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Analyses about Trackability of Hand-eye-vergence Visual Servoing in Lateral Direction

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Abstract. Visual servoing to moving target with fixed hand-eye cameras mounted at hand of robot is inevitably affected by hand dynamical oscillations, then it is hard to keep target at the centre of camera's image, since nonlinear dynamical effects of whole manipulator stand against tracking ability. In order to solve this problem, an eye-vergence system have been put forward, where the visual servoing controller of hand and eye-vergence is controlled independently, so that the cameras can observe the target object at the center of the camera images through eye-vergence functions. The eyes with light mass make the cameras' eye-sight direction rotate quickly, so the track ability of the eye-vergence motion is superior to the one of fixed hand-eye configuration. In this report merits of eye-vengence visual servoing for pose tracking have been confirmed through frequency response experiments.

Introduction

Nowadays, in the field of robot vision, a control method called a visual servoing attracts attention [1]-[4], by which the motion of robot is expected to be applied to changing and unknown environment. The visual servoing is a technique to control robots using information from vision sensor in a feedback loop. In order to improve the recognition ability of visual servoing, many methods are proposed, such as using stereo camera [5], multitude cameras [6]. These methods obtain different views to observe an object by increasing the number of cameras.

An eye-vergence visual servoing system, where the visual servoing controller of the hand and the eye-vergence is separated independently, is said to be superior than fixed ones [7], which have been reported in [1]-[4]. When humans keep tracking a moving object, they may keep up to the object in case of the object moving slowly, but when the object becomes moving faster and faster, human's face cannot be kept positioned squarely to the object, while human's eye can still keep staring at the object because of its small mass and inertial moment. This advantage of eye-vergence can be called "dynamical merit." This merit of eye-vergence concerning dynamical effects to keep tracking a moving target in the camera's view is deemed to be important and useful. Needless to say in visual servoing application, keeping closed loop of visual feedback is vital from a view point of closed loop control stability.

To verify the dynamical superiority of eye-vergence system by real eye-vergence robot system, in this report frequency response experiments where target object moves with sinusoidal time profile have been conducted. In our research before [7], we have evaluated the effects of eye-vergence visual servoing system through approaching motion to a target, in which the desired time-varying pose relation between hand and target was given. But on the view point of above mentioned dynamical merit of hand-eye-vergence, it has yet to be affirmed experimentally. Then we discuss the performance of the eye-vergence system on the view point of how the system improves dynamical stability and trackability against sinusoidal motion of the target by frequency analyses, clarifying that the eye-vergence system has superior stability and trackability performances in pose tracking dynamical motions.

Real-time Pose Tracking "1-step GA"

For real-time visual control purposes, we employ Genetic Algorithm(GA), in a way denoted as "1-Step GA" [8] evolution, in which the GA evolutional iteration is applied several times under 33ms that is video image input period to the newly input image. While using the elitist model of the GA, the position/orientation of a target can be detected in every new image by that of the searching model given by the best individual in the population. This feature happens to be favorable for real-time visual recognition. The current best individual of the GA in every newly input image is output as real-time recognition result. The condition that guarantees the convergence of "1-Step GA" to moving target is that the evolving speed to the solution in the dynamic images should be faster than the speed of the target object in the successively input images. Our current computer system allows to evolve the "1-step GA" 12 times within 33 ms-video rate, 30 frames are input in one second.

Hand & Eye-vergence Visual Servoing Controller

The block diagram of our proposed hand & eye-vergence visual servoing controller is shown in Fig.1.

