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Human-like Patient Robot with Chaotic Emotion for Injection Training

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Abstract: In this paper, we present a system of patient robot developed with the aim at improving abilities of nursing student's medical treatment, such as injection to vein. We propose to realize variable emotion of patient robot by using chaos orbit of non-linear time-differentiation equation. To evaluate the effectiveness of the robot through actual injection training, we measure heartbeat rate of nurse student during the injection training, proving the effects of the robot's similarity to human. To make the patient robot to be self-contained for the training, we propose a 3-D injector pose recognition method of patient robot to help that the robot behave autonomously along with the injection procedures of the nurse students trainings.

Keywords: Patient robot, Chaos, Variable emotion, Injector recognition

1. INTRODUCTION

Nowadays, some human body models for medical training called ''phantom'' imitating parts of human body have been developed, but most of them are used for particular individual technical training. Those phantom do not suit for the nursing training, since they can not be felt to be similar to actual humans. What is important for nurse to prevent medical accidents is the constant awareness to monitor patients physical conditions, where this consciousness appears in the nurses' thinking way when they feel the patient are humans. That is a reason patient robots is required instead of phantoms. The on-line monitoring training by patient robot helps them to notice sudden change of patients' conditions, preventing medical malpractices before dropping in worst situation.

In this paper, we will introduce 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. Contrarily the robot has to monitor the nurse students' injection procedure to measure their ability from the view point of patients. Moreover, the patient robot has to work autonomously to be used as the injection training simulator. Autonomous behavior of the robot makes the simulator to be looked more like human. Therefore, we defined inside state space expressing robot's emotion to make patient robot's behavior more autonomous. We had proposed to use chaos to change the inside state of patient robot, which is existing in real human's inside phenomena what we believe to generate personality. The usage of the chaotic non-linear oscillation had made the training patient robot's behavior to be similar to actual humans.

We defined the action pattern of patient robot and divided the injection procedure into four processes, as shown in Fig.1. Each states of these processes(I-IV) had been decided by an operator controlling manually the patient robot beside, which means the patient robot's action is not autonomous, which is the subject to improve the robot in this report. Thus, to perform autonomous action pattern, we propose a 3-D injector pose recognition method using two cameras set in both eyes of patient robot.

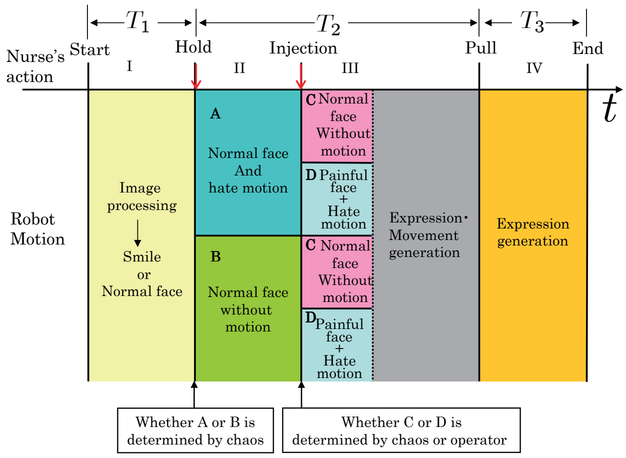


Fig. 1 Action pattern of patient robot

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.3. By these servomotors, the patient robot can express, normal, smile, angry and painful faces, as shown in Fig.2(a)-(d)[1]. The moving parts of patient robot's body are shown in Fig.5. 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[2].

