HAND-EYE COORDINATION FOR OBJECT GRASPING TASK OF HUMANOID ROBOT (BHR-02)

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ABSTRACT

Hand-eye coordination play vital role in object grasping task of humanoid robot. A method proposed for hand-eye coordination addresses four distinct problems i) Integration of vision control and motion control ii) hand-eye coordinate transformation iii) orientation of hand with target object iv) hand-eye localization. For hand localization and to limit the orientation problem a blue colored rectangle block was pasted on the robot hand. The blue colored rectangle block four sides were detected by applying karhunen loeve (K-L) transform, Hough transform and Least Square Error (LSE) methods. For hand-eye coordination a hand-eye model was developed to adjust the position and orientation error for object grasping task. In the hand-eye model world coordinate system was set on right shoulder joint. The position and orientation of the hand was obtained through coordinate transformation from left eye coordinate system to end-effector coordinate system. The results presented in this paper justify the effectiveness of the proposed method.

Keywords: *Humanoid Robot, Hand-eye Model, Localization, Grasping.*

INTRODUCTION

Traditional approach for fixed based robot is that robot hand-eye system should be completely calibrated with common base reference frame which is difficult and error-prone process for dynamic hand-eye system of humanoid robot[1,2]. One among the important tasks of humanoid robot is to grasp the target object in unstructured environment. There have been several methods proposed to perform visual guided object manipulation task for industrial robots[3,4,5]. Industrial robots are fixed base robots and end-effector is well calibrated to the base frame. A common implicit approach for the industrial robot is that the work space of the industrial fixed base robot is known and target object must be placed within the specified workspace of the end-effector, well calibrated hand-eye system made the grasping task accurate under the guidance of stereo vision as reported in[6,7]. Hand-eye coordination is one of the most impressive human behavior. It depends upon the camera and hand configuration, eye-in-hand configuration environment is less error-prone as compared to dynamic had-eye system configuration. Peter K et al[8] proposed hand-eye coordination system for grasping of moving objects, in this system cameras were fixed on end-effector. Ming Xie[9] addressed the issue of system stability, convergence and complexity when feed back control loop is included in to the system.

Conversely, Humanoid robot hand is a dynamic system of multiple degrees of freedom. It is required to work in unstructured and complex environment unlike fixed-base industrial robot manipulators. Object manipulation task of humanoid robot based on stereo vision guidance   was reported by G. Taylor[10]. In this work the upper body is fixed in a frame which reduces the system complexity. The Sony SDR-4X humanoid formally known as Sony dream robot can play with ball and perform ball-kick task under the visual servo guidance[11]. Successful execution of grasping task performed by a robot hand requires pre shape of an arbitrary object. as reported in[12]. Fixed base robot in which control law has been integrated in to a system that perform tracking and stereo control on single processor is reported in[13].

In this paper the problem of hand-ye coordination of object grasping is divided in four phases i) transportation of hand from home position to the vicinity of target object ii) Orientation of the hand to

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the target object iii) Coarse alignment of hand and target object and iv) Selection of feasible and appropriate grasp mode. Hand-eye coordination is based on flexible combination of Feedforward and feedback visual control strategies. Feedback visual control strategy was important to increase accuracy of the proposed hand-eye system and to compensate weakly calibrated error models[14]. Other related issues must also be considered when developing a visual servoing frame work so that high level grasp planning techniques can be employed if necessary[15,16].

In this research work the target object is a red ball which reduces the orientation and shape complexity of target object. For recognition of the humanoid robot hand in vision system and fix the orientation problem of the hand, a blue colored rectangle block is pasted on the hand.

SYSTEM OVER VIEW

Development in the field of bionics and biomechanics technologies, researchers are inspired to develop a system (humanoid) that not only looks like a human but possess the human like characteristics like seeing, sensing, hearing, and touching. It is requirement of the developed society that a humanoid robot should cooperate with people in daily life activities and act as intelligent agent. Human body is a complex system of complicated structure and muscle movement realization. At present, it is not possible to develop a system to behave and act like a human but up to some extent humanoid robot can act as an intelligent agent and can perform object manipulation task by using state-of-the art technologies. Outlook appearance of humanoid robot (BHR_02) is shown in Figure 1.

Humanoid robot is a complex system of comprising multiple sensors (Cameras, force sensors, torque sensors Hall effect sensors) to sense the environment. This humanoid robot straight walk step is not smaller than that of 0.3 meters and highest speed is of 1.3 kilometer per hour. Table No. 1 shows humanoid robot parametric data.

