Improved Image Acquisition in Bionic Eye Using Fuzzy Logic

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***Abstract*—The core of building bionic eye system is to imitate the function of human eye neural circuit so as to design the corresponding control strategy. In this paper, fuzzy adaptive PID control method is adopted to realize the function similar to vestibular nucleus. Besides, the transfer function of controlled object is established according to medical research so as to determine the variation range of PID parameters in MATLAB environment.**

I. INTRODUCTION

IONIC technology is getting increasing attention in the field of robotic universal technology. Eye could be regarded as the most important sensor for human beings, since it can assist human to lock the object at the center of retina even when the attitude of the object or human changes drastically. As for the robots working in the unstructured environment, it is very hard for the existing robots to fulfill the task in the bumpy and vibrant environment, which causes some problems such as jump of tracking video images, image blur and loss of the tracking object. Therefore it is of great significance to build robotic bionic eye system with similar function to human eye. Human eye motion can be regarded as three DOF spherical motions rotating around the geometrical center. Most existing robots only have two DOF which lack for one DOF rotating around the optical axis. The bionic eye system based on the spherical parallel mechanism [1] has three rotational DOF and other advantages such as compactness and simple structure. This bionic eye system can agilely compensate deviation caused by attitude variation of the robot or the tracking object and lower the influence on the quality of video images, thus reducing the difficulty of image processing.

The key of bionic eye control lies in establishing suitable control algorithm to realize the function similar to human eye's. The relationship between the three attitude angles of the bionic eye and three angles of motors is nonlinear and strong coupled, which results in that every parameter could change with variation of time, interruption and Environment factors, thus leading to deviation, low control precision and inability to solve high-speed matter. According to the achievement of preliminary medical research, we have got an intuitive understanding of eye motion control mechanism. So, we use fuzzy adaptive PID control method to realize the core function of vestibular nuclei. Control parameters are adjusted dynamically through fuzzy processing in order to meet the nonlinear and time-varying property of the system. Meanwhile the problem of lower precision and lower dynamic quality caused by fuzzy controller can be eliminated by PID controller.

II. EYE MOTION MECHANISM AND BIONIC CONTROL MODELING

A. Eye motion control mechanism and its equivalent

To realize rapid and precise control of bionic eye, we have to deeply understand motion mechanism of human eye and build mathematical model of controlled object. According to medical research, human eye motion is realized by several ocular muscles synergistically. The main organs related to vision are eyeball, brainstem, cerebellum and vestibular organ. The vestibular organ of high animals consists of utricle, succubus and three semicircular canals [2]. The semicircular canal can detect rotational acceleration, while the other two organs can precisely measure the position and moving direction of head at any time. Variation of rotational and linear acceleration stimulates vestibular organ when the head moves and then the head's moving velocity and attitude variation can be obtained through a series of procession. Neural circuit of eye motion is shown as Fig. 1 according to anatomy and physiology, from which we can see that information, is transferred to vestibular nuclei via two paths. Moreover, the sliding error information of retina is transferred through mossy fibres to flocculus, which has predictive function based on memory and compensatory function for sliding error information of retina according to medical research.

According to the neural circuit of human eye, vestibular nucleus is kind of data processing centre which combines information from semicircular canal, retina and flocculus and then figures out rotational angles of the eye after a series of processing. The processed outcome is then sent to lateral rectus and medial rectus through abducent nucleus and oculomotor nucleus respectively.

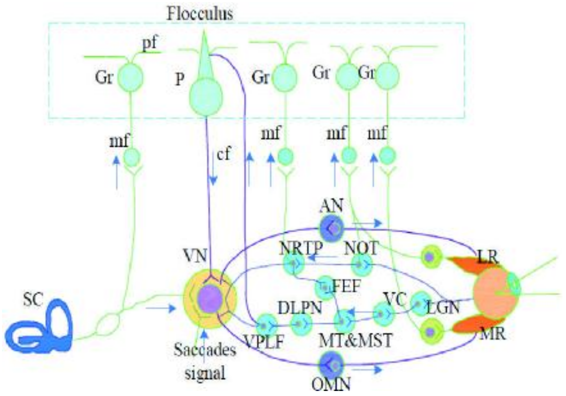

Fig. 1.Neural circuit of eye motion.

