# A Novel Method to Eliminate Blind Areas for Moving Double Cameras System Based on Biomimetic Eyes

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***Abstract*—Based on the characteristics of binocular vergence eye movements, A new type of method to reduce blind areas caused by double cameras in motion platform was put forward, and a model for control binocular vergence eye movements was established according to neural pathways of human binocular oculomotor system. With the model, it is guaranteed that target areas can remain in the public vision field of the double cameras all the time during the double cameras platform moving. This feature is very important for the moving double cameras system, since 3D reconstruction needs the double cameras to have an overlapping field of vision. To evaluate the effectiveness of the proposed method, some experiments on the model were conducted. The simulation and experimental results show that the model can realize adaptive binocular vergence movements. Compared with the traditional methods, this new one can eliminate blind areas for moving double cameras system.**

***Index Terms*—biomimetic eyes, double cameras system, vergence eye movements, oculomotor control modelling**

## I. INTRODUCTION

For an active stereo vision system, the cooperative camera movements are very important. Generally, two cameras gazing at the same spatial point can provide an overlapping field of vision and small stereo disparities around the gaze point, which makes stereo fusion and 3D reconstruction easier[1-2]. In other word, to obtain real-time and accurate 3-D vision information, the target area remains in the public vision field of two cameras all the time. However, in the circumstance that the cameras need to be fixed in the moving platform, the traditional double camera monitoring and ranging system would have blind area and the target couldn't remain in the public vision field of two cameras, as is shown in the Figure.1.

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It is well-known that the oculomotor control system is an effective device for capturing an object in the central pits of the retinas[3-4]. Thus, we develop a stereo vision system based on human binocular vergence eye movements. The purpose of this paper is to put forward a method of eliminating the blind area of double cameras monitoring system fixed in the moving platform according to the principle of the vergence movements of eyeball. By this way we can overcome the problem and shortage of the technology in existence. The double cameras in the moving platform are real-time controlled separately in accordance with the location change of the platform and the target to make sure the target remains in the public vision field of the double cameras and gets the accurate 3-D vision information [5]. Figure.2 shows the effect of this method.

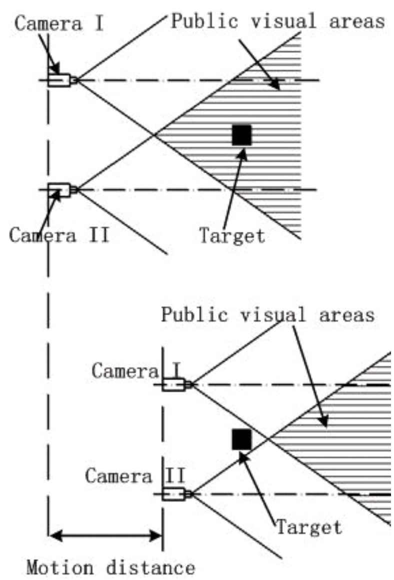


Figure 1. Traditional double cameras system.


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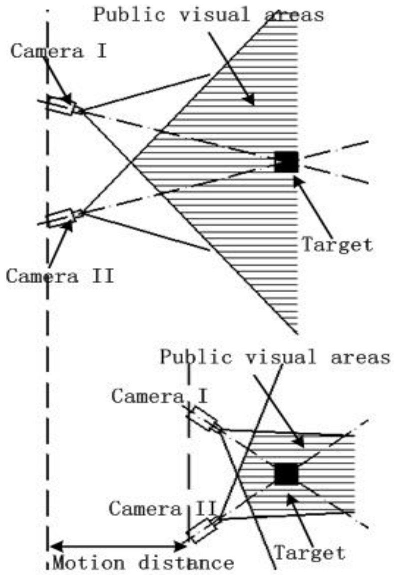



Figure 2. Double cameras system based on vergence eye movements.