INTEGRATION OF VISION CONTROL AND MOTION CONTROL SYSTEM

The Humanoid robot (BHR-02) vision based object grasping task implementation was divided in two sub systems, vision system and the motion control system. One computer was used for information processing the other one used for motion control system. The vision system is based on Windows operating system and support the multimedia func-

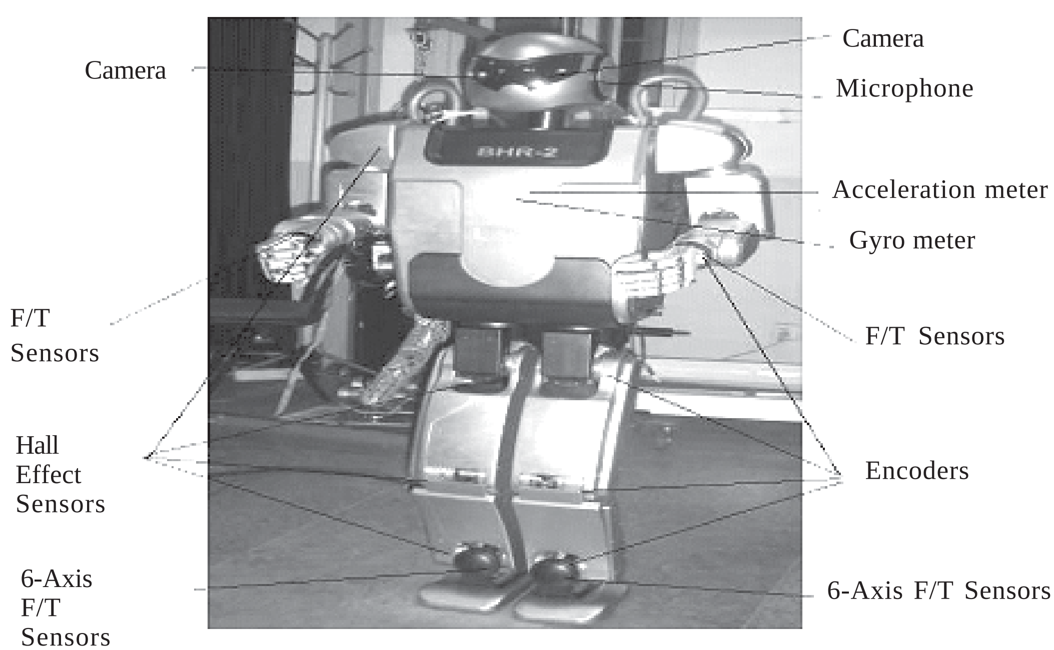

Figure 1: The system overview of Humanoid robot (BHR-02)

Table 1: Specification of humanoid robot

Length (cm)	**Head (Central axis distance)**	**Torso**	**Arm**	**Thai**	**Fore leg**	**Foot**
	20	61.5	60	31.5	31.5	13.5
Weight (kg)	1.2	23.5	8.1	8.7	6.2	2.3

tionality. The control system is Linux and RT-Linux based operating system. The Linux and Rt-Linux is real time operating system that meats all real time requirements of the control system.

The robot vision process is not a real time system to estimate the time required for image processing. The vision processing primary goal is to take image of target scene and extract maximum possible visual information. In order to further enhance the robot functionalities like speech recognition and synthesis system needs multimedia function support.

Communication between two systems is through Memolink card. The memolink card has two parts child card (slave board) and the host card (master board) installed in the visual information processing computer and the motion control computer. The memolink card has the bidirectional read-write RAM memory block (up to 256 Kbytes) for sharing critical resources. This communication has the mutual limitations and relations (At free time only one computer has the priority to carry on the operation). Communication and operation must be incompatible. It is implemented as PC1_busy=1 means computer 1 shows busy, PC2_busy=1 means computer II shows busy. Over all sharing of information between two computers is shown in Figure 2.