As the equivalent of eye motion control mechanism, the fuzzy adaptive PID control method is applied to realize the data processing function of vestibular nucleus. The system receives information from sensor, camera and then processesthem to drive three motors in order to realize 3-DOF motion of the bionic eye namely pan, tilt and zoom. The processor adjusts three parameters of fuzzy PID namely K_p, K_d and $K_i$adaptively to meet different requirements. Moreover, we needto build motion control transfer function of the eye accordingto part of the neural circuit, namely from vestibular nuclei toeye muscles, in order to realize simulation in MATLAB andthrough simulation graph to determine the variation range of PID parameters which will be used in the real bionic eye system.

B. Establishment of transfer function for eye motion control

The research shows that the eye moving unit has been verified to be the simple first order system, which can precisely express the relationship between eye's angular position and oculomotor trigger rate [3]. The relationship between trigger rate $M(t)$ and eyeball angular position and velocity can be expressed as (1) according to the experiments made on monkeys.

$$\Delta M(t) = ke(t) + re'(t) \qquad (1)$$

According to (1), the eyeball model can be similarly expressed by one step transfer

function as (2):

$$P(s) = E(s) / \Delta M(t) = K_e/(T_e s + 1) \qquad (2)$$

Where, E(s) signifies the laplace transform of eyeball position output.K_e =1 deg/spikess,T_e =0.24s. The part between vestibular nucleus and oculomotor nucleus or abducent nucleus can be viewed as an incomplete neural integrator [4], therefore the transfer function from vestibularnucleus to medial rectus and lateral rectus could be expressedas the sum of an incomplete neural integrator and a direct path which can be expressed as (3):

$$NI = T_n/(T_n s+1) + g_e \qquad (3)$$

Where, T_n is the time constant of integrator &g_e is the gain of direct path[5]. Normally, T_n =25 s, g_e=0.24. The transferfunction for eye motion control is then established by multiplying (2) and (3). Since $T_n$is far bigger than g_e, andg_e =T_e ,the expression can be simplified as (4):

$$NI \approx 25/(25s+1) \qquad (4)$$

C. Setting of fuzzy rule

Fuzzy adaptive PID control method applies the basic theory and approach of fuzzy mathematics to express the regular condition and operation through fuzzy sets and stores fuzzy control rules and related information into computer database. Then the computer conducts fuzzy reasoning according to the response status of the control system to adjust the PID parameters automatically and optimally [6].The structure of the controller is shown as Fig.2.

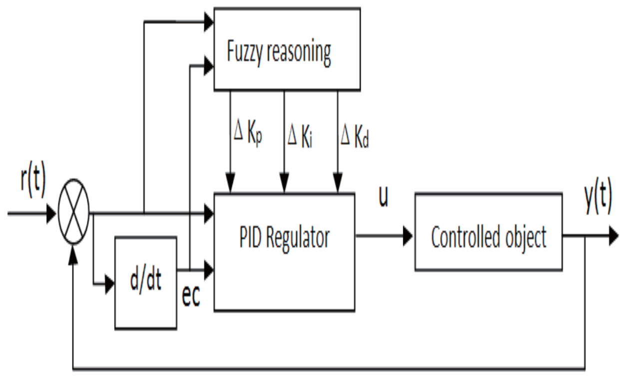

Fig. 2. Structure of fuzzy adaptive PID controller

To realize fuzzy adaptive PID control, we need to set Parameters, namely to find the relationship between three parameters, e and ec. The whole system constantly measures e and ec during operation and conducts fuzzy reasoning according to fuzzy rule, then every parameter is adjusted optimally to meet different requirements for different e and ec. The core part is to build the suitable fuzzy rule tables forK_p, K_i and $K_d$respectively according to engineers' expertise and practical experience. Given the system's timeliness and efficiency, the traditional fuzzy rules are simplified to be ones shown from Table.1 to Table.3.

