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HW/SW Co-design of a Visual Driver Drowsiness Detection System

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요 약 PID 오토 튜닝 컨트롤러는 퍼지 논리를 통해 설계되었다. 이러한 오류 및 오류 파생 의견으로 일반적인 값은 발견적 표현으로 변경, 그들은 퍼지 및 defuzzification 과정을 통해 PID 이득을 결정했다. 퍼지 절차 및 PID 제어기 설계는 개별적으로 간주하고, 그것들을 혼합하고, 분석 하였다. 퍼지 논리에 의해 획득 자동 조정 PID 컨트롤러는 3 차 플랜트 제어 이하의 능력을 보여 주었다. 또한 설계된 자동 동조 방식으로 추적 문제를 참조하는 데 적용한다.

Abstract PID auto-tuning controller was designed via fuzzy logic. Typical values such as error and error derivative feedback were changed as heuristic expressions, and they determine PID gain through fuzzy logic and defuzzification process. Fuzzy procedure and PID controller design were considered separately, and they are combined and analyzed. Obtained auto-tuning PID controller by Fuzzy Logic showed the ability for less than 3rd order plant control. We also applied to reference tracking problem with the designed auto-tuning scheme.

Key Words : Auto-tuning PID, fuzzy logic, heuristic design, 2ndordersystem

1. Introduction

Importance of PID controller has been emphasized particularly on the industrial fields. By its strong and easy handling feature PID control has been widely used and preferred from engineers and operators[ ]. Generally, PID gains are decided by operations of output error and error derivative. By doing such determination of gain it needs manual operation such as trial and error.

However, we have difficulty in tuning PID gains manually. Comparing with its robust and easy maneuvering operator is needed whenever references are changed. For such requirements, auto-tuning schemes are essential for automation. There are lots of researches related with auto-tuning technique [ ].

In this literature, we focus on PID auto-tuning via heuristic approach. Actually, PID controller has much strong points to control, it has robustness and rather easy for tuning. However, if it is not provided auto-tuning algorithm, it shows poor performance for reference varying problem. Hence, to make automation auto-tuning structure is strongly needed. Well-known fuzzy theory, feedback data are fuzzified, and control input variables to plant are determined by fuzzy logic, that is, IF THEN rule. Feedback values are considered as feedback error and error derivative to construct PID controller make easily. Each roles of proportional, integral, and derivative gain are also used for design of fuzzy logic. This control structure provides mixed algorithms of analytic approach and heuristic knowledge.

In the following chapter, auto-tuning schemes are illustrated. PID structure and fuzzy logic are illustrated

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briefly. In Chapter 3, we have combined auto-tuning structure with combination of PID and fuzzy logic structure. In Chapter 4, discussion for simulation, specially, to tracking problem was carried out with computer simulation. Finally, we derived conclusions in Chapter 5.

2. Auto-Tuning Schemes

2.1 PID Control Structure

Consider following feedback system.

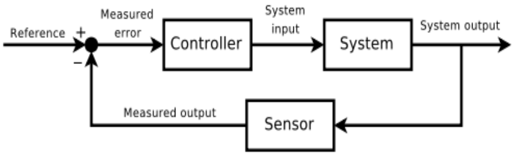


Fig. 1. Feedback Control

Widely used PID control is considered in control scheme. It is considered as classical control because it has been used quite long time by its simple structure and easy adjustability.

Three components, Proportional, Integral and Derivative term are summarized. To obtain the suitable response of system, the three parameters should be tuned iteratively. In order to tune parameters manual tuning and Ziegler-Nichols method are often used, both of them are based on the manipulator's experience and meanwhile the system should be tuned off, we can't get the modified system response until tuned on and we do not know whether the modified parameters are suitable, so the auto-tuning methods are introduced. Auto-tuning means that the PID three terms is updating this case rather than the fixed ones, we need another component as tuner, treats the states' errors as inputs, using the special algorithm e.g. GA, Fuzzy Logic, to compute the updated value of PID terms; this case, the controller will generate a more suitable control signal by sensing the present states to achieve better response.