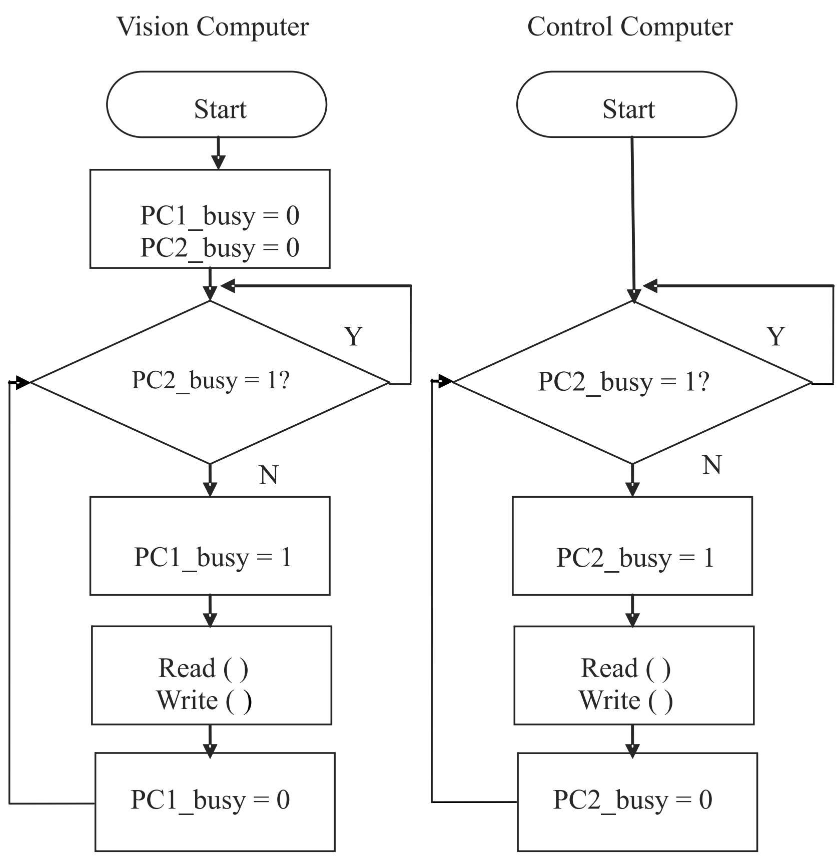

Figure 2: Communication flow in vision computer and control computer

This integrated approach of sharing information has following advantages

- Prior hand shaking is not required and memory block fixed in both computers shares the information to achieve asynchronous communication.
- During read-write operation to the memory block, communication is based on the computer internal PCI bus of enough bandwidth.

HAND-EYE COORDINATION MODEL

Hand-eye coordination is a challenging issue for object grasping tasks of humanoid robot as compared to fixed based industrial robot. Integrated scheme of visual feedback and visual feedforward was adopted in this hand-eye system. Humanoid robot can transport the arm to approach the target object rapidly based on visual feedforward control strategy. Visual feedback loop of the proposed strategy is used for improving accuracy and compensating calibration errors for object grasping task.

Vision system mounted on head of humanoid robot is capable of achieving 3D position information of target object. The detection of target object position and tracking of the target object was done successfully in our previous work[17,18]. For the coordinated work of hand-eye system a hand-eye coordination model was developed. The world coordinate system was decided at the joint of right shoulder of humanoid robot (BHR-02). The transformation from camera coordinate system to world coordinate system and from world coordinate system to end-effector coordinate system was defined by translation and rotation matrix and was presented in[19].

HAND- EYE LOCALIZATION AND ORIENTATION

For object grasping task of humanoid robot it was mandatory to localize the target object and hand in a common video scene. Localization is presented as given below;

A Target object localization

For target object localization system select center of target object, 2D center of object was calculated as given in equation (1)

$$X = \frac{\iint_D x\,\rho(x,y)dxdy}{\iint_D \rho(x,y)dxdy}, \quad Y = \frac{\iint_D y\,\rho(x,y)dxdy}{\iint_D \rho(x,y)dxdy} \qquad (1)$$

Where $\rho(x, y)$ is object surface density and D is the composition at center of gravity.

Surface density is calculated form each pixel intensity value for a specific color (red ball) and a black point of (1x1 pixel) on this red ball is considered as a center of gravity as shown in Figure 3.

Each pixel intensity value of required image can be calculated as given in equation (2).

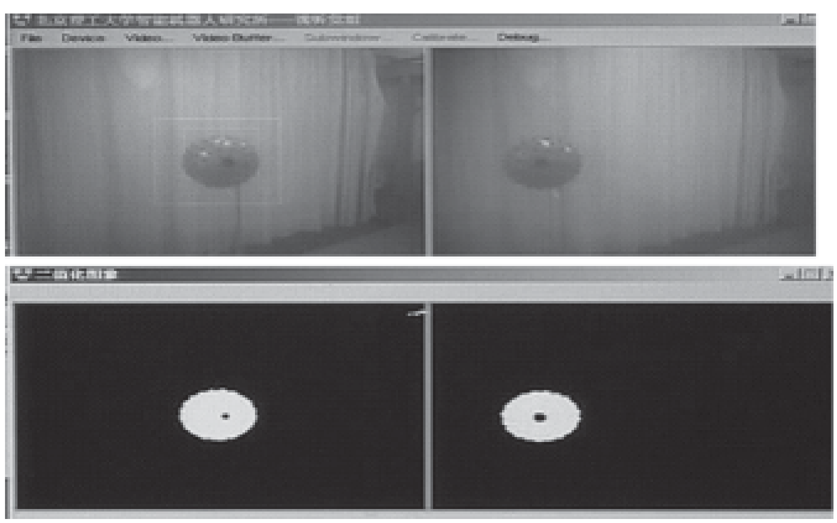

Figure 3: Target object localization

$$X = \frac{\sum_{i=l}^{i=n} x_i \rho(x,y)}{\sum_{i=l}^{i=n} \rho(x,y)}, \qquad Y = \frac{\sum_{i=l}^{i=n} y_i \rho(x,y)}{\sum_{i=l}^{i=n} \rho(x,y)} \tag{2}$$

Where x_j, x_{2n} $\in$ and S is the selected surface area which on target object form a little window, here it takes a value of 1 as given in equation (3)

$$X = \frac{1}{n}\sum_{i=1}^{i=n} x_i, \qquad Y = \frac{1}{n}\sum_{i=1}^{i=n} y_i \tag{3}$$

Figure 3 was result of target object localization. Fist row is the video image captured by cameras and second row is the binary image as result of image processing for localization of the target object.