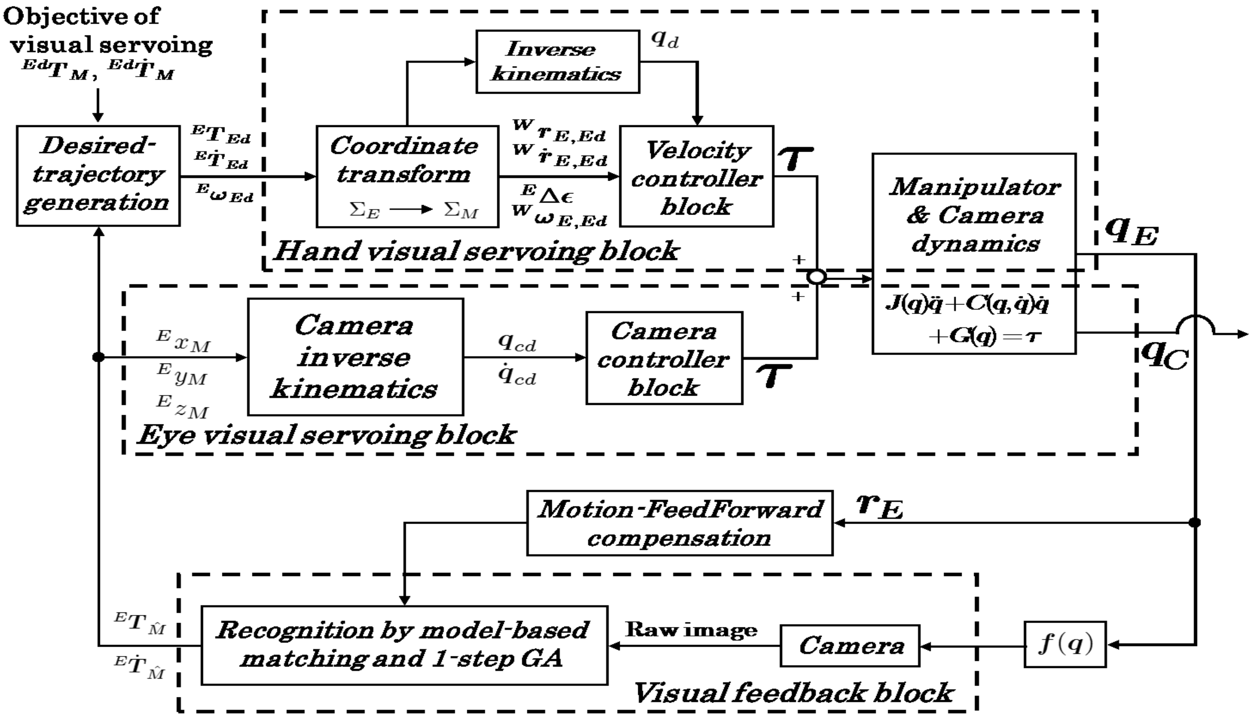

Fig. 1 Block diagram of the hand visual servoing system

The hand-visual servoing is the outer loop. Based on the above analysis of the desired-trajectory generation, the desired hand velocity ${}^{W}\dot{\boldsymbol{r}}_d$ is calculated as,

$$ {}^{W}\dot{\boldsymbol{r}}_d = \boldsymbol{K}_{PP}\,{}^{W}\boldsymbol{r}_{E,Ed} + \boldsymbol{K}_{VP}\,{}^{W}\dot{\boldsymbol{r}}_{E,Ed} \,, \tag{1} $$

where ${}^{W}\boldsymbol{r}_{E,Ed}$, ${}^{W}\dot{\boldsymbol{r}}_{E,Ed}$ can be calculated from homogeneous Matrix connecting End-effector coordinate $\sum_E$, ${}^{E}\boldsymbol{T}_{Ed}$ and ${}^{E}\dot{\boldsymbol{T}}_{Ed}$. $\boldsymbol{K}_{PP}$ and $\boldsymbol{K}_{VP}$ are positive definite matrix to determine PD gain. The desired hand angular velocity ${}^{W}\omega_d$ is calculated as,

$$ {}^{W}\omega_d = \boldsymbol{K}_{PO}\,{}^{W}\boldsymbol{R}_E\,{}^{E}\Delta\varepsilon + \boldsymbol{K}_{VO}\,{}^{W}\omega_{E,Ed} \,, \tag{2} $$

where ${}^{E}\Delta\varepsilon$ is a quaternion error calculated from the pose tracking result, and ${}^{W}\omega_{E,Ed}$ can be computed by transforming into variables on base coordinates of $\sum_W$ using ${}^{E}\boldsymbol{T}_{Ed}$ and ${}^{E}\dot{\boldsymbol{T}}_{Ed}$. Also,

K_{PO} and K_{VO} are suitable feedback matrix gains. We define the desired hand pose as ${}^{W}\Psi_d^T = \left[{}^{W}r_d^T, {}^{W}\varepsilon_d^T\right]^T$