2.2 Fuzzy Logic controller

Applying heuristic thinking fuzzy logic is widely used in the machine control, it deals with analog inputs in terms of logic variables on continuous values between 0 and 1, gives the concept of 'partly true'; by experience and observation, to find the proportion of the effect changing inputs on the outputs; finally compute the corresponding outputs. The input and output variables are always mapped into some overlapped sets (membership function) within their ranges by special sharp. In fig.3, an example explains this concept briefly:

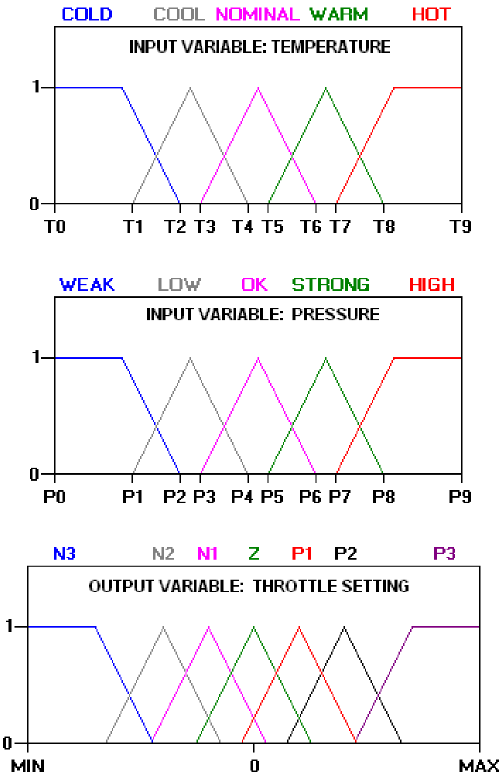


Fig. 2. The example of Membership functions

Where N3, N2, N1, Z, P1, P2, and P3 denote Large negative, Medium negative, Small negative, Zero, Small positive, Medium positive, and Large positive, respectively. Fig. 2 show that two inputs one output variable fuzzification. For input variable, one is temperature and another is pressure; temperature is defined as 5 sets within the range from T0 to T9, named as 'COLD', 'COOL', 'NORMAL', 'WARM' AND 'HOT', where the Membership Function are triangle sharped. Similarly, pressure output variable are defined. The number of the membership function is according to the precision system needed, of course it is the tradeoff between system precision and complexity, the sharp of membership function is less important, and usually based on trails to observe which sharp is better.

Fuzzy rules are the key connections between inputs and outputs, which has the form 'IF inputs are ... Then outputs are ...', they are usually based on experience. For example, If temperature is cool and pressure is weak, then throttle is P3.

By now, the outputs of every rule are prepared shown as , the last step is to combine them computing the control signal for the fuzzy controller. Usually the centroid computation is used.

$$\text{control} = \frac{\mu(x_1)y_1 + \mu(x_2)y_2 + \cdots + \mu(x_n)y_n}{\mu(x_1) + \mu(x_2) + \cdots + \mu(x_n)} \quad (1)$$

3. Hardware Implementation

After learning classical PID control and fuzzy logic, the object of the part is to introduce the concepts of these two control theory, and apply them to design a new controller, firstly, we will look at how to construct the whole system:

3.1 The whole structure

Feedback output variable are considered as the input variable of fuzzy logic. Hence, it is changed as heuristic expression. In order to design PID controller, we need two output feedback variables, error and error derivative. In following figure, auto-tuning structure is designed with Matlab Simulink.

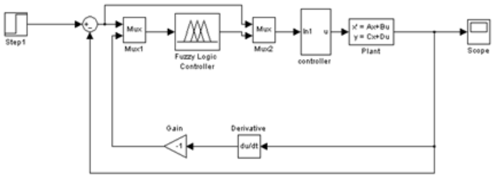


Fig. 3. whole structure

The key component is built on the fuzzy logic Matlab toolbox, the interface between the workspace and simulink is shown in Fig. 4.