## II. CHARACTERISTIC FOR OCULOMOTOR SYSTEM

Human eyeball is basically a spheroid, whose each movement is completed by several extraocular muscles together [6]. The different form of the eyeball movements realizes the natural function of the human eye. The eyeball movements are classified into five kinds: saccade, smoothing pursuit, vergence eye movements, vestibule-ocular reflex and opt-kinetic reflex. Vergence eye movements mean that both eyes rotate to the opposite direction an equal angle and velocity simultaneously when eyes gaze at near target and far target alternately. Its latent period is about 125ms, and its maximum speed is approximately 20°/s.

Retinal visual cells accept the stimulation of the outside light, and then the stimulation is translated to nerve impulse by photochemical reaction and send to visual cortex by bipolar cell, ganglion cells, optic nerve, optic chiasm, optic tract, visual scattering to form vision. According to the anatomy and physiology research [7-8], the nerve loop of eye movement is shown Figure 3. The black circles with connecting lines represent the inhibitory neural fibers, and the white circles with connecting lines represent the excitatory neural fibers. The neural pathway starting from the temporal side of the retinal ② via Chiasma opticum merges with the pathway from the nasal retinal of the other eye ③, and then pursues two different routes. First route: Lateral geniculate nucleus (LGN) → Visual cortex (VC) → Dorsolateral potine nucleus (DLPN) → Ventral paraflocculu (VPFL) ④→ VN type □ neurons. Second route: the nucleus of the optic tract (NOT) → nucleus reticularis tegmenti pontis (NRTP) ⑤→ VN (Vestibular nucleus) type□ neurons. VN type□ neurons and types□neurons ⑥ is connected with inhibitory neural fibers. The excitatory neuron axon from type I neurons of VN connects to : a) Type □ neurons of VN in the other side ⑧; b) Oculomotor nucleus (OMN) ⑫ → Medial rectus ⑭; c) Abducens nucleus (AN) in the reverse side ⑩ →Lateral rectus in the reverse side ⑮, and from the AN to OMN through MLF(Medial longitudinal fasciculus) ⑬.The inhibitory neural pathways from type □ neurons of VN connect to: a) Type □ neurons in the reverse side VN ⑦; b)AN ⑨; c) OMN in the reverse side ⑪.

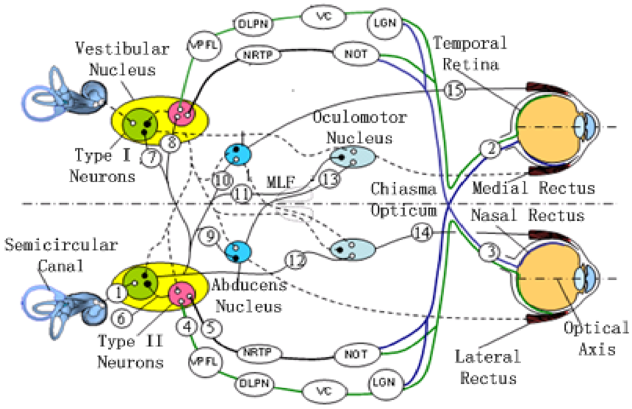



Figure 3. Neural pathways of the binocular eye movements.

## III. MODELING FOR BINOCULAR VERGENCE EYE MOVEMENTS

Biomimetic eye research started in the 60's of 20$^{th}$ century, but it was not developed to establish the artificial experiments and model-validating device until the 1980s. Numerous mathematical models that have mainly focused on input-output relationships were based on this classical oculomotor theory. However, due to lack of data, these early models paid little or no attention to anatomy and physiology, and so suffered from some performance limitations [9]. In recent years, the ocular motor control modeling is developed rapidly, which span from models at the systems level to detailed neural networks using firing rate neurons [10-14].

According to physiology and anatomy, there is independent control system for saccade and the other four kinds are controlled by the same nerve circuit. On the basis of previous study, Zhang [7-8] and other people established a detailed nerve circuit and a model for binocular control. They used a feed forward integrator for the control system. But our model is different from Zhang's model. We use a feedback nerve integrator to model for the binocular eye movements, which can improve the performance of the control system.