1) *Setting Principle ForK_p:* During the upward process of response (e is P), $\Delta K_p$is plus, namely to increase K_p. During overshoot period (e is N), $\Delta K_p$is negative , namely to decrease K_p. When the error is close to zero, there are three cases needed to be dealt with respectively, if ec is N which means overshoot is increasing, then $\Delta K_p$is negative. If ecequals zero, in order to reduce error, $\Delta K_p$is plus. If ec is P which means forward error is increasing, then ΔK_p is plus. So the fuzzy rule for adjusting $K_p$is shown in Table.1.

TABLE 1

Fuzzy rule for adjusting K_p

Δ Ki ec / e	N	Z	P
N	Z	Z	Z
Z	P	P	P
P	Z	Z	Z

2) *Setting Principle For K_i:* Separated integral strategy is adopted, namely if the error is near to zero, ΔK_p is plus, otherwise ΔK_p is negative. So the fuzzy rule for adjusting K_i is shown in Table.2.

TABLE 2

Fuzzy rule for adjusting K_i

Δ Ki ec / e	N	Z	P
N	Z	Z	Z
Z	P	P	P
P	Z	Z	Z

3) *Setting Principle For K_d:* When |e| is large, in order to make the system have good tracking performance, $\Delta K_d$is negative. When |ec| is small ΔK_d is plus. So the fuzzy rule for adjustingK_d is shown in Table.3.

TABLE 3

Fuzzy rule for adjusting K_d

Δ Ki ec / e	N	Z	P
N	P	P	N
Z	Z	Z	Z
P	N	P	P

After the fuzzy rule libraries for the three parameters are built, the system can adjust these three parameters automatically according to the fuzzy control theory. The variation range ofsystematic error e and error rate ec is defined in the fuzzy set as (5).

$$e, ec =\{-1 \ 0 \ 1\} \qquad (5)$$

Its fuzzy subset e,ec={N Z P } , where, N indicates negative, Z indicates zero, P indicates positive. We suppose that e, ec, K_p, K_i, K_d conform to normal distribution, then thedegree of membership of fuzzy subsets could be established.Based on the degree of membership assignment table of fuzzy subsets and fuzzy control models of parameters, fuzzy matrix table of PID parameters can be designed by applying fuzzy synthetic reasoning, where the adjusting parameters could be looked up and then be used in (6).

$$K_p=K_{p0}+K_p, K_i=K_{i0}+K_i K_d=K_{d0}+K_d \quad (6)$$

As for initialization of the system, we make $K_{p0}=0$, $K_{i0}=0$ and $K_{d0}=0$. The control system realizes the online self-adjusting of PID parameters through result procession, table look-up and operation of the fuzzy logic rules during the online running process.

D. Simulation in MATLAB

In MATLAB environment, we can get the membership function of e, ec, kp, ki and kd by running “plotmf” instruction. As shown in Fig.3, there’re 2 inputs, three outputs and 9 rules.

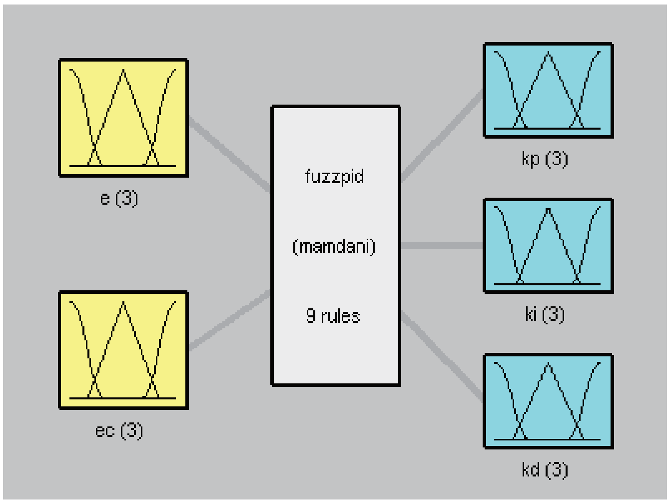

Fig. 3. Membership function

After the fuzzy rules are set, system simulation structure diagram is built in the Matlab’s Simulink as shown in Fig.4.The fuzzy rule is programmed into Fuzzy Logic Controller. The controlled object G(s)=25/(25s+1) is programmed with S function and discrete with the sampling time of 1ms.

