Fuzzy Control of Underwater Vehicles based on Boolean Association Rule Data Mining

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Abstract. Aiming at high overshoot and steady-state error in fuzzy controller of underwater vehicles, a new method based on data mining technique was presented. Apply Boolean association rule data mining to mine the polling list of fuzzy control from the database of manual operation record, and simulation and outfield experiments were carried out on Super Mohawk underwater vehicle to verify the feasibility and superiority. The results show that the controller has lower overshoot, and the polling list of fuzzy control can be constructed automatically by Boolean association rule data mining, which improves the accuracy and the precision of motion control for underwater vehicles.

Keywords: Underwater Vehicle, Fuzzy Control, Data Mining, Polling List.

1. Introduction

With the development of the activities in deep sea, the application of underwater robots is widespread [1, 2]. However, owing to the nonlinearity and unpredictable operating environment of underwater robots, many factors must be taken into consideration during the design of the control system. On the other hand, the performance of sensors, especially optical and acoustical sensors can be seriously degraded by the high frequency oscillating movement. In order to improve the performance, to strengthen the robustness, adaptability and autonomy, a lot of methods of intelligent control have been applied to underwater robots, such as fuzzy control, neural network control and sliding mode control.

Fuzzy control technique has been applied extensively in the field of underwater vehicles [3]. The controller is simple designed and similar to linear PD controller in function, so there is usually good dynamic performance, however, and steady-state error. Moreover, it experiences a deficiency in knowledge acquisition and relies to a great extent on empirical and heuristic knowledge which, in many cases, cannot be objectively elicited.

In recent years, data mining technique has been applied in many fields of science and technology [4, 5]. Implied knowledge and regulation can be mined from a large number of data by adopting data mining. Accordingly, it can be applied to fuzzy controller of underwater vehicles, by which accumulative manual control data can be mined and the polling list of fuzzy control be constructed automatically. In addition, subjectivity and uncertainty can be avoided when a professional extracts the fuzzy control rule.

In this paper, optimization method of fuzzy control is proposed based on data mining, and the automation of constructing the polling list of fuzzy control can be achieved. Finally, simulation and pool experiments are carried out on “SY-II” underwater vehicle to verify the feasibility and superiority.

2. Fuzzy control system

2.1. Structure of fuzzy controller.

The structure of fuzzy controller of underwater vehicles is shown in figure 1. The control inputs are the error between actual position and the reference e and its variance ratio $\dot{e}$, which is navigation velocity of underwater vehicle in this paper. The outputs are forces or force-moments which are created by thrusters u . Firstly ①, fuzzification is done, namely, the controller transforms error signals into the grade values of errors. Secondly ②, the grade values of outputs are obtained by searching the polling list of fuzzy control, which is called fuzzy inference. Finally ③, inverted fuzzification is done, and it is means that the grade values of outputs are transformed into output signals to impel underwater vehicles to the authorized position. As can be seen, the polling list of fuzzy control is the key to control system, and the accuracy affects performance directly.

