Measurement System of Underwater Autonomous Robot

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***Abstract*—Measure system is important part for an autonomous mobile robot. Move-in-mud robot is a new kind of autonomous underwater robot, which is used to dig hole in the mud. Measure system of move-in-mud robot is designed in the paper and measure principle of move-in-mud robot is analysed. Data fusion methods combine multi-sensor information to obtain the uniform description or the understanding to the measured object according to a certain criterion. Kalman filter is chosen as the data fusion method of the measure system to improve the accuracy of measure system. The depth error with fusion is smaller than the direct measure and indirect measure. The simulation results indicate that fusion improves the accuracy of the robot depth obviously.**

***Keywords*—Kalman filter; muti-sensor fusion; measure system; robot**

I. Introduction

Autonomous mobile robot is frequently used in all kinds of fields industry, military, family and space. With the development of sensor and computer technology, the characters of measurement system of robot have improved greatly. In order to improve accuracy and reliability of measure system, different kinds of sensors are in robot to acquire more information. Then the information can be processed with data fusion methods. Data fusion is the process of combining data from several sources into a single unified description of a situation [1].The measure system of an digging robot is studied in the paper. Kalman filter is used to fuse the redundant information.

II. Fusion methods

Data fusion techniques are widely used in many areas such as modern industry, military, tracking, surveillance systems, intelligent Robots, and so on. Data fusion methods have many kinds, such as neural network fusion, D-S evidence theory, Kalman filter method, fuzzy fusion and *etc*. and Bayes decision theory [2,3] Data fusion refers to a wide range of information processing techniques and methodologies to achieve more accurate and reliable information [4,5].

A. Neutral network

Neural networks study complex nonlinear system control and so on. there are some kinds of Neutral network such as CMAC and BP networks. BP network is a nonlinear mapping artificial neural network, which can approach any continuous function of closed region with one hidden layer[6,7].

BP neural network is widely used in various fields of the society. But with the development of the society, the data is becoming more huge and complex. The type of the data comes from simple to multi-class. Bp algorithm is an effective and a lot of problems can be solved with it. Because it has solid theory basis, inferential reasoning process, clear physical conception, the good versatility and so on, it is still in feed-forward neural network until now.

The architecture of a BP network refers to the way it decodes information, that is the direction of information during recall. The architecture of a BP network refers to the way it decodes information, that is the direction of information during recall. In a BP neural network the nodes are organized in input, hidden, and output layers, as figure 1.

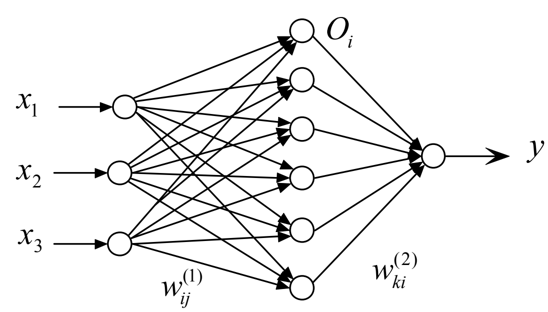


Fig.1. Structure of neural network

The output of neural network input layer

$$O_i^{(1)}(k) = x_i(k) \qquad i = 1,2,3 \tag{1}$$

The output of neural network hidden layer

$$O_i^{(2)}(k) = f[net_i^{(2)}(k)] \quad (i = 0,1,\cdots,5) \tag{2}$$

$$net_i^{(2)}(k) = \sum_{j=0}^{M} w_{ij}^{(2)} O_i^{(1)}(k) \tag{3}$$

Where, $w_{ij}^{(2)}$ is weight of hidden layer and $f[\cdot]$ is the activation function.

The output of neural network output layer

$$y = O^{(3)}(k) = g[net^{(3)}(k)] \tag{4}$$

$$net^{(3)}(k) = \sum_{j=0}^{M} w_j^{(3)} O_j^{(2)}(k) \tag{5}$$

Where, $w_{ij}^{(2)}$ is weight of output layer and $f[\cdot]$ is the activation function.