B Hand Localization

In order to carry on localization of hand a rectangle block of blue color was pasted on the robot hand to recognize the hand position and orientation. Figure 4 shows the robot hand pasted with the blue colored rectangle block of size 56 mm by 35 mm.

C Hand-eye Localization

Stereo geometry, color and shape are the ideal visual candidates for the robot visual servo system. A method combining stereo geometry, color and shape information was applied to separate the target region from the background. At first using the stereo information location of the hand was detected then color information was used to segment the foreground region which was a rough candidate region of the target. This color filter was also used in the ROF (region of foreground) to get the ROIC (Region of Interest Color) region. Finally Hough transformation was used in the ROIC region to detect the target object. In the process of segmentation the candidate region was reduced gradually and approached to the target region[20,21].

Figure 5 presents the original image and its binary image. In this figure target region has been separated from the actual image, separated region still has some noise due to cluttered background. The result of the image segmentation and edge extraction on the colored mark formulates a rectangle block. The feature points extracted were the four sided of a rectangle block. K-L transformation, Hough transformation and least square error (LSE) methods were employed to group the edge point and decide the vertices of the rectangle block. Accurate image coordinates of the feature points of the rectangle block were obtained through line fitting across those feature points. 3D position information of the rectangle block was detected from stereo geometry by applying triangulation law presented in[22].

In the hand-eye coordination process robot hand and the blue colored rectangle block has the rigid connection, orientation of the colored rectangle block and robot hand has one-to-one relationship. Figure 6 shows the orientation relationships between the two coordinate systems in 3D space. In this figure coor-

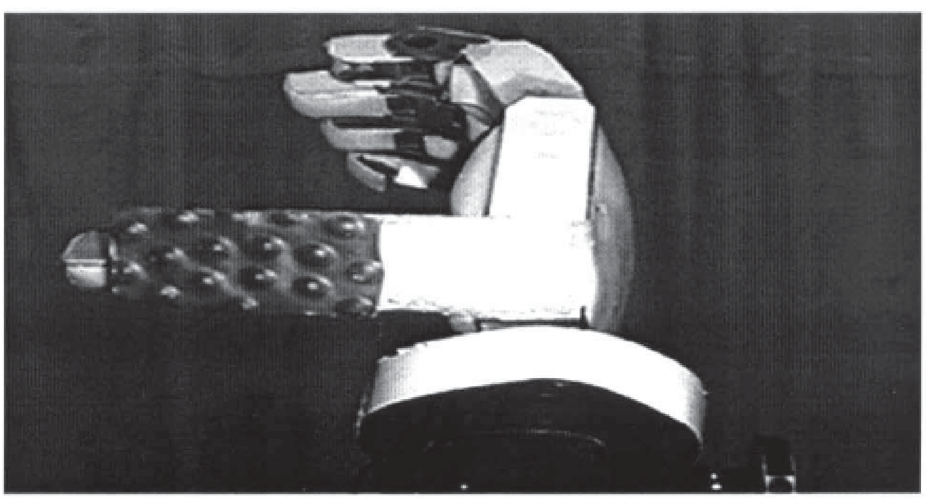

Figure 4: Robot hand with blue rectangle block

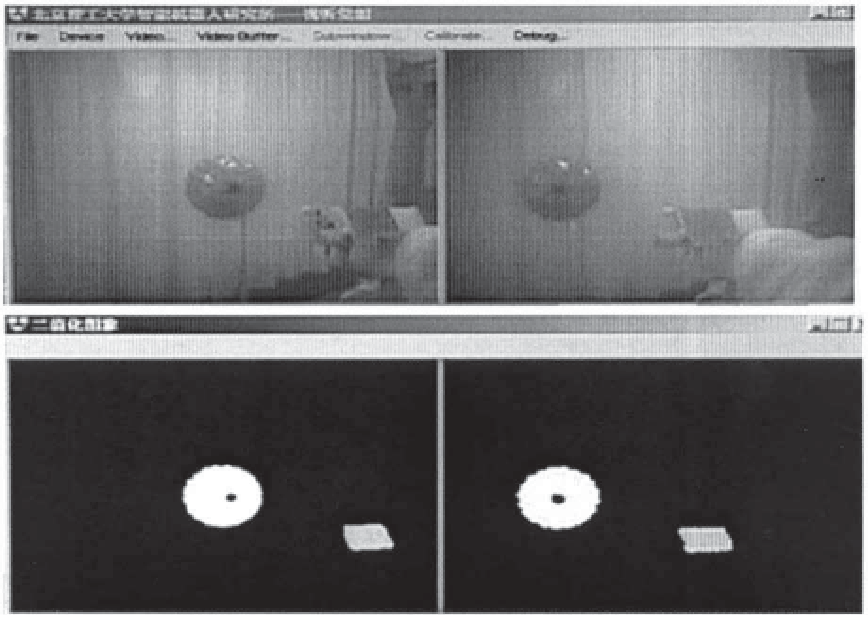

Figure 5: Target region segmentation

dinate $O_7 - x_7 z_7$ presents the end-effctor (hand) palm coordinate system, when the end-effector of humanoid is aligned forward to the target object. The x-axis along lateral of the robot is perpendicular to the hand torso. The z-axis direction is the front of the robot and the y-axis direction is bottom to top of the robot. In figure $O_w - x_w y_w z_w$ presents the world coordinate system.

