The Application of the Fuzzy Theory in the Design of Intelligent Building Control of Water Tank

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***Abstract*—With the rapid development of intelligent buildings, a lot of researchers have found that it is difficult to establish mathematical model when the problem that energy-saving in water supply system of an intelligent building tank is focused, because that the outflow of the tank volume is volatile when the water is daily living water. In this paper, fuzzy control theory is used to establish a fluid level, and the fluid input flow rate to determine the amount of control, which to push the valve's opening size and speed in order to control the water supply valve opening adjustment level, so that the liquid position of container maintains a constant, and the MATLAB software is used to verify the effect of fuzzy control system. The results show that in this fuzzy control system the benefits of economic operation of water supply can be ensured by ensuring a constant level of liquid.**

***Index Terms*—matlab, intelligent building, Constant Level, fuzzy control**

I. INTRODUCTION

The realization of functions of intelligent building system is based on running types of equipments, functions more perfect，more types of equipment systems, and more complex operating and equipments monitoring, which would bring about greater energy consumption. With the development of modern technology, building energy consumption increased significantly in the 21st century which is an era lack of energy. Therefore, studying energy-efficient intelligent buildings is of great strategic significance [1][2]. With the increasing number of today's intelligent buildings, water supply issue has become the property owners' comparatively concerned issue. Water supply and drainage control subsystem of intelligent building are as follows, according to height, and water requirements of the building, forms of the water supply are determined, including: direct water supply, high water tank water supply, and constant pressure water supply. Water supply system composed of high water tanks, pumps for water for life and reservoir at the bottom is generally used in high-raised buildings. The purpose of water control subsystem is via computer control technology to timely display and adjust running conditions of the pumps, the number of operating units of the water pumps, start / stop time, pump overload alarm, water status indicators, water tank level display and alarm, in the water supply system of the building, so as to balance the water supply and demand as well as water input and output, besides to achieve the best pump operation, optimally control of high efficiency and low consumption. So the purpose of water supply equipment operating economically could be achieved [3].

Fuzzy control is a kind of nonlinear control method. Both its working and application range are wide. It is particularly suitable for nonlinear system control. Fuzzy control does not depend on the object's mathematical model even those complex object can not or difficult to be modeled. With the help of the fuzzy control, we can take advantage of people's experience and knowledge to design the fuzzy controller to fulfill control tasks. When designing the controller through traditional control methods, mathematical model of controlled object must be given. Fuzzy control has inherently parallel processing mechanism, shows remarkably robustness, is insensitive against changes in the characteristics of controlled object. The design parameters of fuzzy controller are easy to select for the adjustment. Algorithm is simple and the implementation is fast, so it is easy to implement. It does not require a lot of knowledge about control theory, so it is easy for popularization [4][5]. It is because of the significant advantages of fuzzy control above that many world's famous leading experts and scholars pointed out: 'Fuzzy control is a control technology of the 21st century', so it will have broad prospect of development and product markets. As the outflow of the tank volume is volatile when the water is daily living water, mathematical model is difficult to establish. In this paper, one of the simplest valves is used to control water level, so that the container can maintain a constant level to ensure the water supply operating economically.

II. FUZZY CONTROL

A. The Basic Principle of Fuzzy Control

The fuzzy control system is an automatic control theory, theoretically based on fuzzy mathematics, namely the fuzzy set theory, the fuzzy language knowledge representation and fuzzy logic rule reasoning, and technologically based on the computer control technology and automatic control system. To tell broadly, the fuzzy control system is also a kind of computer control system, the component part of fuzzy controller is actually just a

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kind of algorithm structure.

A fuzzy control system's performance quality mainly depends on the structure of the fuzzy controller, the fuzzy rules adopted, synthesis reasoning algorithm, and the fuzzy decision-making method, and other factors. The fuzzy controller firstly converted the real ascertained input amount to a fuzzy vector, namely fuzzification, then, it established the rule-library with the fuzzy subsets, provided control rules for "reasoning machine". Reasoning realized the function of achieving fuzzy control quantity from fuzzy relation equation, following the completion of fuzzy inference according to the fuzzy control rules, based on the fuzzy amount inputted in fuzzy controller.

B. Fuzzy Controller

Fuzzy Logic Controller, briefly called Fuzzy Controller, is to solve the control problems of some objects. These problems cannot be solved by the traditional control methods while can be solved by some experienced operating workers. So Fuzzy Controller is suitable to imitate the experts' control of some complicated systems which the mathematical models are unknown.