Neutral networks decide the classified standard based on similarity of sample which system obtains. The center of the method is not weight's distribution, to obtain knowledge by certain study algorithm of neutral net and to generate uncertainty inference relation.

B. *Kalman Filter*

Kalman filter is used to fuse dynamic sensor information in real time. The method decides the best fusion data estimate of statistical meaning with statistical recursiveness of measure model. If the system has linear dynamical model and the noise of system and sensor is white noise model with Gaussian distribution, Kalman filter can provide unique best estimate of statistical meaning [8-9]. Kalman filter's recursiveness make the information processing system needn't large store and calculation cells. The data fusion of the positioning system commonly uses the Kalman Filtering[10].

C. *Fuzzy inference*

From the middle period of the eighties of the 20th century, the research of fuzzy logic control has already reached certain level. Besides routine fuzzy control, there are several kinds of fuzzy control to derive [1], such as the fuzzy control technology self-adjusted, fuzzy control on the basis of the neural network, and fuzzy control on the hereditary algorithm et..

Fuzzy Logic provides a flexible environment for creating, modifying, and visualizing fuzzy sets and fuzzy logic-based systems. Built-in functions help users through every stage of the design process to define inputs and outputs, create fuzzy set membership functions, manipulate and combine fuzzy sets and relations, apply differencing functions to system models, and incorporate defuzzification routines.

In the multi-sensor system, the environment information provided by each information source is uncertain in some level. The uncertain information fusion is a course of deducing uncertain in fact. Fuzzy logic can be used to fuse the information of graph analysis and object recognition. Fuzzy logic may directly express certainty of multi-sensor data fusion in the course of inference.

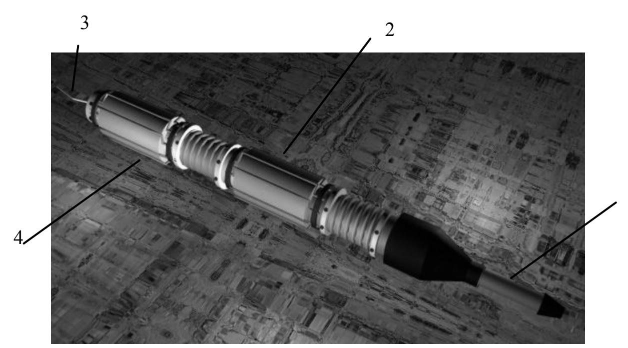
III. MEASURE SYSTEM OF AUTONOMOUS ROBOT

A. *Introduction of Move-in-mud Robot*

With the rapid development of the ocean transportation and exploitation technology, the tragedy of sunken ships often occurs. Wrecks that jam sea-route or have higher value should be salvaged promptly, but at present the technology of rescues by far can not meet the actual needs. So the development of underwater robot that salvage the sunken wreck has the important practical application prospect. The sunken wreck salvage is to dig a hole firstly, which lies under the wreck base to put the steel cable to lift the ship. Then put the steel cable through. Digginging the hole is one of essential working procedures in the wreck salvages. At present, digging the hole is operated by the diver with the manual implement. This method has many faults such as long cycle, low efficiency, difficult working condition and taking great risk.

Move-in-mud robot is a kind of autonomous robot which is used in the wreck salvages. It can excavate the hole according to the planed path automatically. At the same time, move-in-mud robot also can be used in excavating a hole on the land. Therefore, the study of move-in-mud robot has the broad application prospect.

Based on the analysis of autonomous underwater operation vehicle and snake-like mini-robot, and studying on the movement mechanism of scramble animals, a new structure project of move-in-mud robot based on creepage principle is shown in Fig.2. The body of move-in-mud robot is made up of the move-in-mud head, turning mechanism and squirm creeping body (former sustaining mechanism, back sustaining mechanism, squirm feeding mechanism). Between the move-in-mud head and the squirm creeping body, there is a set of a turning mechanism. There is a squirm feeding mechanism among the former sustaining mechanism and back sustaining mechanism.



