

Visual Servoing of Patient Robot's Face and Eye-Looking Direction to Moving Human

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Abstract: We have presented a system of patient robot developed with the aim at improving abilities of nursing student's medical treatment, such as injection to vein. To make patient robot human-like behavior, we have applied chaotic motion to the patient robot's behavior. In this paper, we propose visual servoing to follow a human face by 3-D pose recognition and eye-looking direction to moving human. Moreover, to evaluate the effectiveness of visual servoing, we execute an experiment that patient robot make behaves like a human by visual servoing with camera image.

Keywords: Patient robot, Chaos, Visual servoing, Variable emotion

1. INTRODUCTION

Nowadays, some human body models called "phantom" imitating parts of human body have been developed, but most of them are used for particular individual technical training. Those phantoms do not suit for the nursing training, since they cannot be felt to be similar to actual humans by medical trainees. What is important for nurse to prevent medical accidents is the constant awareness to monitor patients physical conditions. Medical workers—especially beginners—may fall themselves in a state of concentration too much on a medical procedure without paying attention to the patients' condition, which may change quickly and dangerously. Therefore constant awareness of the patients' state is important and it should be attained like customs. That is the reason human-like patient robot is required instead of phantoms. On-line monitoring training through patient robot helps them notice sudden change of patients' conditions, preventing medical malpractices before dropping in worst situation.

Therefore, we have developed a new simulator called "patient robot". To offer safe and effective nursing training, the patient robot must present its mental expression through face actions and body behaviors since nurses are required to monitor the patient's conditions during nursing procedures. On the other hand the robot can monitor the nurse students' injection procedure, for example, to measure their ability from the view point of patients. Moreover, the patient robot should behave autonomously and naturally like humans to make the injection training effective. We use chaos to change the inside state of patient robot autonomously, which exists in real human's inside phenomena what we believe to generate personality by chaos[1].

In order to implement more human-like behavior for patient robot, this paper proposes eye-looking direction to moving human by visual servoing[2]. As the result, new action—"visual servoing of patient robot's face and eye-looking direction to moving human"—for automatic behavior is realized. To verify the validity of the proposed method, we had experiments that patient robot follows



Fig. 1 Patient robot

human face by visual servoing, which makes the patient robot's behavior look like actual human's behavior.

2. PATIENT ROBOT

The patient robot we developed is shown in Fig.2. We mounted the robot's head with two CCD cameras as eyes to observe the training nurse and installed some servomotors inside the head for generating face expression, as shown in Fig.2. By these servomotors, the patient robot can express normal, smile, angry and painful faces, as shown in Fig.3(a)-(d)[3]. The moving parts of patient robot's body are shown in Fig.4. Left arm is made by arm model for blood drawing training, and the artificial vein flowing imitated blood is buried in the arm. Since checking the state of patient periodically is necessary to avoid danger during nursing, the robot detects student's face with eye-cameras to evaluate whether the nurse is paying attentions to the state of patient while injecting[4].

3. PATIENT ROBOT SYSTEM

3.1 Emotional State Space

To engineer that the robot can imitate patient's expressions and behaviors reflecting their mental state, we define patient robot's inside state space representing nurse's

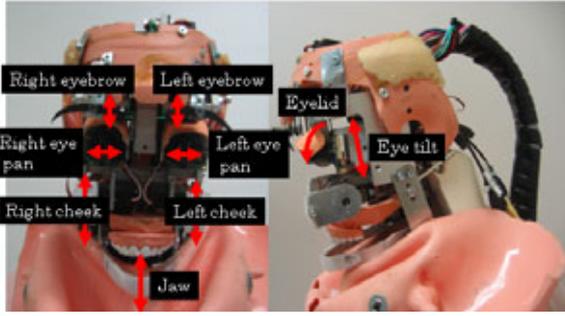


Fig. 2 Structure of robot's head



(a) (b) (c) (d)

Normal face Smile face Painful face Angry face
Fig. 3 Facial expressions

injection level as shown in Fig.5. X-axis in it shows the evaluation of the watching skill (Stressed-Relaxed) and Y-axis shows the injection skill(Painful-Tolerable). Psychological condition of the patient robot is expressed by the point of coordinate $(X(t), Y(t))$ in that state space, and patient robot's expression and motion will be decided depending on the value $(X(t), Y(t))$. In this stage, patient robot can only determine the Stressed-Relaxed axis $X(t)$ because it doesn't have sensor for detecting pain, letting $Y(t)$ be always zero.