Fuzzy Controller is made up of fuzzification interface, fussy inference, defuzzification interface and knowledge base. Fuzzification interface is used to transfer the input accurate quantity into fussy quantity and present the quantity through the corresponding fussy set. As the core of the Fussy Controller, fussy inference is of the ability of inference that imitate human based on fussy concept. This process of inference is based on the relationship and inference rules in the fussy logic. Defuzzification interface is used to transfer the control quantity from the fussy interface into accurate quantity which is used in control. Knowledge base contains the knowledge that in specific application area and required control goals. Knowledge base is usually made up of data base and fussy control rules. Fundamental components of fuzzy controller are shown in Fig. 1.

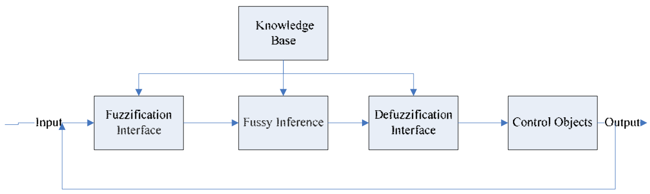

Figure 1. Fundamental components of fuzzy controller

III. THE MODEL OF THE SYSTEM

A. The Structure of Fuzzy Controller

The past few years have witnessed a rapid growth in the number and variety of applications of fuzzy logic. The applications range from consumer products such as cameras, camcorders, washing machines, and microwave ovens to industrial process control, medical instrumentation, decision-support systems, and portfolio selection.

To understand the reasons for the growing use of fuzzy logic it is necessary, first, to clarify what is meant by fuzzy logic. Fuzzy logic has two different meanings. In a narrow sense, fuzzy logic is a logical system, which is an extension of multivalued logic[6][7]. But in a wider sense, which is in predominant use today, fuzzy logic (FL) is almost synonymous with the theory of fuzzy sets, a theory which relates to classes of objects with unsharp boundaries in which membership is a matter of degree. In this perspective, fuzzy logic in its narrow sense is a branch of FL. What is important to recognize is that, even in its narrow sense, the agenda of fuzzy logic is very different both in spirit and substance from the agendas of traditional multivalued logical systems.

In the Fuzzy Logic Toolbox, fuzzy logic should be interpreted as FL, that is, fuzzy logic in its wide sense. The basic ideas underlying FL are explained very clearly and insightfully in the Introduction. What might be added is that the basic concept underlying FL is that of a linguistic variable, that is, a variable whose values are words rather than numbers. In effect, much of FL may be viewed as a methodology for computing with words rather than numbers. Although words are inherently less precise than numbers, their use is closer to human intuition. Furthermore, computing with words exploits the tolerance for imprecision and thereby lowers the cost of solution. Another basic concept in FL, which plays a central role in most of its applications, is that of a fuzzy if-then rule or, simply, fuzzy rule. Although rule-based systems have a long history of use in AI.Fuzzy logic is all about the relative importance of precision: How important is it to be exactly right when a rough answer will do? All books on fuzzy logic begin with a few good quotes on this very topic, and this is no exception. Here is what some clever people have said in the past.

In designing the water tank system, the amount of control which to push the valve opening size and speed, is determined according to level (level) and fluid input flow rate (rate) , so it is a kind of two-dimensional fuzzy controller which has two inputs and one output. the applications of fuzzy logic, a fuzzy logic solution is in reality a translation of a human solution into FDCL[6][7].

A trend that is growing in visibility relates to the use of fuzzy logic in combination with neurocomputing and genetic algorithms. More generally, fuzzy logic, neurocomputing, and genetic algorithms may be viewed as the principal constituents of what might be called soft computing. Unlike the traditional, hard computing, soft computing is aimed at an accommodation with the pervasive imprecision of the real world. The guiding principle of soft computing is: Exploit the tolerance for imprecision, uncertainty, and partial truth to achieve tractability, robustness, and low solution cost. In coming years, soft computing is likely to play an increasingly important role in the conception and design of systems whose MIQ (Machine IQ) is much higher than that of systems designed by conventional methods systems is a machinery for dealing with fuzzy consequents and/or fuzzy antecedents. In fuzzy logic, this machinery is provided by what is called the calculus of fuzzy rules. The calculus of fuzzy rules serves as a basis for what might be called the Fuzzy Dependency and Command Language (FDCL). Although FDCL is not used explicitly in the Fuzzy Logic Toolbox, it is effectively one of its principal constituents. In this connection, what is important to recognize is that in most Among various combinations of methodologies in soft computing, the one that has highest visibility at this juncture is that of fuzzy logic and neurocomputing, leading to so-called neuro-fuzzy systems[8][9]. Within fuzzy logic, such systems play a particularly important role in the induction of rules from observations. An effective method developed by Dr. Roger Jang for this purpose is called ANFIS (Adaptive Neuro-Fuzzy Inference System). This method is an important component of the Fuzzy Logic Toolbox.