To realize simulation, a step signal with the amplitude of 1.0 is input to the system. The system then adjusts PID parameters adaptively until it’s stable. As shown in Fig.5, we have achieved good performance such as rapid dynamic response, no overshoot and no state error. Fig.6 shows the corresponding adaptive adjusting process of PID parameters, which is rapid and lives up to our expectation. So we adopt the current variation range for our real bionic eye system.

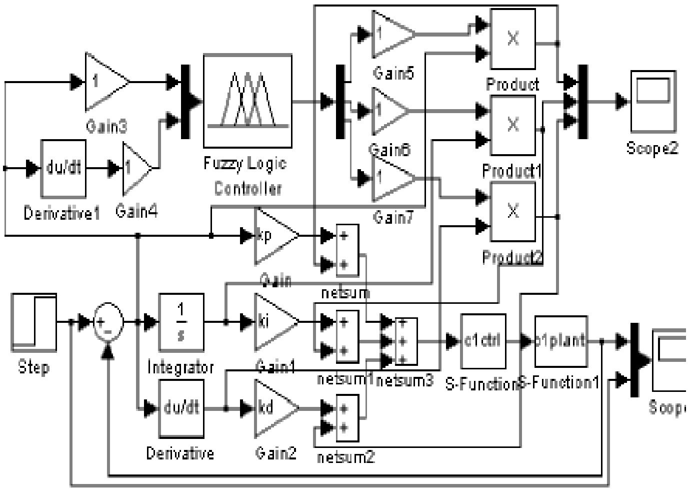

Fig.4. System simulation structure

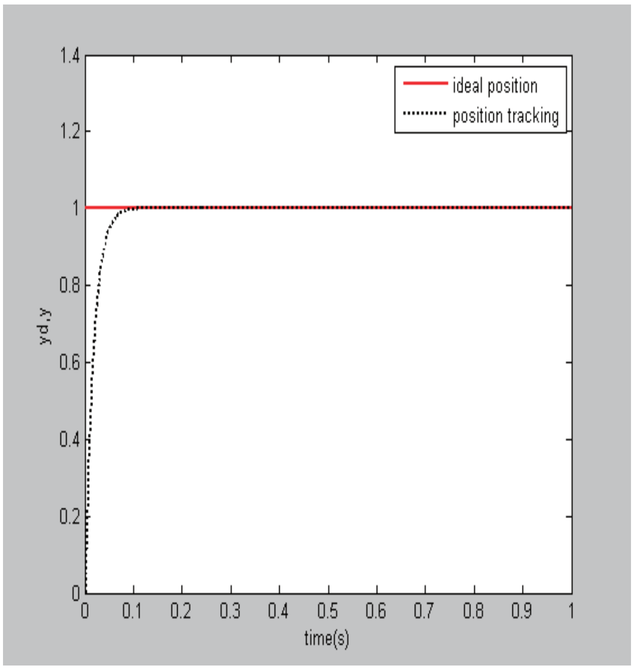

Fig. 5. Step response

E) Conclusion

The experiment results show that the bionic eye systembased on fuzzy adaptive PID control can track the object very well even when the robot attitude changes

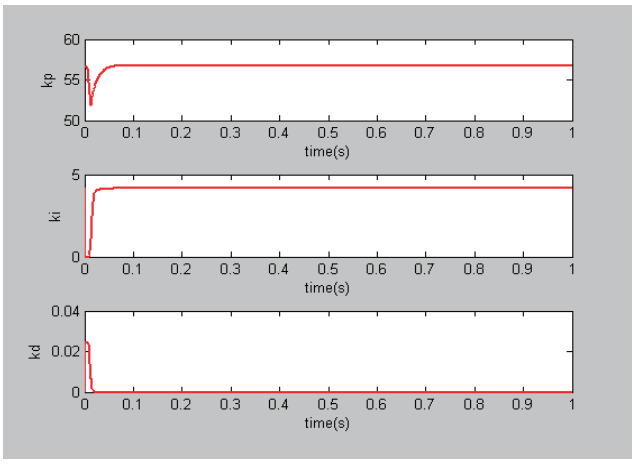

Fig. 6. Adaptive adjusting process of PID parameters

drastically or the tracking object moves fast. This system not only has good quick-response performance, but also has good robustness, which conforms to the control mechanism of human eyes.

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