Fig. 2 Patient robot

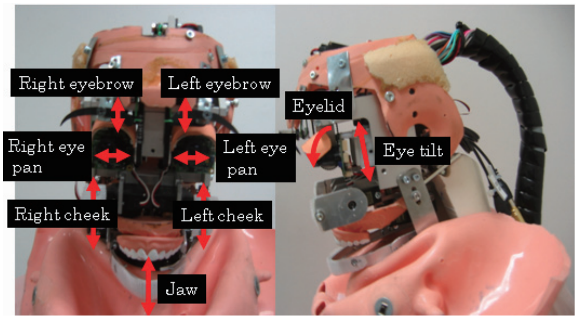


Fig. 3 Structure of robot's head

(a) Normal face (b) Smile face (c) Painful face (d) Angry face

Fig. 4 Facial expressions

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 injection level as shown in Fig.6. 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

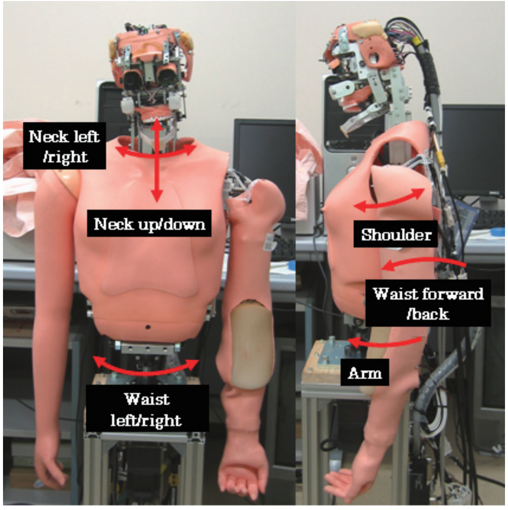


Fig. 5 Structure of robot's body

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

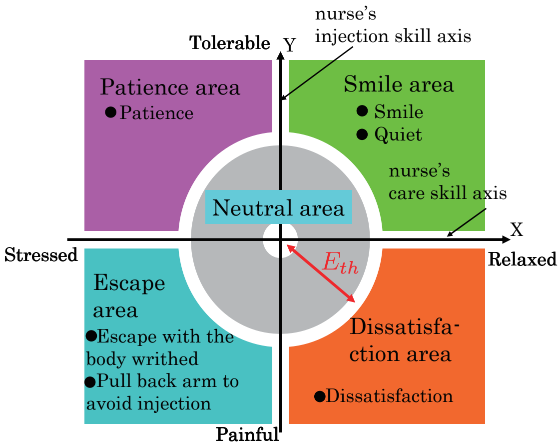


Fig. 6 Emotion model of patient robot

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

$$\begin{aligned} \dot{x} &= -y - z \\ \dot{y} &= x + ay \qquad (a = 0.2, b = 0.2, c = 5.7) \quad (1) \\ \dot{z} &= b + z(x - c) \end{aligned}$$

Fig.7 shows chaos solution orbit of $Rössler$ model. X-axis value $X(t)$ in Fig.6 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 ${}^cE_x(t)$, ${}^cE_y(t)$ as

$$ {}^cE_x(t) = X(t) + x(t) \tag{2} $$

$$ {}^cE_y(t) = Y(t) + y(t) \tag{3} $$

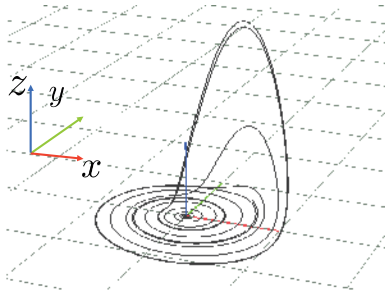


Fig. 7 $Rössler$ model solution orbit

3.3 Motion Generation

The motion of patient robot is decided by value of ${}^sE_x(t)$ or ${}^cE_x(t)$ which are mentioned in sections 3.1 and 3.2. For example, radius of circle of ''Neutral area'' in Fig.6, named E_{th}, is the threshold to change patient robot's motion. Patient robot changes facial expressions, when Eq.(4) is satisfied.

$$
\begin{array}{lcl}
(A)^*E_x(t) & > & E_{th} \longrightarrow smileface \\
(B)^*E_x(t) & \leq & \mid E_{th} \mid \longrightarrow normalface \\
(C)^*E_x(t) & < & -E_{th} \longrightarrow painfulmotion
\end{array} \tag{4}
$$

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.