On the FIS in the MATLAB editor interface, fill in the 'level' override 'input1', carriage return, so that the input variable input1 to be the new name. In the same way, with the new name 'rate' override 'input2'; with the new name 'valve' override 'output'. In the 'fuzzy logic zone', click the edit box, set the 'And method' as 'prod', 'Or method' as 'prober', 'Implication' as 'prod', 'Aggregation' as 'max', 'Defuzzification' as 'centric' in the project pulled out. The final design of dialog box of fuzzy controller GUI is shown in Fig. 2.

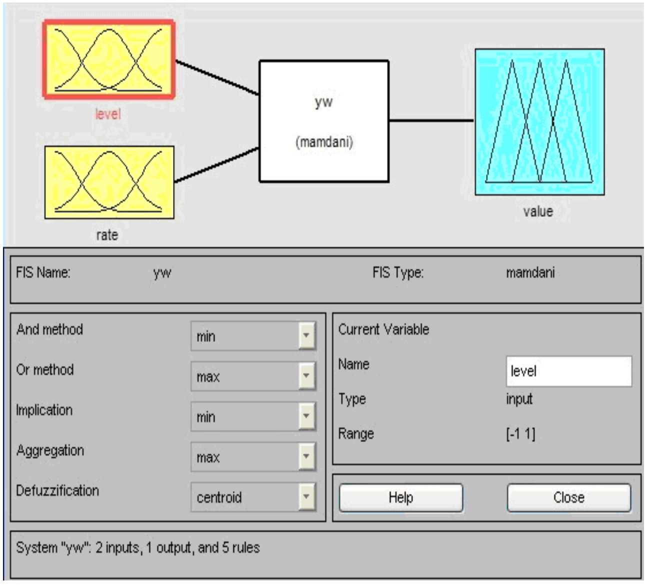

Figure 2. The design structure of controller

B. Variable Settings

Settings of variable level and rate include the value range, indication range, coverage, the number and distribution of fuzzy subsets and the types of membership function. In the MF (level) editor, modify the 'current variable area', through typing [-1，1] into the Range and the Display edit box of the current variable level overwriting the original [0 1]. Secondly, click each membership function curve one by one, change their names into 'high' 'okay' and 'low' from left to right, change its membership function into 'Gaussian', then select value according to table 1 to edit the parameter.

TABLE I.
COVERS THE VARIABLE LEVEL OF FUZZY SETS PARAMETER VALUES

The name of fuzzy sets	high	okay	low
Params	[0.3 -1]	[0.3 0]	[0.3 1]

In the same way, you can edit the input variable 'rate'. The names of the fuzzy subset of 'rate' are 'negative' 'okay' 'positive'; their membership functions are selected as the 'Gaussian', parameters are adjusted to values shown in Table 2.

TABLE II.
COVERS A VARIABLE RATE PARAMETER VALUES OF THE FUZZY SETS

Name of fuzzy sets	negative	None	positive
Prams	[0.03 -0.1]	[0.03 0]	[0.03 0.1]

Take the input variable 'rate' for example, its MF editor interface is shown in Fig. 3.