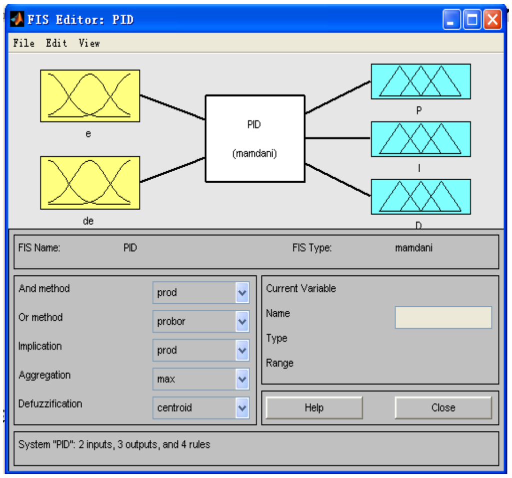


Fig. 4. the Fuzzy Logic interface

There are three main steps to construct a fuzzy logic controller, fuzzifying inputs error and error derivative, fuzzifying outputs PID three gains and designing the fuzzy rules. In addition, the interface gives choices to implement "And, Or, Implication, Aggregation and Defuzzificaiton" method by using the linear of nonlinear algorithms.

Normally, the error signal and its derivative of one system's step response have the form of second order response with different frequency, damping ratio and phase shift, shown as the graph below.

Fig. 5. Error and Error Derivative

With the response desired trend of output variable is illustrated in the next table. They are classified as six types of responses.

Table 1. Desired output trend versus error and error derivative

	Error	Error Derivative	Desired Trend
Type 1	Pos Large	Small	Speeding up
Type 2	Pos Large	Neg Large	No change
Type 3	Small	Don' t Care	Slowing down
Type 4	Neg Large	Large	Slowing down
Type 5	Neg Large	Small	Speeding up
Type 6	Neg Large	Pos Large	No change

As it mentioned before, the error is varying and experiencing from large to small range, thus this signal can be mapped as the graph below shown:

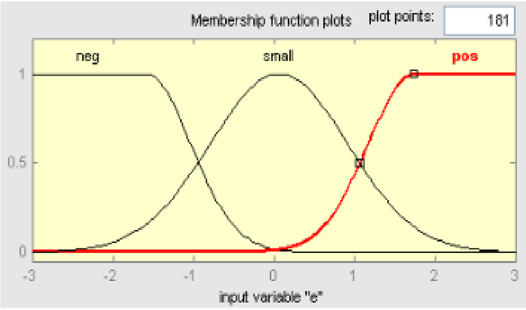


Fig. 6. Membership function of Error

For another input error derivative, its Membership function plot is shown:

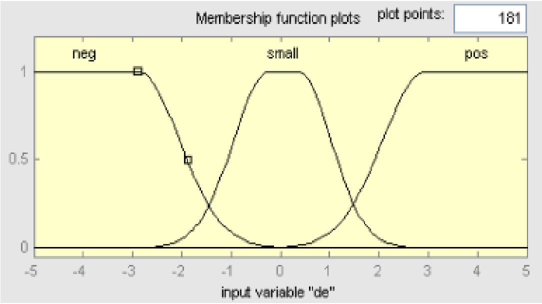
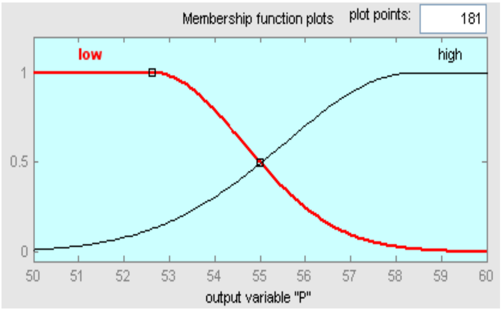