The desired joint variable $q_d = [q_{1d},...,q_{7d}]^T$ and $\dot{q}_d$ is obtained by

$$q_d = f^{-1}\left({}^{W}\Psi_d^T\right) \tag{3}$$

$$\dot{q}_d = K_{PJ}(q_d - q) + K_E J_E^+(q)\begin{bmatrix} {}^{W}\dot{r}_d \\ {}^{W}\omega_d \end{bmatrix} \tag{4}$$

where $f^{-1}\left({}^{W}\Psi_d^T\right)$ is the inverse kinematic function and $J_E^+(q)$ is the pseudo-inverse matrix of $J_E(q)$, and $J_E^+(q) = J_E^T(J_E J_E^T)^{-1}$. K_{PJ} is P positive gain and K_E is feedforward gain. The hardware control system of the velocity-based servo system of PA10 is expressed as

$$\tau = K_{SP}(q_d - q) + K_{SD}(\dot{q}_d - \dot{q}) \tag{5}$$

where K_{SP} and K_{SD} are symmetric positive definite matrices to determine PD gain. The eye-vergence visual servoing loop is depicted at the inner loop of the visual servoing system shown in Fig. 1.

In this paper, we use two pan-tilt cameras for eye-vergence visual servoing. Here the positions of cameras are supposed to be fixed on the end-effector. For camera system, q_8 is tilt angle, q_9 and q_{10} are pan angles, and q_8 is common for both cameras.

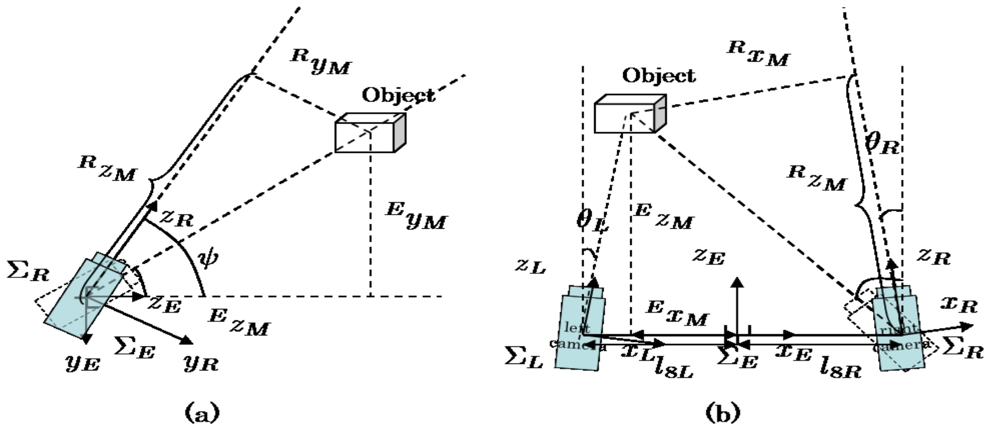

Fig. 2 Calculation of tilt and pan angles

As it is shown in Fig. 2 (a) and (b), ${}^{E}x_{\hat{M}}$, ${}^{E}y_{\hat{M}}$, ${}^{E}z_{\hat{M}}$ express position of the detected object in the end-effector coordinate. The desired angle of the camera joints are calculated by:

$$q_{8d} = a\tan 2({}^{E}y_{\hat{M}}, {}^{E}z_{\hat{M}}) \tag{6}$$

$$q_{9d} = a\tan 2(-l_{8R} + {}^{E}x_{\hat{M}}, {}^{E}z_{\hat{M}}) \tag{7}$$

$$q_{10d} = a\tan 2(l_{8L} + {}^{E}x_{\hat{M}}, {}^{E}z_{\hat{M}}) \tag{8}$$

where $l_{8L} = l_{8R} = 120[mm]$ that is the camera location. The controller of eye-visual servoing is given by

$$\dot{q}_{8Cd} = K_P(q_{8d} - q_8) \tag{9}$$

$$\dot{q}_{9Cd} = K_P(q_{9d} - q_9) \tag{10}$$

$$\dot{q}_{10Cd} = K_P(q_{10d} - q_{10}) \tag{11}$$

where K_P is positive control gain.

Because the motion of camera motor is an open loop, we can only make it rotate a certain degree without getting the actual angle during the rotation, which can not make us get the accurate camera angle. So the desired camera angles are input in every 33ms, and the input is limited to a certain value.