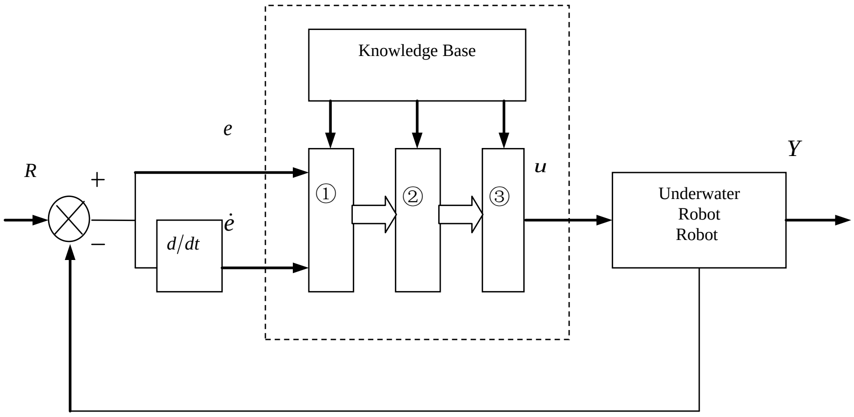

Fig. 1 Structure of fuzzy controller

2.2 Fuzzy rule and the polling list of fuzzy control.

The polling list of fuzzy control is constructed based on the data of manual operation record. It can be considered as control rule described by list form and represents the relationship between inputs and outputs. The process of construction can be divided into three steps: firstly, the data of manual operation record and system error are analyzed and arranged, and they are saved in one database, which is named manual operation database; secondly, the fuzzy subset, relevant language variable, assignment list of membership function and the list of control rule are determined by professionals according to manual operation data and experience, so there exists some subjective random and the accuracy is different for people and the repeatability is not good; thirdly, the polling list of fuzzy control is deduced and calculated, which is hard and complex enough. Usually, unperfect performance is caused by the inaccuracy of the polling list of fuzzy control. The problem can be solved by adopting association rule data mining technique.

Association rule data mining is that mining association rule described as $A \rightarrow B$ from the transaction database. It means that there are some relations with degree of reliability between event A and event B, and it can be described as $P(A \cup B)$ and $P(A|B)$ in theory of probability. On the other hand, the relation between the grade values of outputs and the inputs has been listed by the polling list of fuzzy control, and can be considered as association rule $A \rightarrow B$ described by the grade values, which has high degree of reliability. Accordingly, there is nearly the same meaning between the association rule and fuzzy control rule. As long as changing manual operation database to transaction database, we can mine fuzzy control rule automatically by adopting the Boolean association rule data mining technique, and transform to the polling list of fuzzy control.

The association rule data mining is based on statistic calculation, so the association rule obtained has good accuracy and repeatability. Moreover, the polling list of fuzzy control can be mined by adopting association rule data mining from manual operation database directly, and combined three phases to one, so the polling list of fuzzy control can be constructed automatically without calculating the fuzzy subset, relevant language variable, assignment list of membership function and the list of control rule.

3. Data mining based polling list of fuzzy control

Data mining can be divided into three phased: pretreatment of the manual operation database, and fuzzy rule mining, and construction of polling list of fuzzy control.

3.1. Pretreatment of manual operation database

The manual operation database with a great deal of manual operation record is pretreated firstly, and transformed into Boolean transaction database which is described as the grade values form. Manual operation database is founded showed as table 1.

Table1. Manual operation database

Tid	C_i	C_0
001	-3.7	3.0
002	-2.6	1.6
003	-2.8	2.2
004	-1.8	1.7
005	-1.1	1.0
006	0.2	-0.8
007	0.8	-1.0
008	-0.2	0.8
009	0.7	-0.9
010	0.8	-1.0

In the table, the value of *Tid* its record label to manual operation record. It can be operation time or the serialnumber set artificially; the inputs C_i are the digital values of system error signal; the outputs C_0 are the digital values of operating output signal. Given the span of the grade values is [-4,-3,-2,-1, 0, 1, 2, 3, 4], the data in column C_i are transformed into the grade values Cid by function (1)

$$Cid = < K[Ci - (Ci_{max} + Ci_{min})/2] > \quad (1)$$

Where $[Ci_{max}, Ci_{min}]$ is the span of system errors? Here Co_{max}, Ci_{max} =5, Co_{min}, Ci_{min} =-5; < > represents rounding numbers following half adjust; $K = 8/(Ci_{max} - Ci_{min})$.

In the manual operating output column Co, the data are transformed into the grade values Cod by the same method upwards. In order to identify easily, the grade values in column Cid are added Ii to represent the inputs; the grade values in column Cod are added Io to represent the outputs. So we can obtain the grade values database Dc shown as table 2.