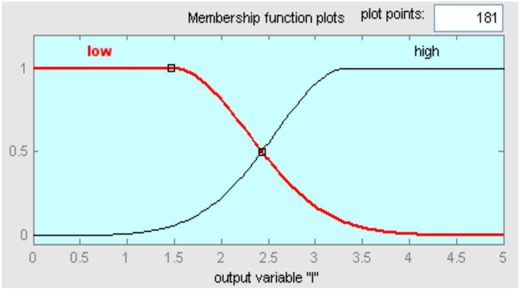
Fig. 7. Membership function of Error Derivative

From the graph, the range of error is from −3 to +3, we define the range between one third of the maximum of the error as the fuzzy set named by "Small", where the region smaller than the previous one is caller "Negative Large" and the remaining is called "Positive Large"; using "gausss2mf" sharp, means that it is a Gaussian distribution sharp, normally the sharp is not the most important part of the fuzzificaiton. Thus every point can be represented as two fuzzy sets with its corresponding proportion. The range of error derivative is normally larger than the previous input, for example from −5 to +5, we define the range where the absolute value smaller than 1 as fuzzy set "Small", the same procedure as before, the region below is called "Negative Large" while the upper area is named by "Positive Large", of course using "guass2mf" sharping method, the sharp will make differences due to the fixed "Small" range.

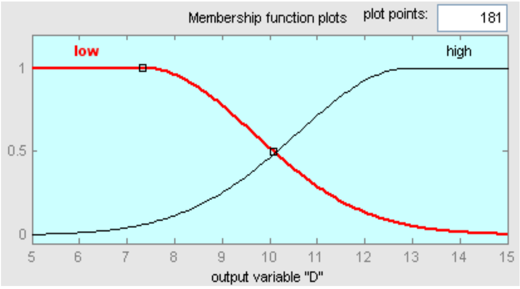
The output of the fuzzy logic controller are three terms, proportional gain, integral gain and differential gain, for our design, the outputs are all restricted to be positive, and for each gain, the output range is determined by the requirement of plants and varying reference input. And thus this part will just give an example how to construct the simple Membership functions. Mentioned output membership functions are illustrated in following Fig. 8.



(a) Proportional gain



(b) Integral gain



(c) Differential gain

Fig. 8. Membership functions of PID gain

Commonly this gain needs to be large enough to drive some plant with small output to approach the reference input, and very large gain will give a relative small error while a relative initial overshoot.

As we can see, this output variable is mapped into two fuzzy sets, named as "Low" and "High", where the intersection point is located at the midpoint of the range and gives "0.5 true" for each set. The range of this gain should be relative small within these three gains, cause this gain has great effect on the steady state error, the sharp is same as the previous one using "guass2mf" sharping method, a view of it is shown later.

This gain's range is determined by how fast the states of plant changes, normally not very large due to that we don't want to result a very fast changing response. The graph below gives the view.

3.2 Fuzzy rules design

So far, the Membership functions of inputs and outputs are already represented, based on them, it needs to conclude the utility of each gains by conducting experiments, and then design the suitable rules by trails and error.

Next parts will give details how to do the experiments, draw the conclusions of the utility of the three gains and give the resulted fuzzy rules. Due to the Proportional Gain has effect on the damping frequency of the original system [6], it would like to change this gain to drive the trend of error derivative: when the error is large and has a decreasing trend, the controller increase this gain to speed up this trend; while the error is small, decrease this term to avoid larger overshoot; the designed fuzzy rules are represented below:

1. If Error is 'Negative' Then Proportional Gain is High.
2. If Error is 'Positive' Then Proportional Gain is High.
3. If Error is 'Small' AND Error Derivative is 'Negative' Then Proportional Gain is Low.
4. If Error is 'Small' AND Error Derivative is 'Positive' Then Proportional Gain is Low.