Experiment of Hand & Eye-vergence Visual Servoing

In this part, analyses of real-time pose tracking performance of hand eye-vergence system are extended using experiments of frequency responses.
The initial hand pose is defined as Σ_{E_0}, and the initial object pose is defined as Σ_{M_0}. The homogeneous transformation matrix from Σ_W to Σ_{E_0} and from Σ_W to Σ_{M_0} are:

$$ {}^{W}\boldsymbol{T}_{E_0} = \begin{bmatrix} 0 & 0 & 1 & -890[\boldsymbol{mm}] \\ -1 & 0 & 0 & -150[\boldsymbol{mm}] \\ 0 & -1 & 0 & 450[\boldsymbol{mm}] \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{12} $$

$$ {}^{W}\boldsymbol{T}_{M_0} = \begin{bmatrix} 0 & 0 & -1 & -1435[\boldsymbol{mm}] \\ 1 & 0 & 0 & -150[\boldsymbol{mm}] \\ 0 & -1 & 0 & 540[\boldsymbol{mm}] \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{13} $$

where the above relations between Σ_{M_0}, Σ_{E_0}, Σ_W are depicted in Fig. 3. The target object moves according to the following time function as:

$$ {}^{M_0}\boldsymbol{x}_M(\boldsymbol{t}) = -150\cos(\omega \boldsymbol{t})[\boldsymbol{mm}] \tag{14} $$

The relation between the object and the desired end-effector is set as:

$$ {}^{Ed}\Psi_M = [0,-90[\boldsymbol{mm}],545[\boldsymbol{mm}],0,0,0] \tag{15} $$

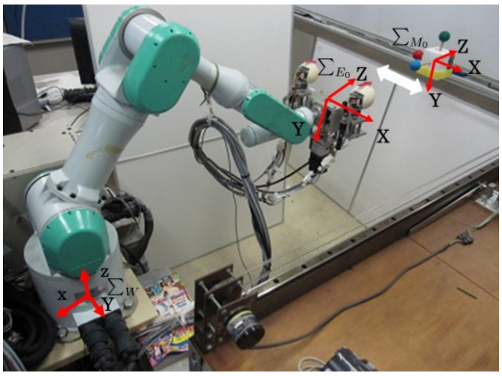

Fig. 3 Coordinate system

In Fig. 4, we show the results of our experiments which gave the position and orientation of the object to the robot directly. We change the ω=0.209, to ω=0.314, ω=0.419, ω=0.628 and ω=1.256, and get the data of the gazing point of the cameras in the eye-vergence system and the tracking ability of the end-effector of the fixed camera system separately. Here only the datas of ω=0.314, ω=0.628, ω=1.256 are shown in Fig. 4 (a), (b), (c). We did each experiment for 60s at each ω above, and got the average delay time and the amplitude to draw the frequency response curve. The amplitude-frequency curve and the delay frequency curve are shown in Fig. 4 (d) and (e). From Fig. 4 (d), it is obvious that the curve of the end-effector is always below the curve of the gazing point, and we can see that the amplitude of the gazing point is more closed to the target object than the end-effector. From Fig. 4 (e), the curve of the end-effector is also below the curve of the gazing point, which means that the delay of the end-effector is bigger than the gazing point. We conducted experiments for x-position, 3-Dof position, and 6-Dof position/orientation which are recognized by the cameras respectively, and here only show the result of 6-Dof in Fig. 5. When the target object moves slowly, both hand and cameras can keep tracking with it, as shown in Fig. 5 (a). While, as the raise of the velocity of the target object, the hand can not keep tracking with it, but cameras can gaze at the object every time, as shown in Fig. 5 (b), (c). From Fig.5 (d), (e), we can see that the gazing point has smaller amplitude error and phase delay which means eye-vergence system can observe the object better, even if the object's position and orientation are recognized by camera (6-Dof).