3.4 Action Pattern

In the injection training, we divided the blood drawing performance into four processes, as shown in Fig. 1. These four processes are

- [Process I] From the time of the action start to the time when the nurse student takes an injector.
- [Process II] From the end time of process I to the time when nurse student sticks injector into the vein of the patient robot.
- [Process III] From the end time of process II to the time when nurse student pulls the injector out.
- [Process IV] From the end time of process III to the time when the injection procedure completes.

These periods from I to IV are shown in Fig.1. The motion of the robot in case of using a sensor model and using a chaos model obeys the motion pattern that is chosen by operator as shown in the figure. Patient robot performs given action pattern based on its inside state ${}^*E_x(t), {}^*E_y(t)$ during each process. During this training process, the patient robot keep detecting the front face of the nurse student to estimate whether the trainee pays attention to the patient's state during the blood drawing. In process II, the operator of the experiment indicates when the trainee took the injector by keying in one of two motions, "A" or "B", where "A" represents a motion to hate and scare the injection without face expression (with normal expression), and "B" does no motion and no expression, are determined by

$$ {}^*E_x(t) \leq E_{th} \longrightarrow motion\text{“}A\text{”} \tag{5} $$

$$ {}^*E_x(t) > E_{th} \longrightarrow motion\text{“}B\text{”} \tag{6} $$

At the end of process II, when the operator chooses the motion on the operation form is ''C'' (no motion with normal face) or ''D'' (motion like hating injection with painful face) in the case of using the sensor model. The motion in case of using the chaos model is given by

$$ {}^cE_x(t) > E_{th} \longrightarrow motion\text{“}C\text{”} \tag{7} $$

$$ {}^cE_x(t) \leq E_{th} \longrightarrow motion\text{“}D\text{”} \tag{8} $$

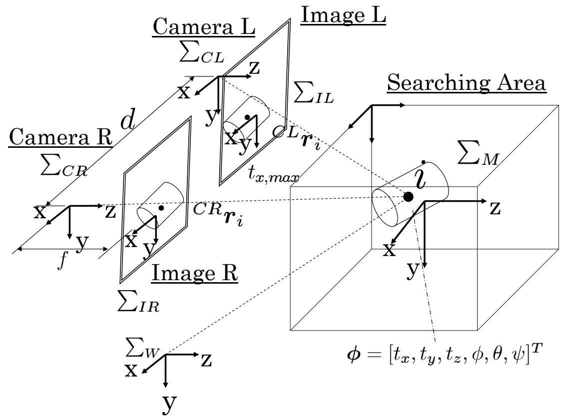


Fig. 8 Coordinate system

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.8 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 ${}^{CR}\boldsymbol{T}_M$. And an arbitrary point i on the target object in Σ_{CR} and Σ_M is defined ${}^{CR}\boldsymbol{r}_i$ and ${}^{M}\boldsymbol{r}_i$. Then ${}^{CR}\boldsymbol{r}_i$ is,

$$ {}^{CR}\boldsymbol{r}_i = {}^{CR}\boldsymbol{T}_M {}^M\boldsymbol{r}_i. \tag{9} $$

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

$$ {}^{IR}\boldsymbol{r}_i = \boldsymbol{P}{}^{CR}\boldsymbol{r}_i. \tag{10} $$

Using a homogeneous transformation matrix of fixed values defining the kinematical relation from Σ_{CL} to Σ_{CR}, ${}^{CL}\boldsymbol{T}_{CR}$, ${}^{CL}\boldsymbol{r}_i$ is,

$$ {}^{CL}\boldsymbol{r}_i = {}^{CL}\boldsymbol{T}_{CR}\, {}^{CR}\boldsymbol{r}_i. \tag{11}$$

By the same way as we have obtained ${}^{IR}\boldsymbol{r}_i$, ${}^{IL}\boldsymbol{r}_i$ is described by the following Eq.(12) through projection matrix $\boldsymbol{P}$.