For integral gain decision, the Integral Gain has the ability of regulating stead state error approach to zero [6]; tests has been done as the previous one, the experimental one is tuning case while the classical one is the matched group, the starting point of these two experiments set same.

1. If Error is 'Small' Then Integral Gain is High.

For derivative gain decision, it is sensitive to suddenly changing signal [6], thus it has apparent effect on the error derivative; I made two experiments for the controlled trails:

1. If Error is 'Positive' AND Error Derivative is 'Small' Then Differential Gain is 'Low'
2. If Error is 'Negative' AND Error Derivative is 'Small' Then Differential Gain is 'Low'.
3. If Error is 'Small' Then Differential Gain is 'High'

Setting the proportional gain as the same of 75.5, the testing result is shown in Fig. 9. As we can see, the two responses respective to the step input, where the red line indicates the classical proportional control while the blue line indicates the tuning case. The tuning one has smaller overshoot and oscillation respect to the steady state. We show only error response with proportional gain. However, response of error derivative represents similar results.

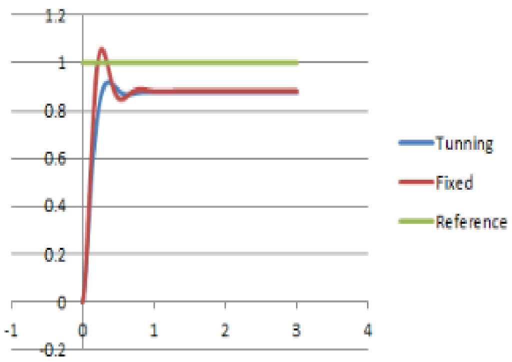


Fig. 9. Effect of Proportional gain on Error

Fig. 10 describes that the integral gain has little effect on error derivative, the modifying range is within 0.2. The designed rules are shown in the above.

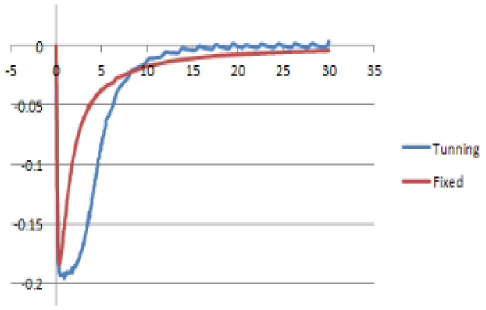


Fig. 10. Effect of Integral gain on Error Derivative

Fig. 11 describes that when the differential gain increases, it minimizes the maximum value error derivative can reach, and gives a smooth declining trend comparing with the fixed case. This graph reveals that the error derivative (blue line) accelerate approaching to zero along with derivative gain growing up, leading that error approaches to the steady state smoothly.

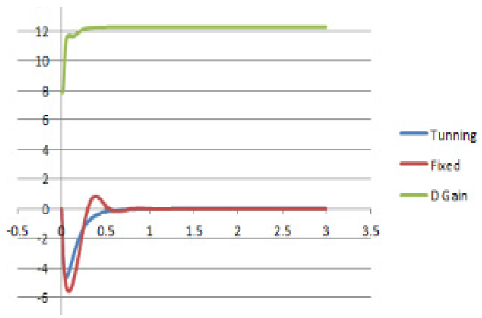


Fig. 11. Effect of Differential gain on Error Derivative

4. Illustrative Example

Combing the fuzzy rules that conclude in the previous part, we simplify the rule as follows. It includes not only error, error derivative variation but also PID gain values.

Fuzzy rules for Auto-tuning

1. If error is 'Positive' AND error derivative is 'Small' Then proportional gain is high, differential gain is 'Low'.

2. If error is 'Negative' AND error derivative is 'Small' Then proportional gain is high, differential gain is 'Low'.
3. If error is 'Small' AND error derivative is 'Negative' Then proportional gain is low, integral gain is high, differential gain is 'High'.
4. If error is 'Small' AND error derivative is 'Positive' Then proportional gain is low, integral gain is high, differential gain is 'High'.