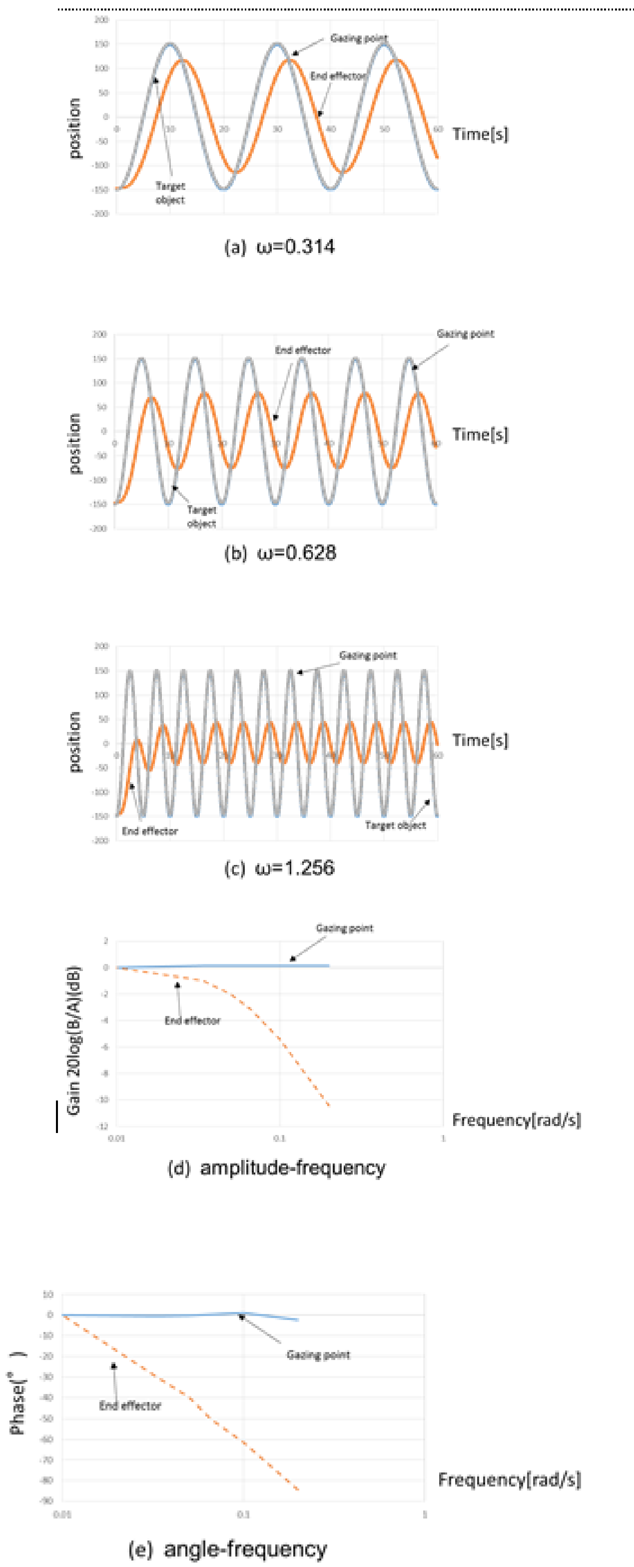

Fig. 4: True object's pose is directly given to the system, then the recognition error is deemed as zero, so in this figure we can see only the error caused by closed-loop dynamics eliminating the pose-tracking errors.