Because of the complexity of human ocular motor system, some assumptions are introduced to simplify the model: First, all the transfer functions in the ocular motor system model were considered Linear. Second, time delays caused by image processing in the visual cortex and signal transmission in the nerves were neglected; Third, cognition in the cerebrum, including synthetic inference, prediction, and the influence of attention. Finally, to simplify the discussion, we focused on binocular vergence eye movements [7-8].

A simple fist-order model was chosen to represent the dynamics of the eye plant. This model has been proven to be an accurate predictor of the relation between eye angular position and motoneural firing rate for movements [9]. In experiments performed on monkeys, researchers found that the firing rate modulation of abducens motoneurons ( $\Delta M(t)$ ) was correlated with the velocity and position of the angular eye trajectory: $\Delta M(t) = ke(t) + r\dot{e}(t)$ . As a result, the following first-transfer function can be used to approximate eye plant dynamics during slow eye movements, as shown in Eq. 1.

$$P(s) = \frac{E(s)}{\Delta M(s)} = \frac{1/k}{r/k\, s+1} = \frac{K_p}{T_p s+1} \tag{1}$$

Where $K_p = 1\deg/\,spikess^{-1}$ , $T_p = 0.28$ s, it is the time constant of the eye plant.

Anatomy and neurology indicates that there is a nerve integrator between vestibular nucleus and oculomotor nuclei or the nucleus of the abducens nerve. The neural filter that proposed to exist in the prepositus hypoglossi (PH) represents an internal model of the eye plant [10]. Robinson et al. proposed a feed forward nerve integrator. H.L Galiana et al. built a feedback nerve integrator [11,13]. The binocular control system model that we develop in this paper uses a feedback nerve integrator.

$$F(s) = \frac{K_f}{T_f s+1} \tag{2}$$

Where $T_f = 0.28$ s, and $K_f = 1$ ,it is low-frequency gain of the neural filter.

A oculomotor control system model for binocular vergence eye movements is developed as shown in Fig.4 , VN, NI, OMN, AN, LR, MR and EPH separately represent vestibular nucleus, neural integrator, oculomotor nucleus, abducens nucleus, lateral rectus , medial rectus and eye plant model. $T_l$ and $T_r$ are respectively desired values to fix the lines of sight of left and right eyes onto the visual target. $E_l$ and $E_r$ are respectively the controlled rotation angles of left and right eyes. $g_l$ is constant gain of LR, $g_m$ is constant gain of MR. $\gamma_1$ , $\gamma_2$ , $\gamma_3$ , $\beta_1$ , $\beta_2$ are constant gains of corresponding neural circuit. Thus, Fig. 4 is simplified as shown in Fig.5.

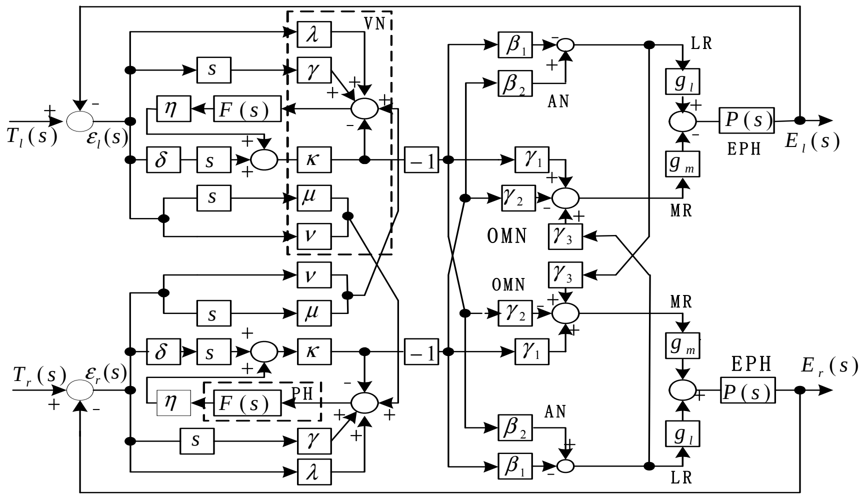



Figure 4. The control system diagram for binocular vergence eye movements.