According to the detection ratio of trainee's face with constant checking period representing how frequently the trainee checks the patient robot face to monitor his/her condition through two cameras set at the robot's two eyes, patient robot can evaluate the injection procedure with how much the trainee makes efforts to get patient's inside information.

The function of normalized detection ratio of trainee's

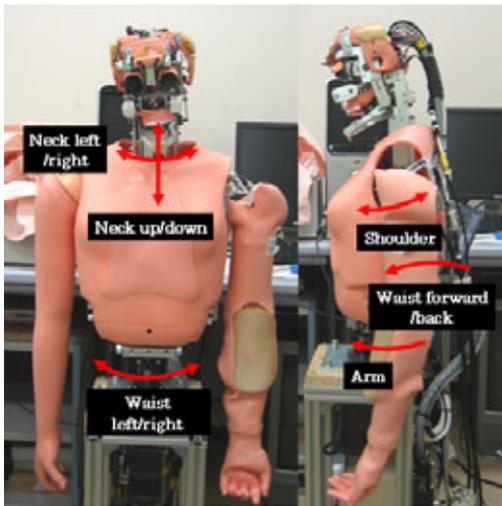


Fig. 4 Structure of robot's body

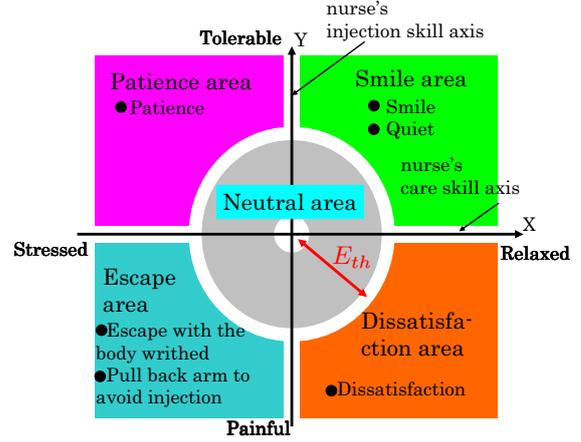


Fig. 5 Emotion model of patient robot

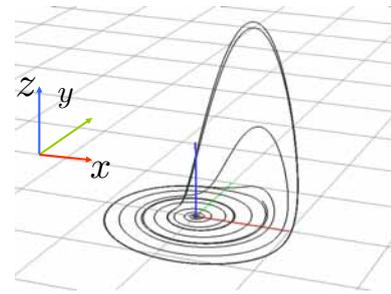


Fig. 6 Rössler model solution orbit

face ${}^s E_x(t)$ ($-1 < {}^s E_x(t) < 1$) is determined by real-time face detecting system in the patient robot.

3.2 Emotional Fluctuation by Chaos

Inside state of patient robot that is decided only by sensing result makes the motion of patient robot simple and easy to be predicted by trainee during injection training, resulting in deleting the essential meaning of learning how the caring mind about the patient's condition can avoid malpractices. Therefore we use chaos to change the inside state of patient robot autonomously, which is existing actually in human's inside phenomena. Here, we use the chaos orbit of a non-linear differential equation called a Rössler model defined as

$$\begin{aligned}\dot{x} &= -y - z \\ \dot{y} &= x + ay \\ \dot{z} &= b + z(x - c)\end{aligned}\quad (1)$$

where a, b and c are set to be 0.2, 0.2 and 5.7 respectively. Fig.6 shows chaos solution orbit of Rössler model. X-axis value $X(t)$ in Fig.5 is changed into $X(t) + x(t)$ by adding chaos orbit $x(t)$. Also, $Y(t)$ is changed into $Y(t) + y(t)$ and denoted by ${}^c E_x(t), {}^c E_y(t)$ as

$${}^c E_x(t) = X(t) + x(t) \quad (2)$$

$${}^c E_y(t) = Y(t) + y(t) \quad (3)$$

3.3 Motion Generation

The motion of patient robot is decided by value of ${}^s E_x(t)$ or ${}^c E_x(t)$ which are mentioned in sections 3.1