Coordinate system $O_M - x_M y_M z_M$ shown in figure presents the colored block coordinate system when the end-effector opened forward. Its x-axis lies in the same direction as that of end-effctor (hand) palm direction ($O_7 - x_7 y_7 z_7$) where as its y and z-axis rotate counterclockwise 40° at the origin of end-effector (hand) palm coordinate system. The two coordinate systems in 3D space were at a distances of 90mm on x- axis, 40mm on y - axis and 55mm on z- axis.

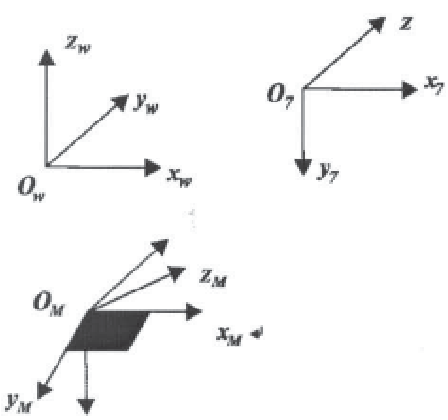

Figure 6: Relationship between the colored rectangle block and the hand coordinate

The orientation between hands palms coordinate system and rectangle colored block coordinate is shown in equation (4)

$$T = \begin{bmatrix} 1 & 0 & 0 & -90 \\ 0 & \cos 40^\circ & \sin 40^\circ & -40 \\ 0 & \sin 40^\circ & \cos 40^\circ & -55 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (4)$$

The orientation of the hand (end-effector) coordinate system can be calculated from the orientation of the rectangle colored block coordinate system.

VISUAL SERVO CONTROL

The Visual Servo control system is a cycle of real-time data processing and decision making. The real-time control process receives the data from visual processing cycle. Vision system complete many sub process of object recognition, position of the target object as will as position of hand. After a visual processing cycle the system should complete the motion control cycle. In the object manipulation process both feed forward and feedback visual servo control approaches were applied, at the transportation stage to move the hand from home position to the visual field of robot head feed forward approach was applied, entire control process is a serial process vision has not been introduce as feedback at transportation stage. At this stage of transportation position and orientation errors were not considered. Position and orientation errors were compensated in the feedback loop when both end-effector (hand) and target object are in the view field of humanoid robot head. The orientation errors are compensated during hand-eye localization process. In the third stage of coarse alignment the linear distance between target object and hand is considered as a visual servo control error function. This error function (E(x)) is defined as distance difference of end-effector (hand) centre 3D position (x (t)) and target object (ball) current position (x_T) information as shown in equation (5).

$$E(x) = x_T - x(t) \quad (5)$$

The simple proportional controller was used to guarantee the index error to decrease progressively, this proportional controller was designed as shown in equation (6)

$$\dot{x}(t) = k \times E(x(t)) = k(x_T - x(t)) \quad (6)$$

Desired velocity ($\dot{x}(t)$) of the hand is computed from hand to target object distance, error is measured as a Cartesian position where as k is proportional constant in the above equation. For the grasping of target object a model based grasping algorithm defined in[21] is used.

EXPERIMENTS

A Vision Control panel

On vision control panel upper row shows the actual video image taken by the stereo vision lower row shows the tracked result as process output. Parameters such as target position, hand position, and image 2D and 3D information are shown on vision control panel. The Vision Control panel also shows position of the target object in left camera image coordinate and position of target object in vision coordinate system as shown in Figure 7.

B 3D localization of hand and target object

In order to obtain 3D position accuracy a pallet of 160x160 pixels and area of 10 cm^2 were selected for experimentation as shown in Figure 8. In Figure 8 Upper row is the actual video image and lower row is the processed binary image.

A series of experiments were carried out to keep the location of end-effector within the precise range of 100 mm from the object to make it easy for grasping the target object. At first hand and target object were placed in the x, y plane and error was measured in z-axis coordinate system as shown in table No. 2. Those errors are due to backlash and complex structure of