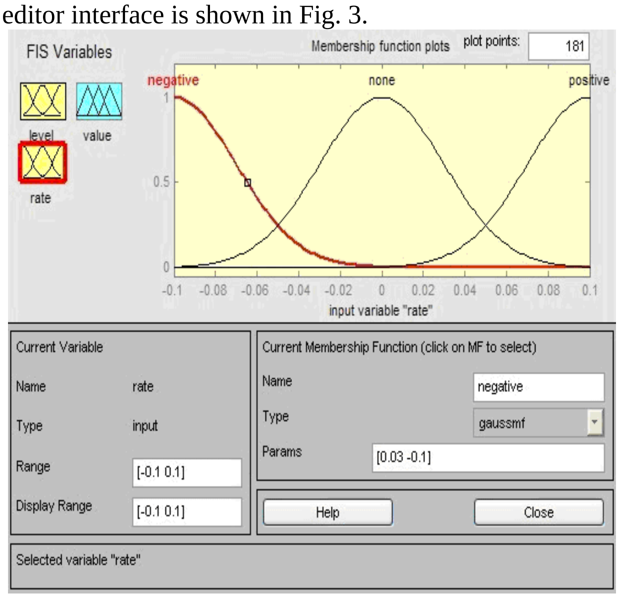

Figure 3. The input variable 'rate' of the MF editor interface

Take the input variable 'level' for example, its MF editor interface is shown in Fig. 4.

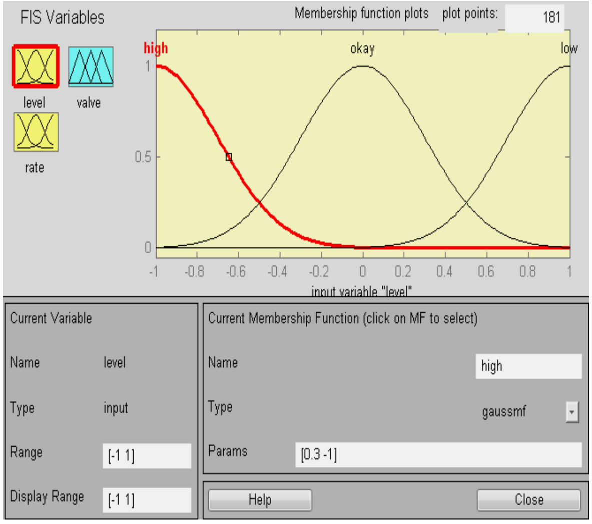

Figure 4. The input variable 'level' of the MF editor interface

In the MF (valve) editing interface, replace the original value [0 1] with the output fuzzy variable valve domain of [-1，1]. Secondly, add the number of fuzzy subsets. In the MF editor, click the menu Edit-Add MFs orderly..., set the number into 2 on the MF dialog box popped up, then click ok. Five triangular membership functions Chart are shown on the graph function area. Once again, edit the name of fuzzy subsets respectively, from left to right, set into 'close fast', 'close slow', 'no change', 'open slow', 'open fast'. Finally, adjust the parameters of fuzzy subsets. In the 'Current membership function area', modify 'prams (parameters)' and 'parameter value' of the edit box. Set the output parameters of the fuzzy subsets as shown in Table 3 respectively.

TABLE III.
OUTPUT VALVE RANGE VALUES

Name of fuzzy sets	close fast	close slow	no change	open slow	open fast
Range	[-1 -0.9 -0.8]	[-0.6 -0.5 -0.4]	[-0.1 0 0.1]	[0.2 0.3 0.4]	[0.8 0.9 1]

C. The Establishment of Fuzzy Rules

According to the operational experience accumulated, a few operating rules to maintain a constant level of liquid in the container are summarized (this is the important material foundation and basis of the design of fuzzy controller):

1). If level is okay then valve is no change.

2). If level is low then valve is open fast.

3). If level is high then valve is close fast.

Based on the fuzzy rules above, the simulation model of 'level fuzzy controller' is established .In the 'input variables Area', and 'output variable area' of the 'Edit zone' of 'fuzzy control rule editor interface , names of fuzzy subsets covering input and output variables have been listed. According to the fuzzy rules above, click the name of the corresponding fuzzy subsets successively, and then click the Edit function button, you can edit out the fuzzy rules.

D. The Establishment of System Model

According to the conditions above, the model of water tank fuzzy control system is shown in Fig. 5.