$$ {}^{IL}\boldsymbol{r}_i = \boldsymbol{P}\, {}^{CL}\boldsymbol{r}_i \tag{12}$$

Then position vectors projected in the Σ_{IR} and Σ_{IL} of arbitrary point i on target object can be described ${}^{IR}\boldsymbol{r}_i$ and ${}^{IL}\boldsymbol{r}_i$. Here, position and orientation, i.e. pose, of the origin of Σ_M based on Σ_{CR} are represented as $\boldsymbol{\phi} = [t_x, t_y, t_z, \phi, \theta, \psi]^T$, in which ϕ, θ, ψ are roll, pitch and yaw angles respectively, and then Eq.(10), (12) are rewritten as,

$$\begin{cases} {}^{IR}\boldsymbol{r}_i = f_R(\boldsymbol{\phi}, {}^{M}\boldsymbol{r}_i) \\ {}^{IL}\boldsymbol{r}_i = f_L(\boldsymbol{\phi}, {}^{M}\boldsymbol{r}_i). \end{cases} \tag{13}$$

This relation connects the arbitrary points on the object and projected points on the left and right images with the variables $\boldsymbol{\phi}$ representing the injector'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 3D 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 Model

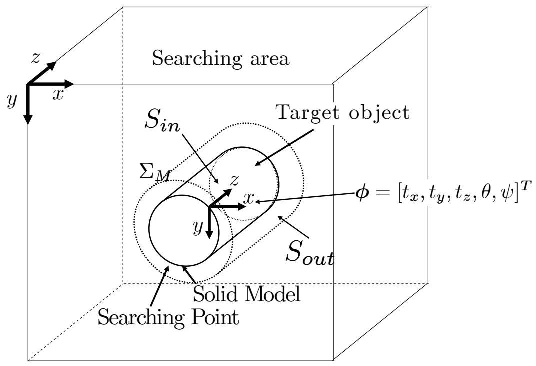
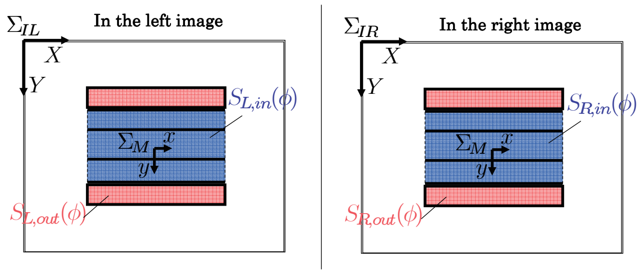


Fig. 9 3-D solid model

We define solid model of human head and injector to recognize pose. Firstly, to recognize human head pose, we use the solid model composed of two circle, which is expressed in literature[3]. Secondly, to recognize injector pose, we define the column model being approximated from the injector's shape, as shown in Fig.9. Since The model's shape is column, five components of the injector's pose as $\boldsymbol{\phi} = [t_x, t_y, t_z, \theta, \psi]^T$ are enough. Then, the set of coordinates inside of the column is depicted as S_{in} and the outside space enveloping S_{in} is denoted as S_{out}. The set of the points of solid searching model consisted of S_{in} and S_{out}, which are projected onto the 2-D coordinates of right camera are expressed as,

$$\begin{cases} S_{R,in}(\boldsymbol{\phi}) = \{{}^{IR}\boldsymbol{r}_i \in \Re^2 \mid {}^{IR}\boldsymbol{r}_i = f_R(\boldsymbol{\phi}, {}^{M}\boldsymbol{r}_i), \\ \qquad\qquad {}^{M}\boldsymbol{r}_i \in S_{in} \in \Re^3\} \\ S_{R,out}(\boldsymbol{\phi}) = \{{}^{IR}\boldsymbol{r}_i \in \Re^2 \mid {}^{IR}\boldsymbol{r}_i = f_R(\boldsymbol{\phi}, {}^{M}\boldsymbol{r}_i), \\ \qquad\qquad {}^{M}\boldsymbol{r}_i \in S_{out} \in \Re^3\}. \end{cases} \tag{14}$$

where the right searching model projected to right camera coordinates is shown in Fig.10(b). The area composed of $S_{R,in}$ and $S_{R,out}$ is named as S_R. The left one is defined in the same way and the projected searching model is shown in Fig.10(a).