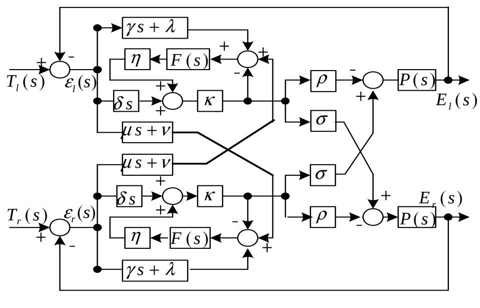



Figure 5. The simplified control system block diagram for binocular vergence eye movements.

Where $\sigma = g_l\beta_2 + g_m\gamma_2 + g_m\beta_1\gamma_3$ and $\rho = g_l\beta_1 + g_m\gamma_1 + g_m\beta_2\gamma_3$ . According to the experimental results of physiology and anatomy [2][7], the model parameters used in all simulations are $\gamma = 0.3$ , $\mu = 0.25$, $\rho = 7.5$ , $\sigma = 5$ , $\nu = 1$ , $\lambda = 8$ , $\kappa = 0.1$, $\eta = 5$ , $\delta = 0.25$ . The Mathematical control model can be obtained from Figure.4 and Figure.5, wWhich can be stated in Eq.3 and Eq.4, and $\varepsilon_l(s) = T_l(s) - E_l(s)$ , $\varepsilon_r(s) = T_r(s) - E_r(s)$ .

$$E_l(s)=\frac{\varepsilon_l(s)\{[\kappa K_f\eta(\rho\gamma-\sigma\mu)+\kappa\rho\delta]s+\kappa K_f\eta(\rho\lambda-\upsilon\sigma)]+T_f\kappa\rho\delta s^2\}}{T_fT_ps^2+[(1+\kappa\eta K_f)T_p+T_p]s+1+\kappa\eta K_f}K_p$$
$$+\frac{\varepsilon_r(s)\{[\kappa K_f\eta(\rho\mu-\sigma\gamma)-\kappa\delta\sigma]s+\kappa K_f\eta(\rho\upsilon-\lambda\sigma)-T_f\kappa\delta\sigma s^2\}}{T_fT_ps^2+[(1+\kappa\eta K_f)T_p+T_p]s+1+\kappa\eta K_f}K_p \quad (3)$$

$$E_r(s)=\frac{\varepsilon_r(s)\{[\kappa K_f\eta(\rho\gamma-\sigma\mu)+\kappa\rho\delta]s+\kappa K_f\eta(\rho\lambda-\upsilon\sigma)]+T_f\kappa\rho\delta s^2\}}{T_fT_ps^2+[(1+\kappa\eta K_f)T_p+T_f]s+1+\kappa\eta K_f}K_p$$
$$+\frac{\varepsilon_l(s)\{[\kappa K_f\eta(\rho\mu-\sigma\gamma)-\kappa\delta\sigma]s+\kappa K_f\eta(\rho\upsilon-\lambda\sigma)-T_f\kappa\delta\sigma s^2\}}{T_fT_ps^2+[(1+\kappa\eta K_f)T_p+T_f]s+1+\kappa\eta K_f}K_p \quad (4)$$

## VI. Experimental Results and Analysis

### A. System Simultion

To evaluate the effectiveness of the proposed method, some simulation experiments on the model were conducted, and all simulation results were obtained using MATLAB-Simulink. In order to easily simulate the process and analyze the results, according to the feather of vergence eye movement, we input TR and TL, which are respectively the position angle of location target point relative to left and right cameras, and the output is EL and ER. TL is positive, TR is negative.