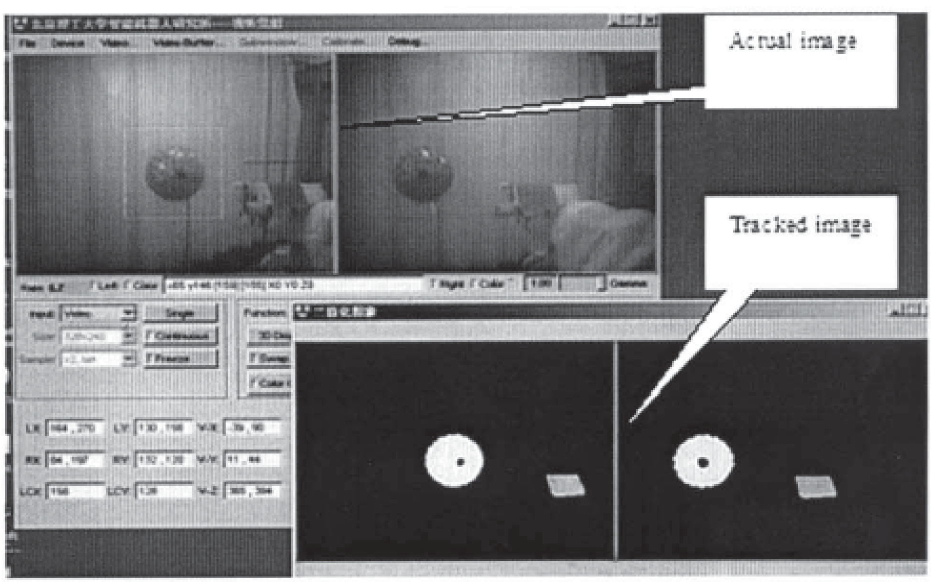

Figure 7: Vision control panel.

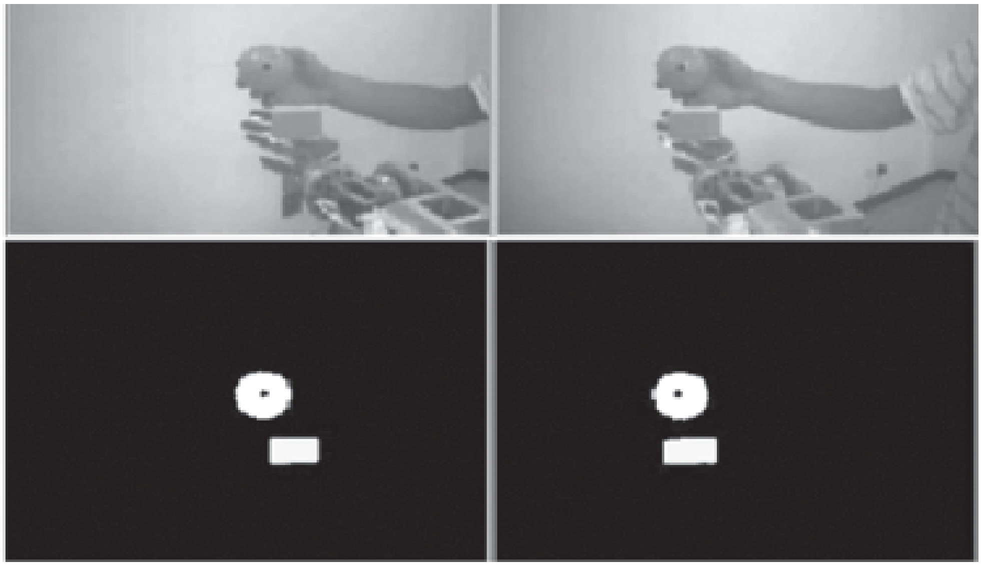

Figure 8: Target objects and hand localization

the hand-eye system. Errors were compensated through feedback loop of visual servo control system.

Table 2: Pallet (red ball) and mark relative measurement in x, y plane

S. No.	Pallet (red ball) Z-axis (mm)	Mark Z-axis (mm)	Difference (mm)	Error (%)
1	164	273	(109-100)/100	9.0
2	167	268	(101-100)/100	1.0
3	163	257	(94-100)/100	6.0
4	161	262	(101-100)/100	1.0

Second time hand and target object was placed in the x, z plane and error was measured in y-axis coordinate system as shown in Table No. 3.

Table 3: Pallet (red ball) and mark relative measurement in x, z plane

S. No.	Pallet (red ball) y-axis (mm)	Mark y-axis (mm)	Difference (mm)	Error (%)
1	606	497	(109-100)/100	9.0
2	599	499	(100-100)/100	0.0
3	593	497	(96-100)/100	4.0
4	587	496	(91-100)/100	9.0

In third setup hand and target object are placed in the y, z plane and error is measured in x-axis coordinate system as shown in Table No. 4.

Table 4: Pallet (red ball) and mark relative measurement in y, z plane

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S. No.	Pallet (red ball) x-axis (mm)	Mark x-axis (mm)	Difference (mm)	Error (%)
1	–360	–265	(95-100)/100	5.0
2	–362	–262	(100-100)/100	0.0
3	–359	–255	(104-100)/100	4.0
4	–360	–270	(90-100)/100	10.0

The result showed that for object manipulation task of humanoid robot deviation error was within tolerance of 10 mm, it is clear that developed hand-eye system was effective for object grasping task.

C Object Grasping experiment

The Object grasping experiment is shown in Figure 9 in the first row of the figure the humanoid robot is forwarding to the target object by walking second row shows the progress of transportation, Coarse alignment and grasping of the target object. Figure 10 shows the vision computer panel during the object grasping task Figure 10 (a) shows the process of target object localization. Figure 10 (b) and (c)

Figure 9: Target object grasping

shows the process of feed forward approach of control strategy, both the target object and hand are in visual field of the humanoid robot head.