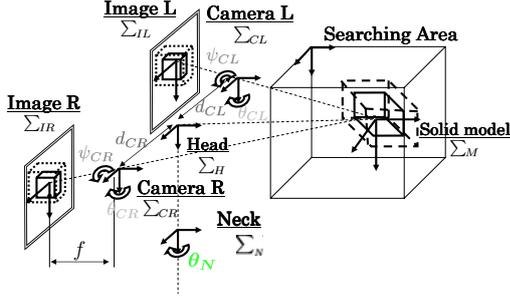


Fig. 7 Coordinate system

and 3.2. For example, radius of circle of ‘‘Neutral area’’ in Fig.5, named E_{th} , is the threshold to change patient robot’s motion. Patient robot changes facial expressions, when Eq.(4) is satisfied.

$$\begin{aligned} (A)^*E_x(t) &> E_{th} \longrightarrow \text{smileface} \\ (B)^*E_x(t) &\leq |E_{th}| \longrightarrow \text{normalface} \\ (C)^*E_x(t) &< -E_{th} \longrightarrow \text{painfulmotion} \end{aligned} \quad (4)$$

In Eq.(4), $*E_x(t)$ expresses either ${}^sE_x(t)$ or ${}^cE_x(t)$. The motion being influenced from chaos is hard for trainee to predict the motion of the patient robot, appearing like human by not repeated behaviors.

4. STEREO-VISION

4.1 Kinematics of Stereo Vision

We utilize a perspective projection as projection transformation. The coordinate systems of left and right cameras and object (here we take a solid column model as an example) in Fig. 7 represent world coordinate system Σ_W , model coordinate system Σ_M , camera coordinate systems Σ_{CR} and Σ_{CL} , image coordinate systems Σ_{IR} and Σ_{IL} . A point i on a solid model of the target object can be described using these coordinates and homogeneous transformation matrices. At first, a homogeneous transformation matrix from Σ_{CR} to Σ_M is defined as ${}^{CR}T_M$. And an arbitrary point i on the target object in Σ_{CR} and Σ_M is defined as ${}^{CR}r_i$ and ${}^M r_i$. Then ${}^{CR}r_i$ is,

$${}^{CR}r_i = {}^{CR}T_M {}^M r_i. \quad (5)$$

The position vector of i point in right image coordinates, ${}^{IR}r_i$ is described by using projection matrix P of camera as,

$${}^{IR}r_i = P {}^{CR}r_i. \quad (6)$$

Using a homogeneous transformation matrix of fixed values defining the kinematical relation from Σ_{CL} to Σ_{CR} , ${}^{CL}T_{CR}$, ${}^{CL}r_i$ is,

$${}^{CL}r_i = {}^{CL}T_{CR} {}^{CR}r_i. \quad (7)$$

By the same way as we have obtained ${}^{IR}r_i$, ${}^{IL}r_i$ is described by the following Eq.(8) through projection matrix P .

$${}^{IL}r_i = P {}^{CL}r_i \quad (8)$$

Then position vectors projected in the Σ_{IR} and Σ_{IL} of arbitrary point i on target object can be described as ${}^{IR}r_i$ and ${}^{IL}r_i$. Here, position and orientation, i.e. pose of the origin of Σ_M based on Σ_{CR} , are represented as $\phi = [t_x, t_y, t_z, \phi, \theta, \psi]^T$, in which ϕ, θ , and ψ are roll, pitch and yaw angles respectively, and then Eq. (6) and Eq. (8) are rewritten as,

$$\begin{cases} {}^{IR}r_i = f_R(\phi, {}^M r_i) \\ {}^{IL}r_i = f_L(\phi, {}^M r_i). \end{cases} \quad (9)$$

This relation connects the arbitrary points on the object and projected points on the left and right images with the variables ϕ representing the human face’s pose, which is considered to be unknown in this paper. When evaluating each left and right point i above mentioned, the matching problem of corresponding point in left and right images is arisen. Therefore, to avoid this problem, the 3-D model-based matching that treats the points of the object model as a set, is chosen instead of point-based corresponding.

4.2 3-D object pose recognition

In this paper, patient robot recognizes human face to decide the border of each process automatically. This method is given by using Model-based Matching(MBM) method and genetic algorithm(GA)[5]. In action patterns of patient robot of the previous system, the border of each process had been decided by operator of the robot. Since each process must relate to the recognition of human face, we propose 3-D object pose recognition method[6] of patient robot by using two CCD cameras as robot’s eyes.