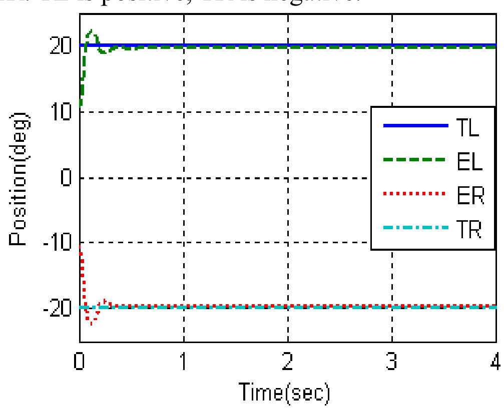



Figure 6. The simulation result during TL=20° and TR=-20°

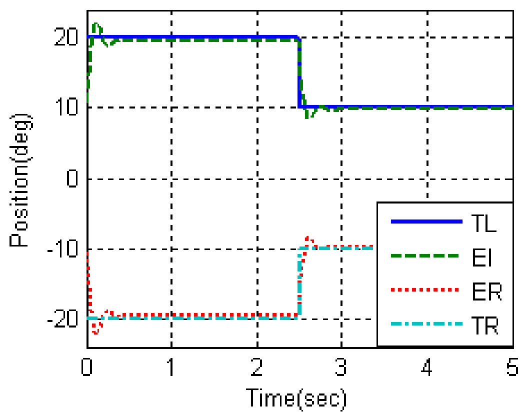



Figure 7. The simulation result during the input changes suddenly.

Fig. 6 shows the simulation results during TL=20° and TR=-20°. The results of simulation show that this system has fast response and small static error. Fig. 7 shows the simulation results that when time is 2.5s and the input changes from 20° to 10° suddenly, the system also performs well and has good robustness.

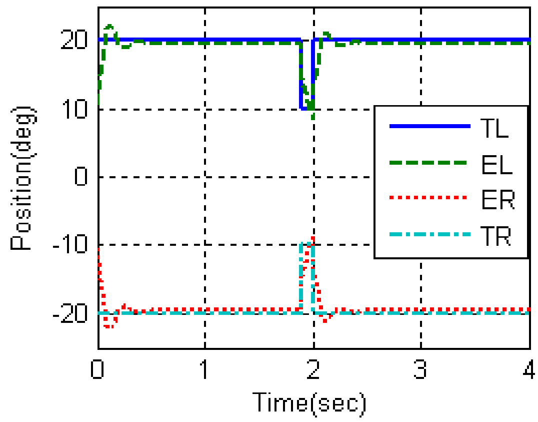



Figure 8. The simulation result during the system was input an interference signal.

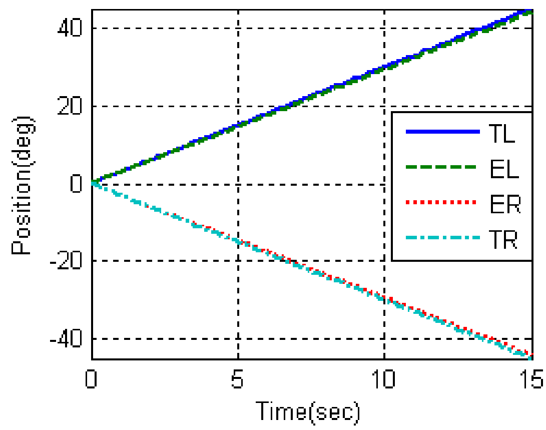



Figure 9. The simulation result for the platform moving towards the target at the speed of 3°/s

Fig. 8 shows the simulation result when the control model is input a disturbance signal of 10° and last for 0.1s. The system can recover in a short time, which also indicates that the model has robust. Fig. 9 shows that the moving platform moves towards the target at the speed of 3°/s. When t=0s, the input location TL and TR are both 0°, because the moving platform is too far from the target. The simulation result shows that the target can remain in the public vision field of the two cameras all the time when the platform is moving. Fig. 10 shows the result that when the platform is moving away from the target at the speed of 3°/s. When t=0s and the input TL and TR are both 90°, the target can remain in the public vision field of the double cameras all the time during the platform is moving.