1. Move-in-mud head 2. former sustaining mechanism
3. complex cable 4. former sustaining mechanism
Fig.2 Schematic diagram of move-in-mud robot

B. *Measure System Design*

The move-in-mud robot moves forwards by squirming means. In the process of move-in-mud robot's squirm of each step, the pitching angle of move-in-mud head changes small. So the dispersion of the attitude angle between before and after the squirm is small. In fact, the movement of move-in-mud head is made up of the moving and turning. According to the location and attitude of the head, we can receive the location and attitude of every other part of the robot by its structure parameter and pitching angle.

The move-in-mud robot's measure system consists of a electronic compass, a depth sensor, two angular sensors and two linear sensors. Electronic compass is fixed on the back part of the robot. The measure of azimuth and rolling angle is used to accomplish the supervision of robot's attitude. The pitch angle is the attitude angle of the robot, which is used to calculate the location of robot. The depth sensor is a pressure transforming exchanger which is linked together with a water pipe parallel with a complex cable. The measurement of the robot's depth is accomplished by the pressure changes affecting in the water pipe. Angular sensor 1 is used to detect turning angle of move-in-mud head. Angular sensor 2 is used to detect turning angle between front and back of sustaining mechanism. The linear sensor 1is used to detect stroke of move-in-mud head. The linear sensor 2 is used to displace of creepage mechanism.

In Move-in-mud robot's measure system, the depth information can be received with electronic compass, angular sensors and linear sensors based on the analysis as ahead. The depth information can be measured directly with depth sensor, which is an absolute positioning method. Thus, the depth information is redundant. The redundant information can be processed with the data fusion arithmetic. This will improve the precision and reliability of the positioning system. So Kalman filter arithmetic is used to fuse the redundant dept.

IV. EVALUATION INDEX AND SIMULATION RESULTS

A. *Design of Kalman Filter*

On the point of time t=KT, the depth displacement directly measured by depth sensor is $y_p(k)$. The depth displacement can be indirectly acquired by the pitching angle measured by electronic compass and angular potentiometer. and linear displacement sensor. That is $Z(k) = y_p(k)$. In the moving process of robot, the indirect depth displacement shows the model's control parameter, that is $u(k) = y_c(k)$. W(k) is the noise signal of the state space; V(k) is the measurement noise of the sensor. we suppose W(k),V(k) as the white noise with no correlation, namely

$$Cov[W(k),W(j)] = E[W(K)W(j)^T] = Q\delta_{kj} \tag{6}$$

$$Cov[V(k),V(j)] = E[V(k)V(j)^T] = R\delta_{kj} \tag{7}$$

Then we get the expression of discrete state function and measuring equation of the system as bellow

$$X(k+1) = \hat{X}(k+1/k) + u(k) + W(k+1) \tag{8}$$

$$Z(k+1) = X(k+1) + V(k+1) \tag{9}$$

State one-step estimation function is

$$\hat{X}(k+1/k) = X(k) + u(k) \tag{10}$$

Estimation of state is

$$\hat{X}(k+1) = \hat{X}(k+1/k) + K(k+1)(Z(k+1) - \hat{X}(k+1/k)) \tag{11}$$

Filtering gain is

$$K(k+1) = P(k+1/k)(P(k+1/k) + R)^{-1} \tag{12}$$

The error quadratic mean of one-step forecast is

$$P(k+1/k) = P(k/k-1) + Q \tag{13}$$

The error quadratic mean of estimate values is

$$P(k+1) = (1-K(k+1))P(k+1/k)(1-K(k+1))^T + K(k+1)RK(k+1)^T \tag{14}$$

B. *Simulation Results*

With the above formulas of Kalman filter, the simulation of the measure system is studied in this part. An arc whose chordal length is 25m and chordal height is 3 m is chosen as the planned trajectory of the robot in simulation. The depth information of the move-in-mud robot can be fused with the Kalman filtering equation. The turning mechanism of the move-in-mud robot can constantly control the changes of the pitching angle, when the robot movies along the whole trajectory. In simulation, the move-in-mud head's moving step displace is 0.05 m each time, Q=0.0001m^{2,} and R=0.01m^2. The depth errors in direct measure, indirect measure and fusion measure of simulation results are shown in Fig3 - Fig.5

In indirect measure, the depth information error in one step is small, but the depth error is accumulated in the robot moving process along the planned trajectory. In the direct measure, the depth error at one step distance is a little large, but the error does not change with the increase of moving distance. The depth error with fusion is small and does not change with the increase of moving distance. It improves the accuracy of the robot depth obviously.