4.3 Visual Servoing

This subsection shows visual servoing system for the improvement of human-like behavior in the actions of patient robot. Here, the pose of the target head is recognized by two cameras installed in the inside head of the patient robot, and the objective of the visual servoing is to control the patient head pose to keep observing human face at the center of the right camera image. Patient robot can rotate pan and tilt angles of two eyes (3-DOF), neck (2-DOF), and there are totally 5-DOF to perform the motion. Here, we use the model-based recognition method explained in [6], and measure in real time the head’s pose. From relation between coordinate system of right camera Σ_{CR} and coordinate system of object’s head Σ_M as shown in Fig.8, we can calculate the angle deviation $\Delta\theta_{\hat{M}}, \Delta\phi_{\hat{M}}$ by Eq. (10) and Eq. (11), using the recognized face position (x, y, z) with respect to coordinate system Σ_{CR} .

$$\Delta\theta_{\hat{M}} = \text{atan2}(x, z) \quad (10)$$

$$\Delta\phi_{\hat{M}} = \text{atan2}(y, z) \quad (11)$$

The tilt angle of the patient robot is controlled to decrease $\Delta\theta_{\hat{M}}$ to zero, and pan is done by $\Delta\phi_{\hat{M}}$. We verified that the patient robot can generate the motion that is more similar to human by performing visual servoing. Here, we explain a controller of patient robot. A target value of pan angle is defined as $\theta_{\hat{M}}^i$ and tilt angle is defined as $\phi_{\hat{M}}^i$. A present value of pan angle is defined as θ_M^i

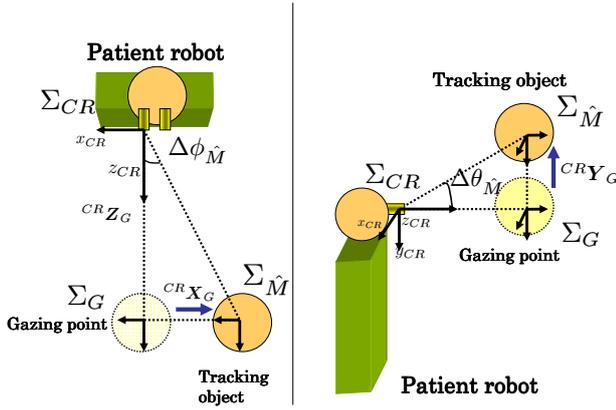


Fig. 8 Angle of servoing

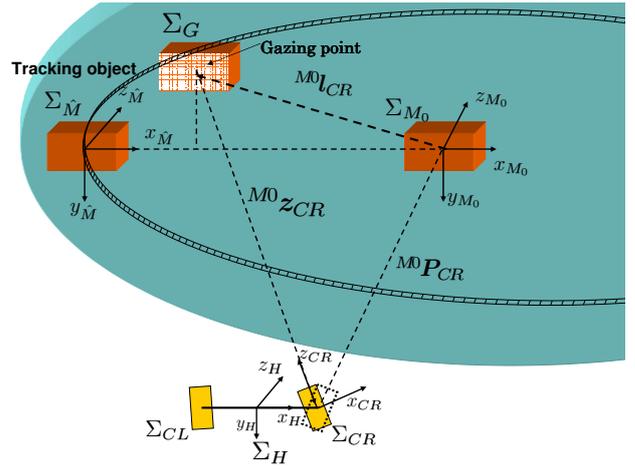


Fig. 9 Patient robot's gazing point

and tilt angle is defined as ϕ_M^i . Time series is defined as $i(0, 1, 2, \dots, i, i+1, \dots, t)$.

$$\theta_M^i = \theta_M^i + k_M \Delta\theta_M \quad (12)$$

$$\phi_M^i = \phi_M^i + k_M \Delta\phi_M \quad (13)$$

The solutions θ_M^{i+1} and ϕ_M^{i+1} of differential equation with eye direction of pan angle and tilt angle are given by Eq. (14) and Eq. (15) and are measured by experiment.