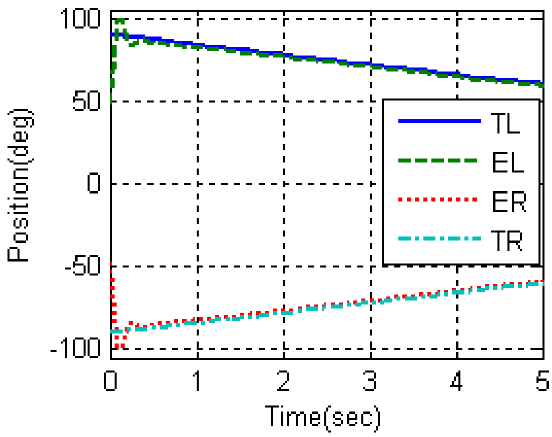



Figure 10. The Simulation result for the platform moving away the target at the speed of 3°/s

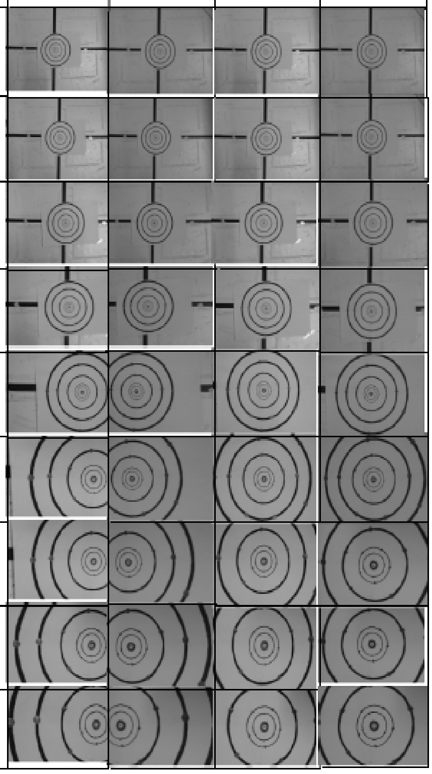
## B. *Experimental Validations*

Figure 11. The experimental platform

Figure.11 shows the control system experimental platform we designed. The experimental system uses two Can VC-50i PZT cameras. The cameras are installed on a fixed plate. The plate is suspended by a steel wire to simulate moving platform and do up and down movement vertically. Table 1. shows the experimental results we tested based on the moving platform. The experimental results show that the control system can track the target point continuously, smoothly, clearly, and stably, just like the human eyes. With the control system based on the binocular vergence eye movements, it is guaranteed that target areas can remain in the public vision field of the double cameras all the time during the double cameras platform moving. Compared with the traditional moving double cameras system, this new one can effectively reduce bind areas.

TABLE I.
EXPERIMENTAL RESULTS COMPARISON BETWEEN TRADITIONAL METHODS AND METHODS BASED ON BIOMIMETIC EYES

| Hight (mm) | Traditional Method | | Novel Method | |
|---|---|---|---|---|
| | right | left | right | left |
| 3000 | | | | |
| 2500 | | | | |
| 2000 | | | | |
| 1500 | | | | |
| 1000 | | | | |
| 700 | | | | |
| 500 | | | | |
| 400 | | | | |
| 300 | | | | |



## V. CONCLUSION

(1) According to the characteristics of the binocular vergence eye movements, a novel type of method to reduce blind areas caused by double cameras in motion platform was put forward.

(2) Based on the neural pathway of the binocular eye movements, this paper developed a new binocular vergence control model by using a feedback nerve integrator.

(3) This model can be applied in binocular cameras system to obtain 3D vision information. Compared with traditional method, this new one can eliminate blind areas. The results of simulation show that the system can have robustness and the target can remain in the public vision field of the two cameras all the time when the cameras platform is moving. Finally, physical experiments were conducted, and the test results are encouraging.

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