V. CONCLUSION

Move-in-mud robot is a new kind of underwater robot, which is used to dig hole in the mud. The exact and dependable measure system is a key technique of the robot. The measure system of the robot is studied in this paper. Data fusion is a new technology of information synthesis and information processing. It is applied in the measure system of the robot. The main ideas of this paper can be summarized as bellows:

General methods of multi-sensor data fusion such as neutral networks, Kalman filter and fuzzy inference, are analyzed. Kalman filter is frequently used in mobile robot measure system.

According to working environment of move-in-mud robot and its mechanical structure, measure system of move-in-mud robot is designed.

The measure system of the robot can offer redundant depth information. Kalman filter is chosen as the data fusion method of the measure system to reduce the accuracy of measure system. The depth information of measure system is simulated in the paper to reduce the measure error. The simulation result, The depth error is accumulated with the increase of moving steps along the planned trajectory in indirect measure. In the direct measure, the depth error at one step distance is a little large, but the error does not change with the increase of moving distance. The depth error with fusion is smaller than the order two measure methods. It improves the accuracy of the robot depth obviously.

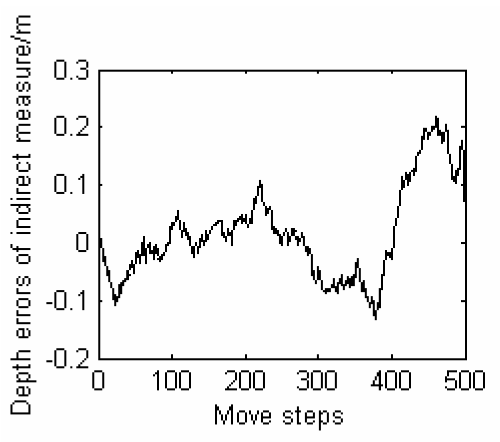


Fig.3 Depth errors with direct measure

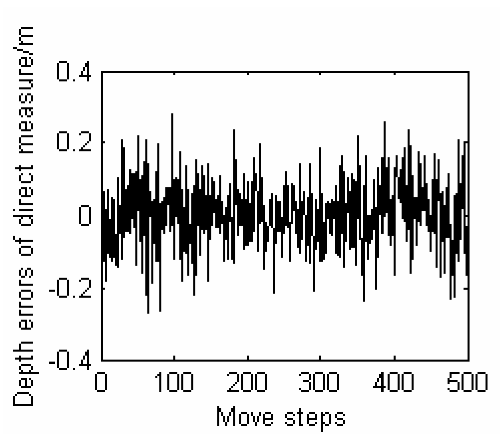


Fig.4 Depth errors with indirect measure

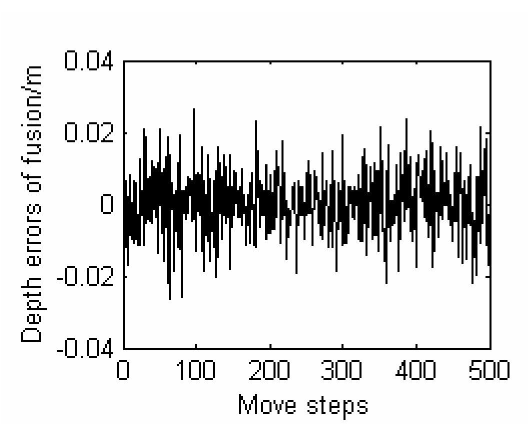


Fig.5 Depth errors with fusion measure

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