$$\theta_M^{i+1} = f_{\theta_M}(\theta^i, \phi_M^i) \quad (14)$$

$$\phi_M^{i+1} = f_{\phi_M}(\phi^i, \phi_M^i) \quad (15)$$

4.4 Gazing Point

Here, to make visual servoing of patient robot, we define a concept of gazing point. As it is shown in Fig. 9 the intersection of the gazing line of right camera and the $x_{M_0}-y_{M_0}$ plane is defined as the gazing point. The relative relation between Σ_{M_0} and Σ_{CR} is given by homogeneous transformation as $M^0\mathbf{T}_{CR}$, $M^0\mathbf{T}_{CR}$ concludes the rotation matrix $M^0\mathbf{R}_{CR}$ and the position vector $M^0\mathbf{p}_{CR}$, and the rotation matrix $M^0\mathbf{R}_{CR}$ can be written as $[M^0x_{CR}, M^0y_{CR}, M^0z_{CR}]$. The direction of $M^0\mathbf{l}_{CR}$ in Fig. 9 is same to the direction of z_{CR} , and $M^0\mathbf{l}_{CR}$ can be expressed as:

$$M^0\mathbf{l}_{CR} = M^0\mathbf{p}_{CR} + kM^0z_{CR} \quad (16)$$

Here k is a scalar variable. The gazing point of the right camera expressed in Σ_{M_0} is $M^0\mathbf{p}_G = [M^0x_G, M^0y_G, 0]^T$. For $M^0\mathbf{l}_{CR} = M^0\mathbf{p}_G$ in z direction, $(M^0\mathbf{p}_{CR})_z + k(M^0z_{CR})_z = 0$. And usually $(M^0z_{CR})_z \neq 0$, k can be calculated by $k = -(M^0\mathbf{p}_{CR})_z / (M^0z_{CR})_z$, and the x, y coordinate of the gazing point in Σ_{M_0} can be calculated by:

$$M^0x_G = (M^0\mathbf{p}_{CR})_x + k(M^0z_{CR})_x \quad (17)$$

$$M^0y_G = (M^0\mathbf{p}_{CR})_y + k(M^0z_{CR})_y \quad (18)$$

5. EXPERIMENT

We had experiment that patient robot kept recognizing the object by neck and eyes in an experimental environment of Fig. 10. Patient robot follows human face printed a rotation object. The rotation object rotates at a

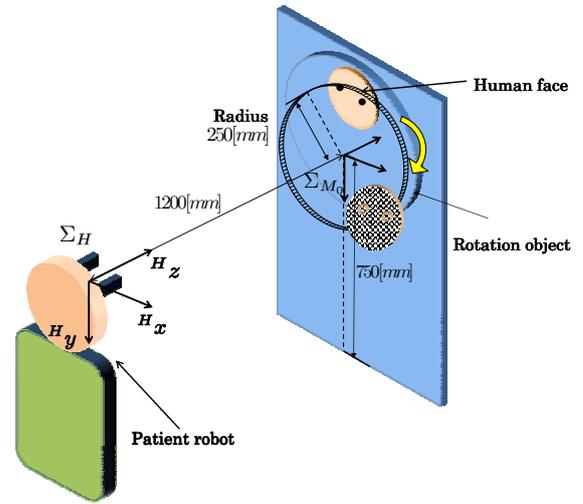


Fig. 10 Experiment environment

constant velocity (0.63[rad/s], 0.21[rad/s], 0.063[rad/s]). Three kinds of angular velocity are applied to experiment in the case with eye following response and without eye following response. Then we measured and calculated eye direction given by Eq. (14), Eq. (15) and fitness value of facial recognition.

5.1 Experiment of Visual Servoing

We make patient robot follow human face without eye following response. The results are shown in Fig. 11, Fig. 12 and Fig. 13 for angular velocity 0.63[rad/s], 0.21[rad/s] and 0.063[rad/s]. Fig. 14, Fig. 15 and Fig. 16 show that patient robot follows human face with eye following response (0.63[rad/s], 0.21[rad/s] and 0.063[rad/s]). A fitness value average \tilde{f} of each angular velocity is shown in Table. 1 and given as,

$$\tilde{f} = \frac{1}{T} \sum_{i=0}^T f^i \quad (19)$$

Where f^i is a fitness value and calculated from MBM and GA. The function T is a termination time of experiment.