To test the reliability of this controller, we have applied it to DC motor. The electronic circuit of the armature and the free body diagram of the rotor are shown below:

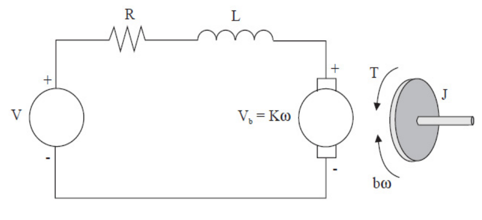


Fig. 12. DC motor modeling

This plant is modeled by the differential equations:

$$\begin{cases} T = Ki - J\dot{\omega} - b\omega \\ V = K\omega + L\dot{i} + Ri \end{cases} \tag{2}$$

And the transfer function is shown here:

$$\omega(s) = \frac{K}{(R+Ls)(Js+b)+K^2}V(s) - \frac{R+Ls}{(R+Ls)(Js+b)+K^2}T(s) \tag{3}$$

Where the physical parameters are defined:

Table 1. Motor specifications

Moment of Inertia of the rotor	*J*=0.01
Damping (friction) of the mechanical system	B=0.1
Back-Electromotive force constant	*K*=0.01 *Nm/A*
Electric Resistance	R=1
Electric Inductance	L=0.5*H*

As we can see, it is a two inputs one output plant: Voltage and Torque as input and the Angular Speed as output, we assumed that the external torque is zero for simplification, thus the transfer function from the input Voltage to the output Angular Speed is shown:

$$H(s) = \frac{\omega(s)}{V(s)} = \frac{K}{s^2+12s+20.02} \tag{4}$$

By giving the open loop response, the natural character of this plant is concluded that it's a slow response about 1.5 second rising time and with a small output about 10% of the input reference.

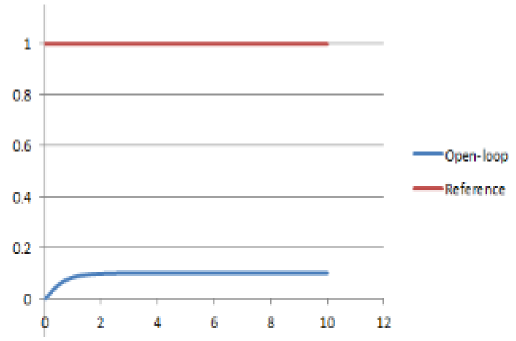


Fig. 12. Open loop response

The whole control loop is same as before, except the signal builder which creates a step reference input, giving a step with output 1 at 2 second and another step with output 2 at 6 second. The simulated result is given:

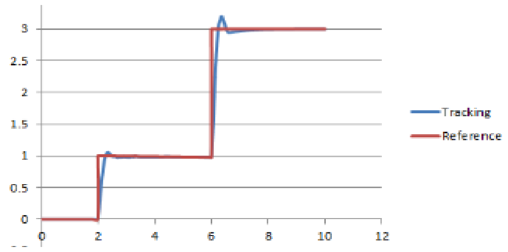


Fig. 13. Reference tracking

The red line indicates the reference while the blue line is the tracking signal, it states that the natural response of the plant has been modified, the system gives a faster response with rising time about 1 second, initial overshoot less than 5% and steady state error approaches to zero.

4. Conclusions

Auto-tuning design by heuristic knowledge was provided in this literature. We have determined control input for plant by combining PID control input and fuzzy logic. Fuzzy logic is composed by fuzzification, fuzzy rule, and defuzzification of the error and error derivative. Transforming error values to heuristic meaning, each control components, proportional, integral, and derivative fuzzy rule also considered and verified via simulation. By combining three fuzzy rules, we provided unitary PID fuzzy rule as unified form. Finally, DC motor simulation was done with auto-tuning and also applied to tracking problem, that is, reference variation. Obtained result can be mainly applied to 2^{nd} order system, and we have left as a future research for actual application.

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