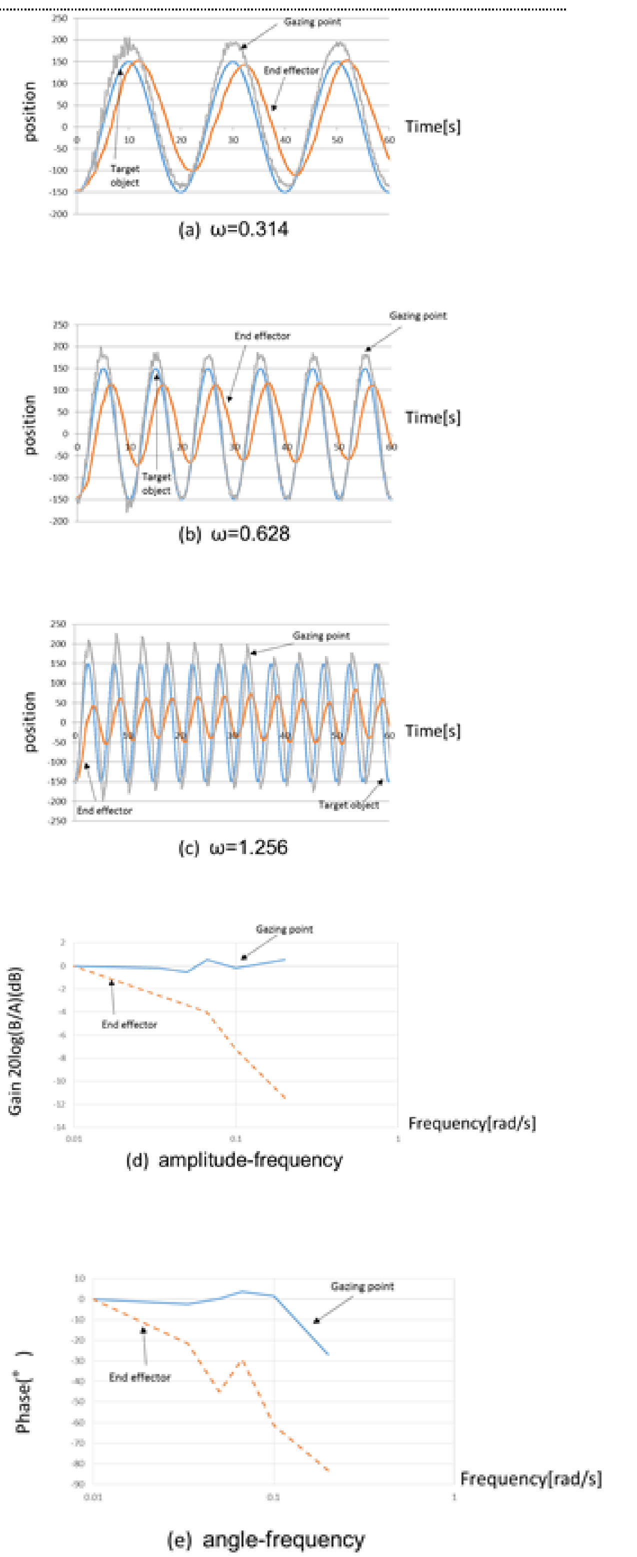

Fig. 5: The object’s position and orientation are estimated through “1-step GA”, then they are informed to the visual servoing controller as shown Visual Feedback Block in Fig.1. Then the frequceny response results in this figure include robot's dynamics and pose-tracking dynamics.

Conclusion

In this paper, the hand-eye-vergence visual servoing system, that eyes can rotate independently with its' control system separated from hand control system, is stated. The trackability is analysed through experiment of frequency response, where the moving target in lateral direction is recognized with "1-step GA".

Based on the result of the experiment, we have analysed the trackability, amplitude-frequency and phase-frequency responses of the cameras of the eye-vergence system under moving object with different angular velocity. Compared with hand of robot, eyes can keep up with fast-moving object (ω=1.256). That means the trackability of eye-vergence system is superior than the one of hand's.

References

[1] S.Hutchinson, G.Hager, and P.Corke, "A Tutorial on Visual Servo Control", IEEE Trans. on Robotics and Automation, vol. 12, no. 5, pp. 651-670, 1996.

[2] P.Y.Oh, and P.K.Allen, "Visual Servoing by Partitioning Degrees of Freedom", IEEE Trans. on Robotics and Automation, vol. 17, no. 1, pp. 1-17, 2001.

[3] E.Malis, F.Chaumentte and S.Boudet, "2-1/2-D Visual Servoing", IEEE Trans. on Robotics and Automation, vol. 15, no. 2, pp. 238-250, 1999.

[4] P.K.Allen, A.Timchenko, B.Yoshimi, and P.Michelman, "Automated Tracking and Grasping of a Moving object with a Robotic Hand-Eye System", IEEE Trans. on Robotics and Automation, vol. 9, no. 2, pp. 152-165, 1993.

[5] W. Song, M. Minami, Y. Mae and S. Aoyagi, " On-line Evolutionary Head Pose Measurement by Feedforward Stereo Model Matching " , IEEE Int. Conf. on Robotics and Automation (ICRA), pp. 4394-4400, 2007.

[6] J. Stavnitzky, D. Capson, " Mutiple Camera Model-Based 3-D Visual Servoing " , IEEE Trans. on Robotics and Automation, vol. 16, no. 6, pp. 732-739, 2000.

[7] Wei. Song, M. Minami, Fujia Yu, Yanan Zhang and Akira Yanou "3-D Hand & Eye-Vergence Approaching Visual Servoing with Lyapunouv-Stable Pose Tracking ", IEEE Int. Conf. on Robotics and Automation (ICRA), pp. 5210-5217, 2011.

[8] W. Song, M. Minami, S. Aoyagi, "On-line Stable Evolutionary Recognition Based on Unit Quaternion Representation by Motion-Feedforward Compensation", International Journal of Intelligent Computing in Medical Sciences and Image Processing (IC-MED) Vol. 2, No. 2, pp. 127-139 (2007).