(a) Left searching model (b)Right searching model

Fig. 10 Searching model

4.3 Fitness Function

In this research, the input images are directly matched by the projected moving models, S_L and S_R, which are located by only $\boldsymbol{\phi}$ as described in Eq.(14) that includes the kinematical relations of the left and right camera coordinates. Here, we define evaluation function to estimate how match the moving solid model S_{in} defined by $\boldsymbol{\phi}$ lies on the injector being imaged on the left and right cameras. In order to search for the injector, the surface-strips model shown in Fig.10 and its position calculated by Eq.(13) are used.

In injection training, nurse student wear a white coat and injector's color is light white. Therefore, it is hard to recognize an injector from camera images. Here, we use blue injector to make the recognition easy and perform to estimate how match the solid model lies on the injector by using hue value of HSV color system. It is easy to understand that the blue color can be limited only by hue value in HSV parameters. Take the right image as an example, for blue region, we define color evaluation function $h({}^{IR}\boldsymbol{r}_i)$ based on hue value $H({}^{IR}\boldsymbol{r}_i)$ as

$$ h({}^{IR}r_i) = \begin{cases} 1 & 220 < H({}^{IR}\boldsymbol{r}_i) < 270 \\ 0 & otherwise \end{cases} \tag{15}$$

Then the evaluation function $F(\boldsymbol{\phi})$ of the searching models is given as

$$\begin{aligned} F_R(\boldsymbol{\phi}) &= \frac{1}{n_{in}} \sum_{\boldsymbol{r} \in \boldsymbol{S}_{R,in}(\boldsymbol{\phi})} h({}^{IR}\boldsymbol{r}_i) \\ &\quad - \frac{1}{n_{out}} \sum_{\boldsymbol{r} \in \boldsymbol{S}_{R,out}(\boldsymbol{\phi})} h({}^{IR}\boldsymbol{r}_i) &(16) \\ F(\boldsymbol{\phi}) &= (F_R(\boldsymbol{\phi}) + F_L(\boldsymbol{\phi}))/2 &(17) \end{aligned}$$

In Eq.(16), n_{in} is a number of searching point in S_{in} and n_{out} is a number of searching point i in S_{out}. Where, in case of $F(\phi) < 0, F(\phi)$ is given to zero. This function expresses the hue value difference between the one of the internal surface and the one of the contour-strips of the surface-strips model, and being used as a fitness function in genetic algorism(GA) process. In this paper, we use ‘‘1-step GA” to search maximum value of fitness function in real-time[4].

4.4 Visual Servoing to Human Head

We perform a 3-D visual servoing experiment of the patient robot by using the recognition result of the 3-D head pose. 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 the nurse student's 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 waist (2-DOF), and there are totally 7-DOF to perform the motion. Here, we use the model-based recognition method explained in [3], 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.11, we can calculate the angle deviation $\Delta\theta_1, \Delta\theta_2$ by Eq. (18) and (19), using the recognized face position (x, y, z) with respect to coordinate system Σ_{CR}.

$$\Delta\theta_1 = atan2(y, z) \quad (18)$$
$$\Delta\theta_2 = atan2(x, z) \quad (19)$$

The tilt angle of the patient robot is controlled to decrease $\Delta\theta_1$ to zero, and pan is done by $\Delta\theta_2$. In order to imitate human's motion, this control is done by patient robot's motion as shown in Fig.12. Fig.12(a) shows initial position of patient robot. In (b), target started to move to right, and patient robot chased target by turning of both eyes. In (c), when target moved to right further, patient robot chased by turning of neck and eyes are settled at the center position. Patient robot repeated (b) and (c) until the neck turned to the limit of moving range. Then, situation (d) was start. In (d), target moved to right further, then patient robot chased target by turning of both eyes. In (e), target moved to right further, and patient robot chased by turning of waist and turn the eyes to the center position at the same time. Patient robot repeated (d) and (e) until the waist turned to the limit of moving range. It is the same action in case of target moving to left, up and down.