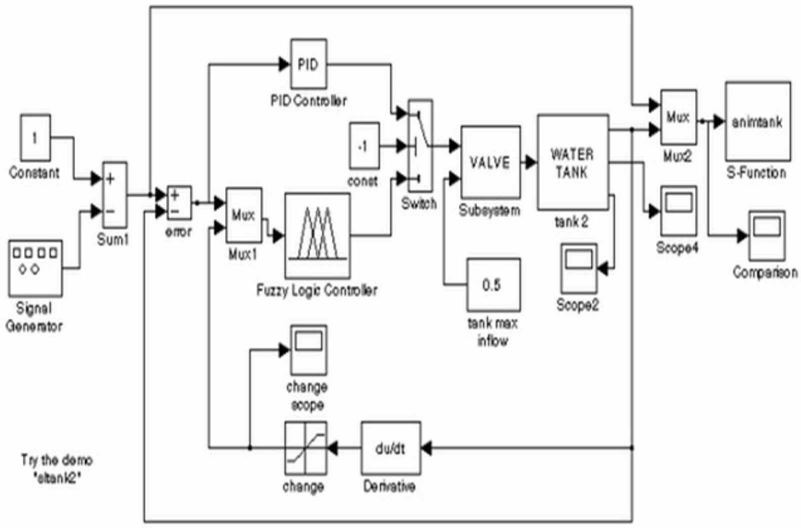

Figure 5. The simulation model of the system

The content of the water tank is presented in the Fig.6.

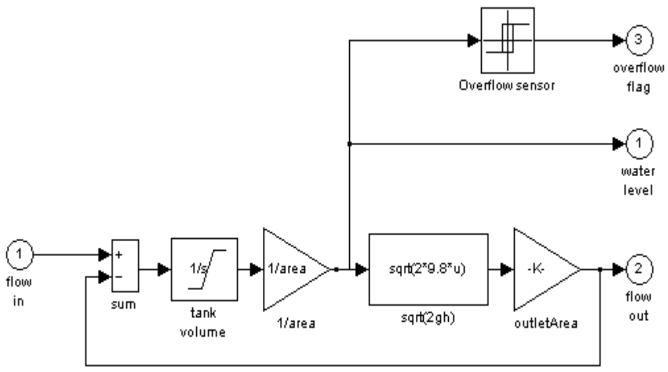

Figure 6. The simulation model of the water tank

The model of the water tank is presented in the Fig.7.

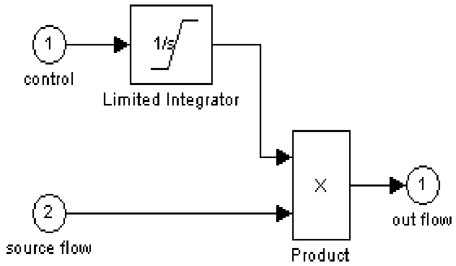

Figure 7. The simulation model of the water tank

The simulation model of the fuzzy logic controller is presented in the Fig.8.

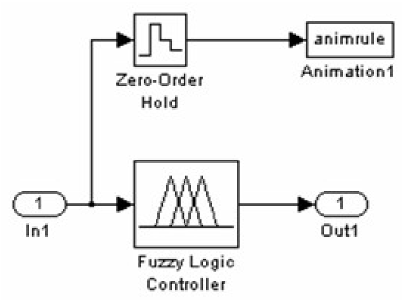

Figure 8. The simulation model of the fuzzy logic controller

Especially, they are duplicated from an example 'sltank' of the model simulation. In addition, double-click the 'signal generator', select the square from the right preset waveform editor area of its 'waveform'; in the edit box under the 'Amplitude', fill in 0.5; in the edit box under the 'Frequency', fill in 0.1; in the edit box right of 'Unit', choice Hertz, thus settings of the signal simulation are completed. The signal generator of the system is shown in the Fig.9.

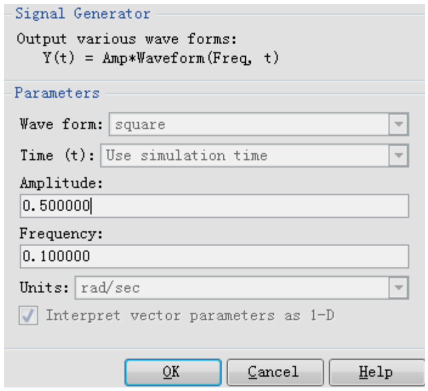

Figure 9. The interface of the signal generator

IV. Simulation Results

Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions can be made, or patterns discerned. The process of fuzzy inference involves all of the pieces that are described in the previous sections: membership functions, fuzzy logic operators, and if-then rules. There are two types of fuzzy inference systems that can be implemented in the Fuzzy Logic Toolbox: Mamdani-type and Sugeno-type. These two types of inference systems vary somewhat in the way outputs are determined. References to descriptions of these two types of fuzzy inference systems can be found in the bibliography [8, 9, 10].