Table2. Grade values database Dc

Tid	*Cid*	*Cod*
001	-2*Ii*	2*Io*
002	-2*Ii*	1*Io*
003	-2*Ii*	2*Io*
004	-1*Ii*	1*Io*
005	-1*Ii*	1*Io*
006	-0*Ii*	-1*Io*
007	1*Ii*	-1*Io*
008	0*Ii*	1*Io*
009	1*Ii*	-1*Io*
010	1*Ii*	-1*Io*

As can be seen, the data in the column Cid , Cod are the character strings composed of the grade values adding some character suffix. One character string can be considered as an identifier to item, which represents a kind of state. So the grade values database is transformed into the transaction database, and one character string represents the Boolean value in some state, implying the original grade values. Each record has the same amount of item; however, the label of item may be different. Then, we can apply the Boolean association rule data mining to mine association rule from the database upwards to mine the frequent mode.

Because of some characteristics of the control system, the frequency of some manipulations is lower than the frequency of others. However, these manipulations are exact and necessary. If we apply association rule data mining based on statistic calculation directly, it is impossible to mine the control rule by the unitized least threshold value minus. To improve the integrity and accuracy, and mine the control rule of low frequency but necessary one, the database is level divided according to the values column Cod, and some sub databases are merged into according to the same value in column Cod. As can be seen, the database shown as table 2 are divided into three sub databases shown as table 3. In these sub databases, the frequency of the manipulations are improved highly enough.

Table3. Grade values sub databases

Tid	*Cid*	*Cod*
006	0*Ii*	-1*Io*
007	1*Ii*	-1*Io*
009	1*Ii*	-1*Io*
010	1*Ii*	-1*Io*
Tid	*Cid*	*Cod*
002	-1*Ii*	1*Io*
004	-1*Ii*	1*Io*
005	-1*Ii*	1*Io*
008	0*Ii*	1*Io*
Tid	*Cid*	*Cod*
001	-2*Ii*	2*Io*
003	-2*Ii*	2*Io*

Every sub database is relatively small enough, so it is more convenient to operate with each sub databases in the internal memory of computers to increase the mining velocity.

3.2 Mining of fuzzy control rule

Apriority algorithm can be applied to mine the association rule to the sub databases.

Because of the level division to the grade values database Dc in column Cod, the frequency of this manipulation is improved highly in sub databases, so we can select high minus value in Apriority algorithm to improve the accuracy of association rule data mining. In practice, the value of minus should be determined according to the characteristics of the control system, here minus=60%.

The frequent mode set can be obtained by mine the association rule to the three sub databases, shown as:

{1*Ii*, -1*Io*}, {-1*Ii*, 1*Io*}, {-2*Ii*, 2*Io*}

According to the characteristics of the control system of underwater vehicles, the control rule can be constructed as follows.

1*Ii*→-1*Io*, -1*Ii*→1*Io*, -2*Ii*→2*Io*

3.3 Construction of the polling list of fuzzy control

According to the control rule, the polling list of fuzzy control can be constructed conveniently, shown as table 4. E Are the grade values of errors, and U are the grade values of outputs of the fuzzy controller. Each column corresponds to one control rule.

The left character strings of the control rule are getting rid of Ii, and the values are filled into the line E in the polling list of control; the right character strings of the control rule are getting rid of Io, and the values are filled into the line U . After sequential dealing with, the other rules are filled into, so we can get the polling list of fuzzy control shown in table 4. It is saved previously into the fuzzy controller, and the control system can run normally.

Table4. Polling list of fuzzy control

E	1	-1	-2
U	-1	1	2

3.4 Data mining algorithm

In this part, some codes are given to describe the mining algorithm.

Input: manual operation database D , the span of the grade values is Co_{max} , Ci_{max} , Co_{min} , Ci_{min} , minus;

Output: polling list of fuzzy control;

Method: frequent mode set R ;

D Is transformed to the grade values database Dc ;

Dc Is transformed to the transaction database Dt ;

Dt Is divided into sub databases Dt_i ; (I =1, 2… *m*)

For *I*=1; *I*=*m*; *I*++

{Call Apriority (Dt_i) // call Apriority algorithm; Dt_i is mined and the values are loaded into *R*}

Where *R* is transformed to the polling list of fuzzy control.