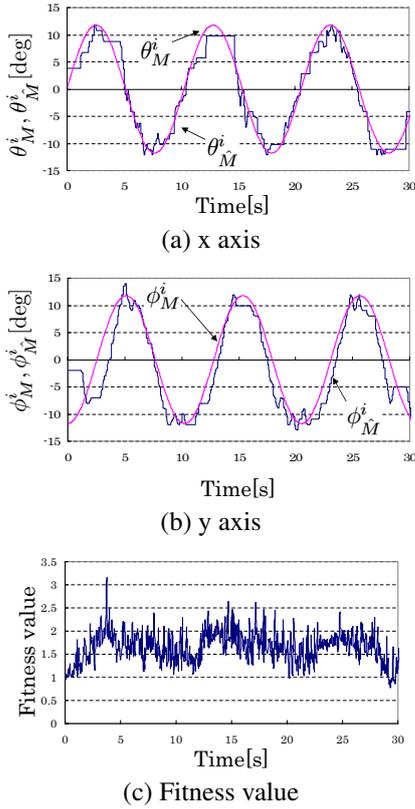


Fig. 11 Without eye following responses ($\omega = 0.63[\text{rad/s}]$)

angular velocity	(a)	(b)
0.63[rad/s]	1.74	1.68
0.21[rad/s]	1.82	1.84
0.063[rad/s]	1.92	1.90

Table 1 Fitness value average: (a)with eye following response, (b)without eye following response

5.2 Result

Patient robot can follow human face as shown in Fig. 11~ Fig. 16. As shown in Table. 1, in which case human face moves slowly to use eye following responses and not to use it are almost the same fitness value. While in which case human face moves fast fitness value of using eye following responses is higher than not using it. This means recognition accuracy and tracking performance are better if fitness value is higher. From these experimental results it finds that patient robot can follow human face with eye following responses better than without it.

6. CONCLUSION

In this paper, we introduced the patient robot system. To behave like a human, we made the patient robot follow face by visual servoing driving vertically and horizontally. From the experimental results, we verified the validity of proposed method and authenticated potency of using eye following response. As future works, to make patient robot more human-like behavior, we will evaluate reaction time when human follows an object. And we will install reaction time of human-like on patient robot.

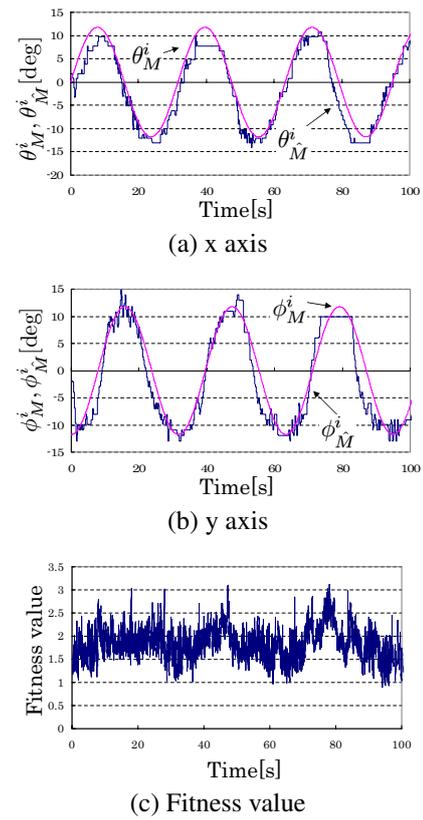


Fig. 12 Without eye following responses($\omega = 0.21[\text{rad/s}]$)

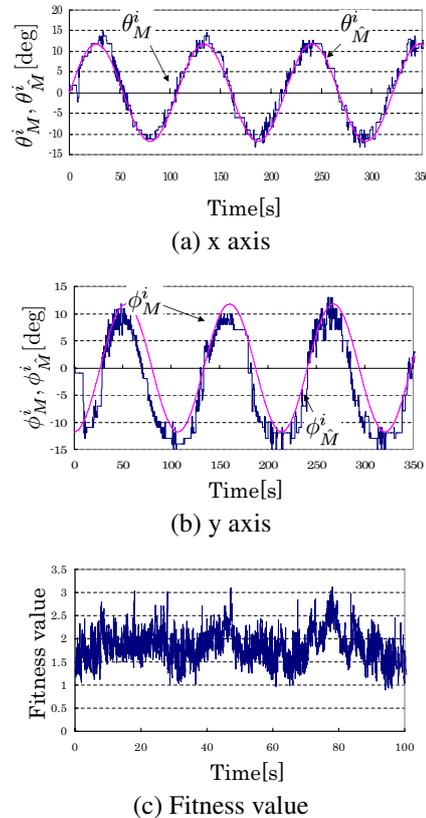


Fig. 13 Without eye following responses($\omega = 0.063[\text{rad/s}]$)