We verified that the patient robot can generate the motion that is more similar to human by performing visual servoing.

4.5 3-D Injector Recognition

We confirmed whether our proposed system can detect the transition of nurse's injection actions (“Hold”, “Inject” and “Pull”) by recognizing of injector's pose to make the patient robot can adapt its behavior autonomously to the injection procedure transition.

The posture of patient robot in the experiment is as shown in Fig.13. We defined four sets of $\Omega_0 - \Omega_3$ by

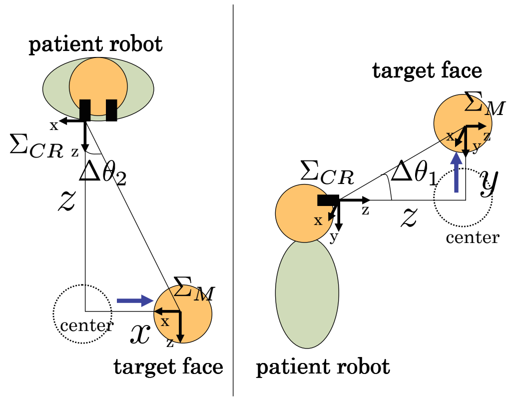


Fig. 11 Angle of servoing

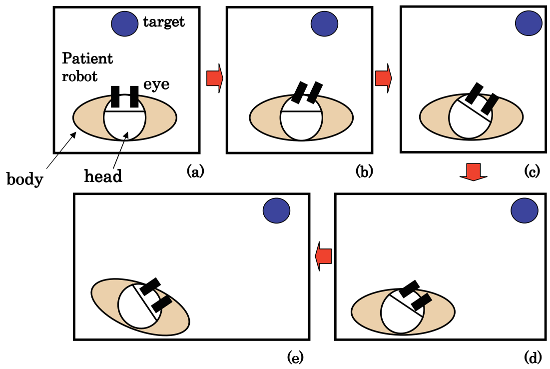


Fig. 12 Flow of servoing motion

the following conditions below, which is corresponding with the periods describing the injection states as shown in Fig.1. The sets of $\Omega_1 - \Omega_3$ in right camera image can be shown in the image depicted in Fig.14. At first, the Ω_0 expresses the state which fitness value of the recognition is low and which is the state that there is not an injector in right camera image.

$$\Omega_0 = \{ \ \phi \ \mid F(\phi) < 0.6 \ \} \quad (20)$$

Also, we define that injecting area of left arm in right camera image is Ω_2 and its outside area is Ω_1.

$$\Omega_1 = \{ \ \phi \ \mid F(\phi) \geq 0.6, -180 \leq t_x < -30 \ , 30 < t_x \leq 180, -50 \leq t_y < -20 \ \} \quad (21)$$
$$\Omega_2 = \{ \ \phi \ \mid F(\phi) \geq 0.6, -30 \leq t_x \leq 30 \ , -20 \leq t_y \leq 40, 150 \leq t_z \leq 350 \ \} \quad (22)$$

When the robot recognizes the injector in Ω_1, the robot judges that nurse is holding an injector. When the robot recognizes injector in Ω_2, the robot judges that nurse will inject to the left arm. Moreover, we define Ω_3 when injector's position is in Ω_2 and orientation is in certain value. In Ω_3, the robot judges that nurse is injecting to the left arm.

$$\Omega_3 = \{ \ \phi \ \mid \Omega_2 \cap (0 \leq \theta \leq 40, 35 \leq \psi \leq 50) \ \} \quad (23)$$

When the recognized result of injector shifts from Ω_3 to Ω_0, the robot judges that nurse is pulling the injector.