Fuzzy inference systems have been successfully applied in fields such as automatic control, data classification, decision analysis, expert systems, and computer vision. Because of its multidisciplinary nature, fuzzy inference systems are associated with a number of names, such as fuzzy-rule-based systems, fuzzy expert systems, fuzzy modeling, fuzzy associative memory, fuzzy logic controllers, and simply (and ambiguously) fuzzy systems. Since the terms used to describe the various parts of the fuzzy inference process are far from standard, we will try to be as clear as possible about the different terms introduced in this section.

Mamdani's fuzzy inference method is the most commonly seen fuzzy methodology. Mamdani's method was among the first control systems built using fuzzy set theory. It was proposed in 1975 by Ebrahim Mamdani

[Mam75] as an attempt to control a steam engine and boiler combination by synthesizing a set of linguistic control rules obtained from experienced human operators. Mamdani's effort was based on Lotfi Zadeh's 1973 paper on fuzzy algorithms for complex systems and decision processes [Zad73]. Although the inference process we describe in the next few sections differs somewhat from the methods described in the original paper, the basic idea is much the same.

Mamdani-type inference, as we have defined it for the Fuzzy Logic Toolbox, expects the output membership functions to be fuzzy sets. After the aggregation process, there is a fuzzy set for each output variable that needs defuzzification. it is possible, and in many cases much more efficient, to use a single spike as the output membership function rather than a distributed fuzzy set. This is sometimes known as a singleton output membership function, and it can be thought of as a pre-defuzzified fuzzy set. It enhances the efficiency of the defuzzification process because it greatly simplifies the computation required by the more general Mamdani method, which finds the centroid of a two-dimensional function. Rather than integrating across the two-dimensional function to find the centroid, we use the weighted average of a few data points. Sugeno-type systems support this type of model. In general, Sugeno-type systems can be used to model any inference system in which the output membership functions are either linear or constant.

After the above model is established, then load the dialog box of fuzzy controller, click the Run button on the tool table simulink, then animation of Water Level Control appeared on the screen (water level control), as shown in Fig.10.

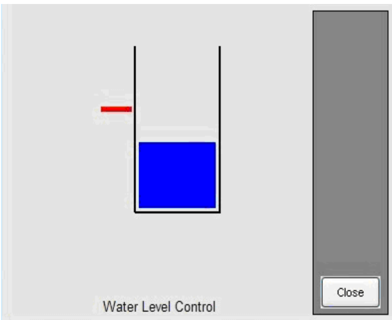

Figure 10. Water level control of animated

Double-click comparison module in order to make the oscilloscope appear on the screen, so that the change of before and after the square wave from the signal source passing through the system can be observed. The smaller the difference between before and after the Square-wave passing through the system is, the stronger the following performance of the system is. As what is shown in Figure 5, set the color of curves of before and after square wave from the signal source passing through the system yellow and red, respectively. Analysis of the differences can make the system's performance be understood, so as to have the design of the system improved.

Some experimentation shows that three rules are not sufficient, since the water level tends to oscillate around the desired level. This is seen from the Fig.11.

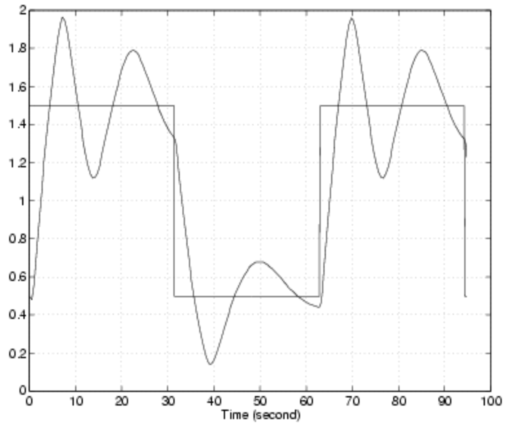

Figure 11. The response of the system of three rules

We need to add another input, the water level's rate of change, to slow down the valve movement when we get close to the right level. So the five rules are as follows.

1. If level is okay then valve is no change.
2. If level is low then valve is open fast.
3. If level is high then valve is close fast.
4. If (level is good) and (rate is negative), then (valve is close_slow)
5. If (level is good) and (rate is positive), then (valve is open_slow) .

The rule is shown in the Fig.12.