4. Experiments

Super Mohawk is a kind of remotely operated underwater vehicle (ROV) designed for the inspection of faults and other potential problems of the submarine cables. It is designed as open-frame structure for the reason of being equipped with many different advanced inspecting sensors according to different tasks, which results in the difficulty in acquiring the precise model of it. Because of the particularity of open-frame structure, Super Mohawk does not have streamlined geometry profile, so it is more difficult to control precisely. The problem has not yet been solved very wel1.

Fig. 2 Super Mohawk ROV

Super Mohawk ROV runs at low speed when it carries out detection tasks. Therefore, the coupling of motion in six degrees of freedom is not severe. To make the design of control system convenient, we ignore the coupling function and consider the motion of underwater vehicles separate. Accordingly, the controller should be divided into several modules, including heading control module, vertical control module, longitudinal control module and transverse control module and so on. Each module has the same structure and algorithm. Simulation and pool experiments have been carried out on Super Mohawk ROV by adopting Boolean association rule data mining to verify the feasibility and superiority. Apply data mining presented upwards to mine association rule from the running record-oriented data of the control system and the polling list of fuzzy control is constructed automatically. Moreover, certain fixed disturbances which can adjusted are added to eliminate steady-state error [9].

In simulation, the reference input is 5 m, the velocity of current is 0 m/s, and the voltage of thrusters is restricted by 2.5V. Fig.3 shows the comparison of the fuzzy control performance between Boolean association rule data mining and conventional method. As can be seen, the overshoot falls down greatly and there is hardly steady-state error by adopting Boolean association rule data mining.

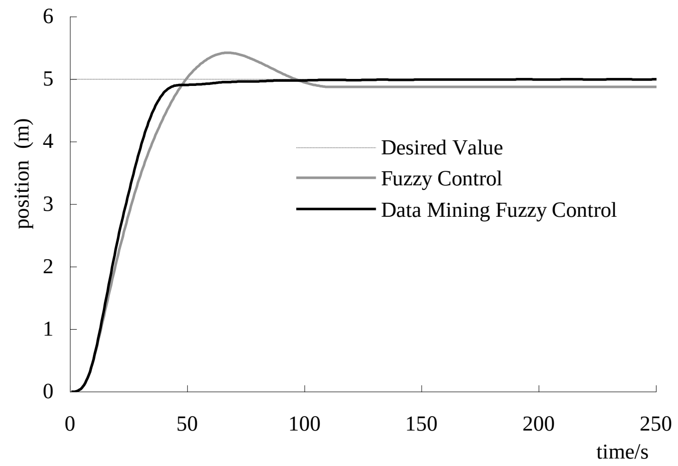

Fig. 3 Control performance of simulation

In outfield experiments, only heading control results are presented in this paper, shown in figure 4. As can be seen, exactly control can be achieved by adopting fuzzy control based on data mining, and the controller has lower overshoot and good robustness to external disturbance. It should be declared that the oscillation near 80 second is caused by the precision and performance of the sensors.

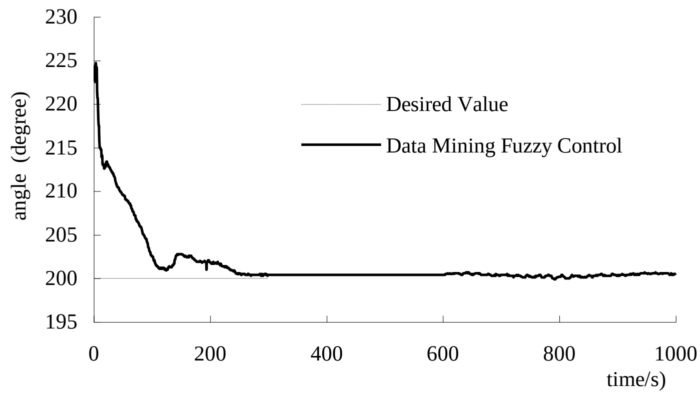

Fig. 4 Control performance of pool experiments

5. Conclusions

The feasibility and superiority of applying fuzzy control based on data mining to motion control of underwater vehicles has been verified. Apply the Boolean association rule data mining to mine the polling list of fuzzy control from the database of manual operating record, and the polling list of fuzzy control can be constructed automatically, which improves the accuracy and the precision of motion control.

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