Figure 10 (d) (e) (f) shows the execution process of feedback strategy of the visual servo system, when appropriate position of the hand and target object was achieved then model based grasping approach is used to grasp the target object.

During the grasping process the humanoid robot arm position of six joints is shown in Figure 11.

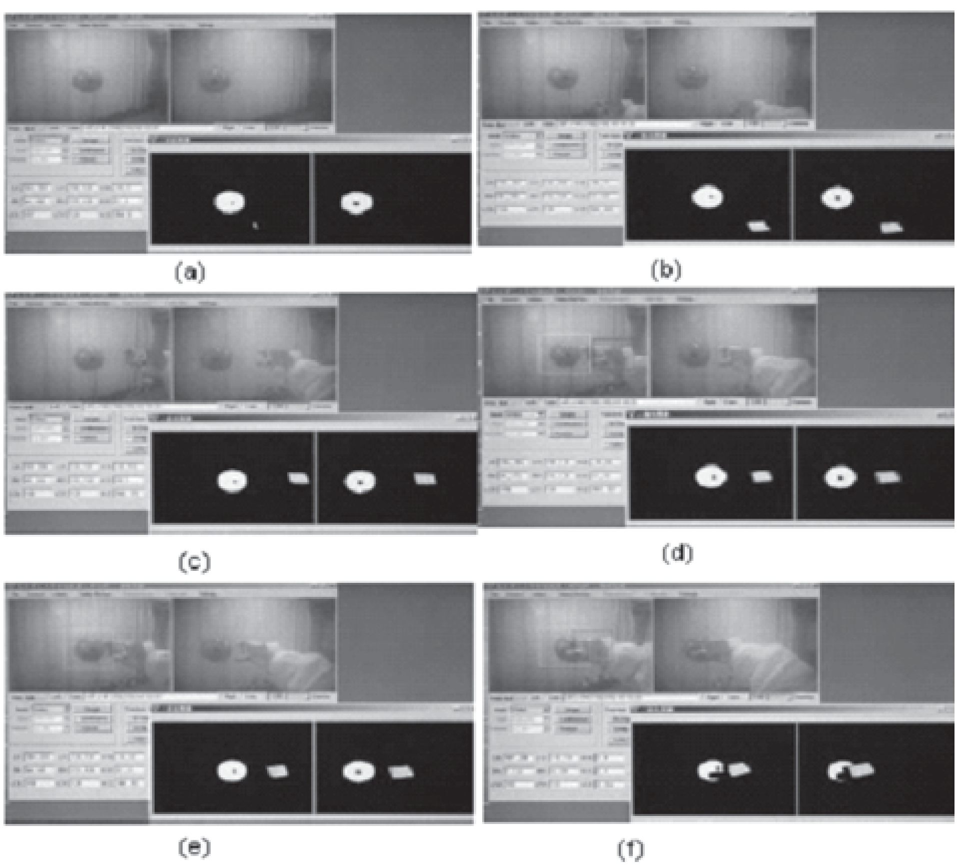
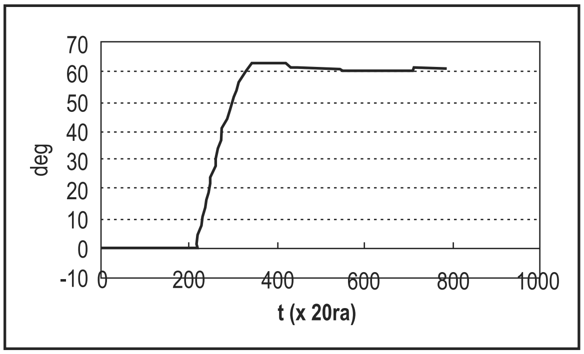
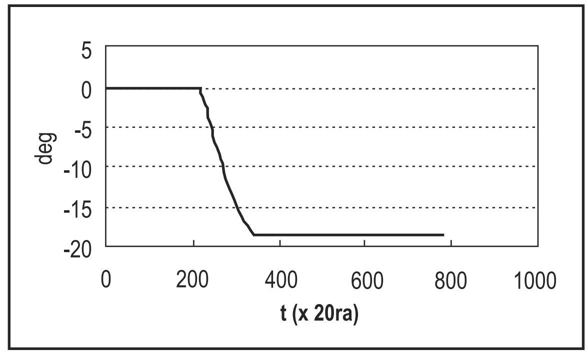


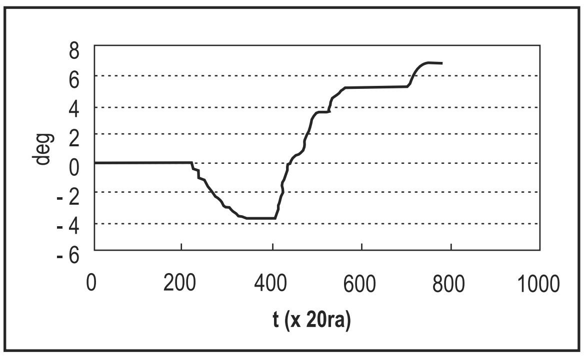
Figure 10: Vision computer panel shows object grasping process