Right Camera image

Fig. 13 Experimental situation

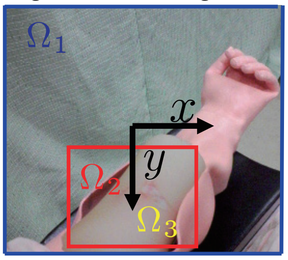


Fig. 14 Action pattern area of right camera image

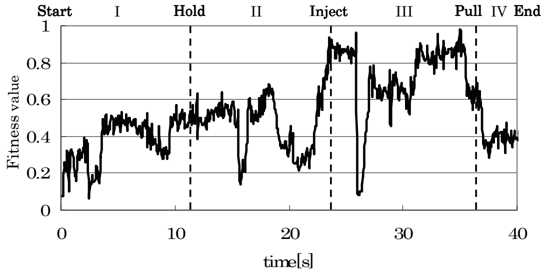
The result of 3-D injector recognition experiment is shown in Fig.15. Fig.15(a)-(d) shows the fitness value, recognized position of injector, recognized orientation and transition of Ω type.

In progress of 12 seconds, fitness value and position come under Ω_1, it means the robot can recognize the injector in camera image and decide the time of the nurse's act "having the injector" (transition process I to II). Then in 23 seconds, recognition result of injector's pose come under Ω_2, it means that the robot recognizes the injector in injecting area. And soon, the orientation of recognized injector come under Ω_3 and the robot decides the time of the nurse's act "sticking an injector" (transition process II to III). Finally in 37 seconds, fitness value decreases and comes under Ω_0, that means the injector disappears in robot's camera image and the robot decides the time of the nurse's act "pull out the injector"(transition process III to IV). As a result, according to the recognition of the injector's position / orientation, patient robot can decide the transition time during the whole injection process. From this experiment fact we can say that patient robot is able to generate motion autonomously.

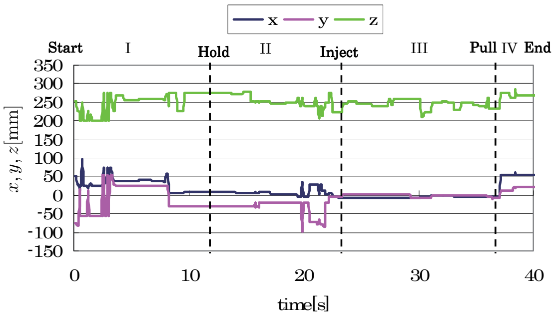
5. CONCLUSION

In this research, we installed the motion generated by chaotic emotion to the patient robot. The effectiveness of the psychological motion of the patient robot had been verified by the experiments before.

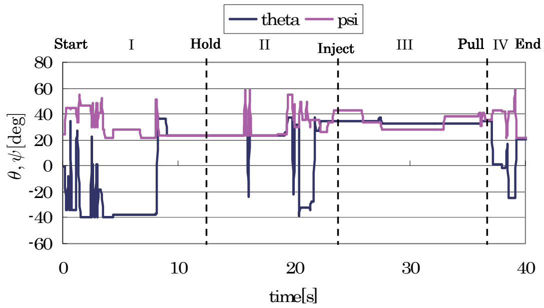
Then, we installed the 3-D head and injector pose recognition to patient robot, which make the robot more autonomous and human-like. We improved such ability of patient robot as it adapts its behaviors based on the trainees' procedure of injections through visual recognition results of the robot's eye cameras.



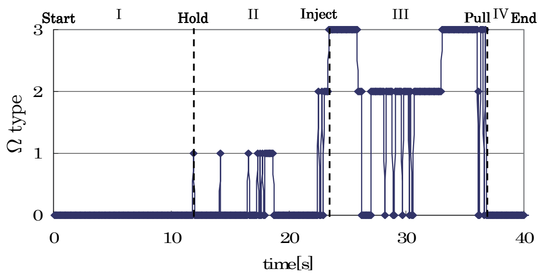
(a)Fitness value



(b)Position x,y,z



(c)Orientation θ, ψ



(d)Ω type

Fig. 15 Recognition result

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