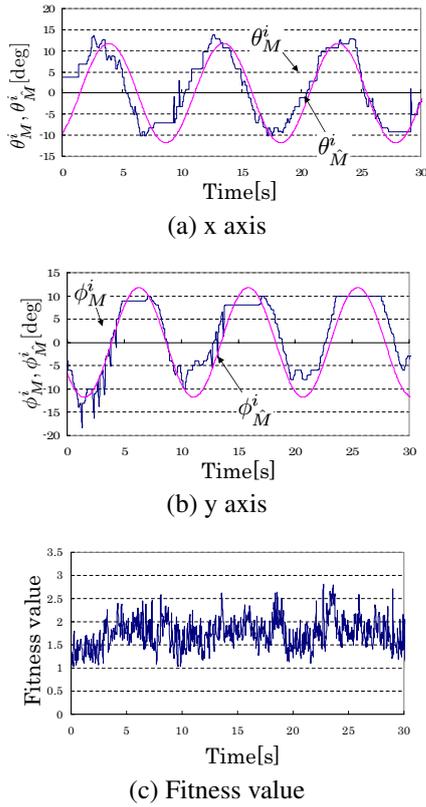


Fig. 14 With eye following responses($\omega = 0.63[\text{rad/s}]$)

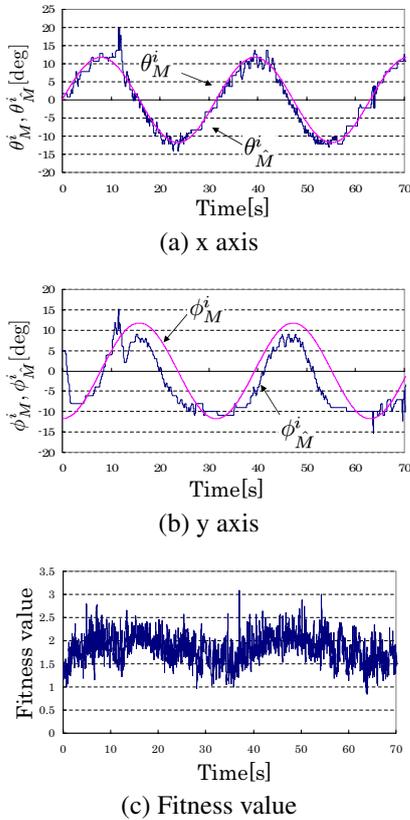


Fig. 15 With eye following responses($\omega = 0.21[\text{rad/s}]$)

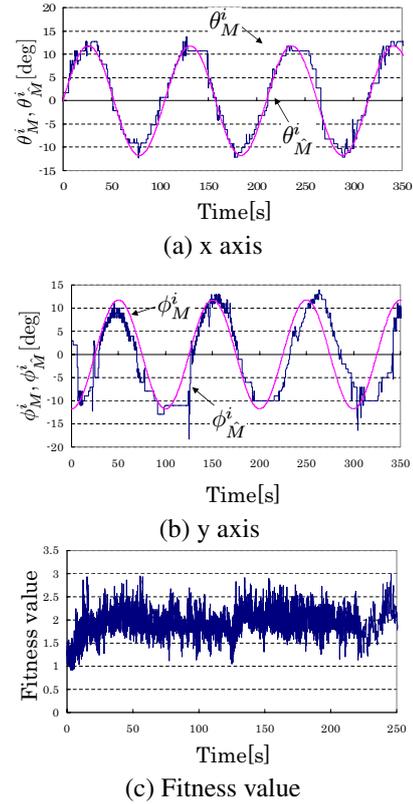


Fig. 16 With eye following responses($\omega = 0.063[\text{rad/s}]$)

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