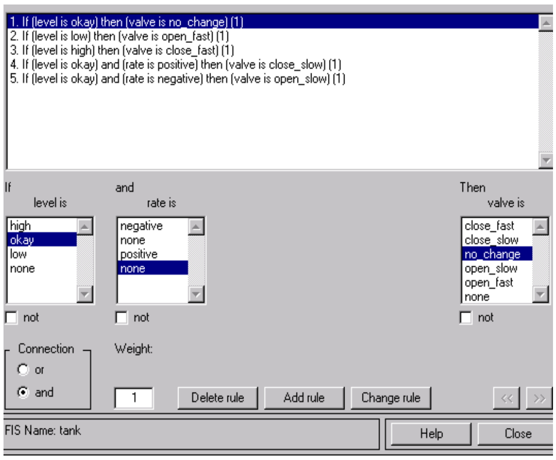

Figure 12. The response of the system of five rules

The results of the level, rate and valve are presented in the Fig.13.

The demo, tank is built with these five rules. With all five rules in operations, you can examine the step response by simulating this system. This is done by clicking Start from the pull-down menu under Simulate, and clicking the Comparison block. The result looks like this. If level is okay and but rate of the input fluid is positive then valve is close slow. If level is okay but rate of the input fluid is negative then valve is open slow. The response of the system of five rules is presented in Fig. 14.

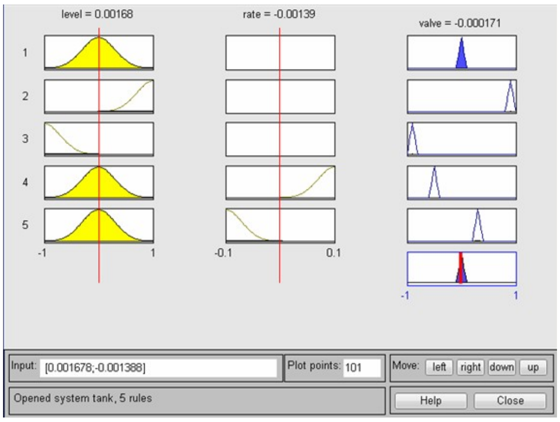

Figure 13. The results of the level , rate and valve

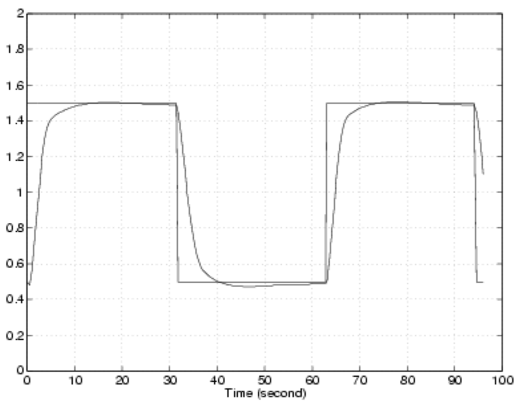

Figure 14. The response of the system of five rules

One interesting feature of the water tank system is that the tank empties much more slowly than it fills up because of the specific value of the outflow diameter pipe. We can deal with this by setting the close_slow valve membership function to be slightly different from the open_slow setting. A PID controller does not have this capability. The valve command versus the water level change rate and the relative water level change surface is presented in Fig.15.

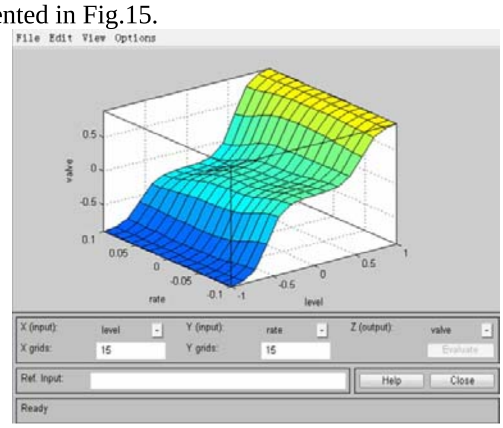

Figure 15. The valve command versus the water level change rate and the relative water level change

V. Conclusions

In practice, when the liquid level (level), and the fluid input flow rate (rate) are determined, the fuzzy controller will automatically adjust the valve opening size and speed to control the water supply valve opening adjustment level, so that the liquid level in the container can be constant; due to a rapid response adjustment time can be negligible; in intelligent building water supply systems, water level in the water tank can always be maintained set capacity, so that users can be ensured their water and pump motor power consumption at the same time, waste of water can't occur. Therefore, purpose of saving water can be achieved and economic benefits of water supply are also improved.

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