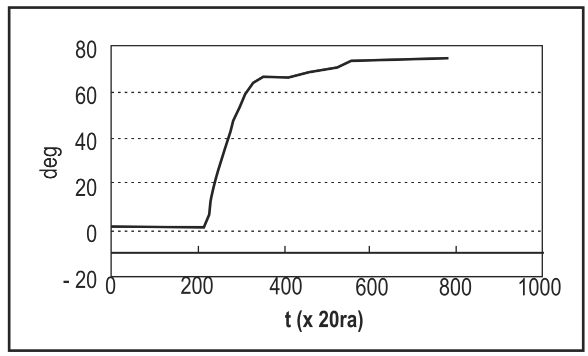
(a) First joint movement



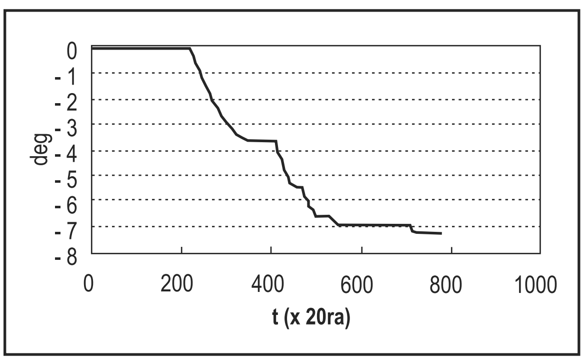
(b) Second joint movement



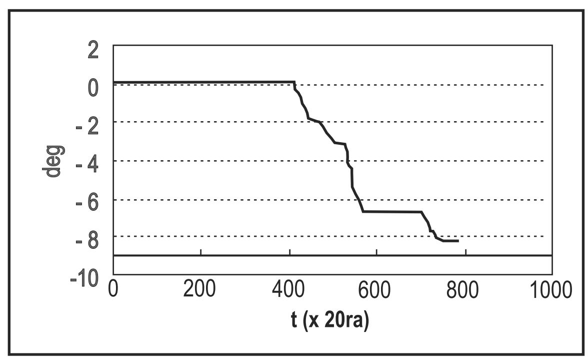
(d) Third joint movement



(e) Fourth joint movement



(f) Fifth joint movement



(g) Sixth joint movement

Figure 11: Trajectory of humanoid robot right arm each joint during object grasping process

The vision scanning cycle was about 200ms. Arm transportation was achieved in 400 ms (hand movement form initial position to vision field of the humanoid Robot) and for the coarse alignment (both hand and target object are in vision field) 400 ms are required and finally object grasping task was achieved successfully

CONCLUSION

This paper addressed the issue of hand-eye coordination for object grasping task of the humanoid robot. Kinematics errors during the hand eye coordination are compensated through the visual feedback loop of the control system. For a dynamic model of the hand-eye system kinematics errors and pose errors can not be accommodated by conventional kinematics error methods, because after walking several steps the humanoid robot head joints and arm joints deviate off form their home position.

Target object grasping task of the humanoid robot is a vision based real time grasping, in which control scanning cycle is much less then vision scanning cycle. The Vision scanning cycle is 200 ms where as the servo control cycle is about 3 ms thus guarantees real time object grasping.

Visual servoing is independent of stereo calibration process, visual feedback component of the proposed visual servo control compensate calibration as well as backlash errors. Proposed visual servo control increases the accuracy and robustness of object grasping.

At the time of experimentation home position of the pan tilt head and zero position of the arm joints are set manually, when humanoid robot walks towards the target object, its head joints and arm joints deviate off the home positions. In this experiment tilt joint deviation is considered because pan joint has little effect in straight walk experiment, the position error caused by the head joint deviation is expressed in equation (7).

$$Z_t = g_1(Sin\theta_1) + g_2(Sin\theta_2) + aSin(\Delta\theta_2) \quad (7)$$

In this equation $g_1(Sin\theta_1)$ is the polar space deviation of tilt joint when $\Delta\theta_1 > 90^0$ and $g_2(Sin\theta_2)$ is polar space deviation of tilt joint when $\Delta\theta_2 < 5^0$ where α is compensation vector so that tilt joint of the head should not overshoot the boundaries

When $\Delta\theta_2$ is less then 5 degree and $\Delta\theta_1$ is greater then 90 degree such deviation affects seriously on position estimation and it can be compensated by visual feedback control loop.

In this experimental study target object is a ball there is no orientation problem and a color mark is pasted on the hand of the humanoid robot to limit the orientation error. In future orientation of the target object, detection of the object of interest among multiple objects in a common scene and orientation of the hand without colored mark are the crucial issues of hand-eye coordination for object grasping task.

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