# Object Manipulation with Robot Arm Using Motion Stereo and Tactile Sensor

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***Abstract***: At present, the autonomous robots that move under the dynamic environment are few. The robot that moves under the limited environment is most. If the robot acts flexibly is developed without human's aids even if the environment changes, human's load can be reduced. It is necessary to make the robot recognize the environment to have it act in various environments. We aim at developing a robot arm that recognizes the environment around it and the holding and the movements of the object. The object recognition is performed based on shape information. A hybrid control is constructed by combining a torque control (the main control), an image processing and tactile sensors to adapt to the change of the environment flexibly.

***Keywords***: Robot arm, Image processing, Motion stereo, Tactile sensor

## I. Introduction

At present, autonomous robots that move under the dynamic environment are few. If the robot that accepts a goal requirement from a user and flexibly attains the goal is developed without human intervention under dynamic environment, the robot will surely help us.

A robot has to recognize the environment to moves autonomously in a dynamic environment. Moreover, it is important for the robot arm to recognize and grasp an object. Image processing is use to recognize both environment and objects.

We aim at constructing a robot which recognizes the environment around itself with a CCD camera mounted inside the hand and grasps and manipulates the object specified by the user. To measure the distance from the arm to the object, a motion stereo is exploited but it is important to locate the camera appropriately as the camera is constrained with the robot arm machinery. To grasp the target object a hybrid control is conducted that collaborates among a torque control, image processing and tactile sensor.

We aim at developing the robot that grasps and delivers the target object to a user by grasping it with a hand mounted on the mobile robot.

## II. Construction of This System

Figure 1 shows the system that controls the robot arm. A motor, camera and tactile sensor are controlled with a laptop computer (Linux OS). Table 1 shows the max torque, reduction ratio of the motor and resolution of an encoder.

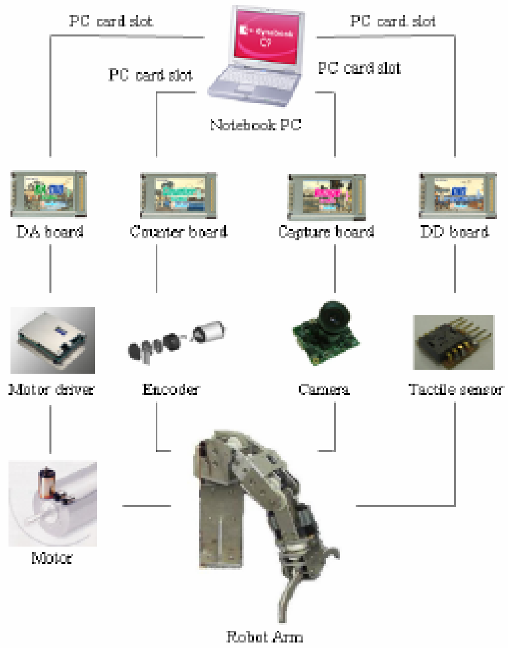



**Figure.1 System Configuration**

**Table 1 Torque, Reduction Ratio and Resolution**

| Region | Max Torque [mNm] | Reduction Ratio | Resolution |
|---|---|---|---|
| Finger | 3.24 | 29 : 1 | 256 |
| Wrist | 3.24 | 29 : 1 | 256 |
| Elbow | 28 | 72 : 1 | 512 |
| Shoulder | 28 | 80 : 1 | 512 |
| Body | 44 | 100 : 1 | 512 |

## III. Control of Robot Arm

### 1. Torque Control

Torque control is a method of controlling the output torque of a motor. To control the output torque, it is necessary to control the current of a motor.

Assuming that the motor torque is $T$ [Nm], the torque constant is $Kt$ [Nm/A] and the current that flows to a motor is $i$ [A], the relation between the torque and the current can be shown as follows:

$$T = Kt \cdot i \tag{1}$$

The counter electromotive force $V_{rev}$ [V] proportional to revolution $n$ [rpm] is generated because a motor generates electricity when it rotates.

$$V_{rev} = \frac{n}{Kn} \tag{2}$$

$Kn$ [rpm/V] is a rotational number constant. The voltage of $V$-$V_{rev}$ [V] is impressed to the motor by considering this counter electromotive force. According to Ohm's law, the current that flows to the motor is

$$i = \frac{V - V_{rev}}{R} \tag{3}$$

$R$ [Ω] is resistance between terminals of the motor. The torque of the motor can be calculated from the above-mentioned expression as follows:

$$T = Kt \cdot \frac{V - n/Kn}{R} \tag{4}$$

An actual output torque changes depending on the reduction ratio. It follows that adequate control of voltage can control the output torque.

### 2. Calculation of Angle of Joint

To move the robot arm to the target position, it is necessary to calculate the angle of each joint using the inverse kinematics.

The inverse kinematics can be calculated by using trigonometric function because the number of links is a few and the machinery of the robot arm is simple. Moreover, we provide beforehand the robot with the solution because the solution cannot be calculated when the robot arm became straight.

Figure 2 shows states of a robot arm seen from the top and side respectively. $\theta_0$, $\theta_1$, and $\theta_2$ are angles of a body, shoulder and elbow respectively.

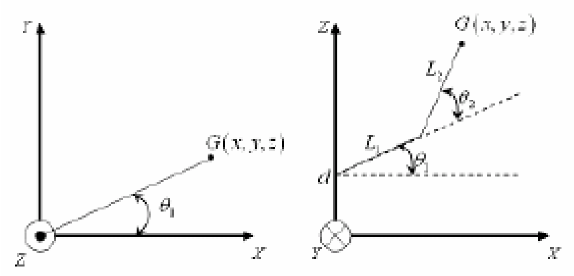



**Figure.2 Inverse Kinematics**

The angle of each joint is calculated from Figure 2 as follows:

$$\theta_0 = \tan^{-1}\frac{y}{x} \tag{5}$$

$$\theta_1 = \tan^{-1}\frac{z-d}{x} - \cos^{-1}\frac{L_1^2 + L^2 - L_2^2}{2 \cdot L_1 \cdot L_2} \tag{6}$$

$$\theta_2 = \pi - \cos^{-1}\frac{L_1^2 + L_2^2 - L^2}{2 \cdot L_1 \cdot L_2} \tag{7}$$

Set $L = \sqrt{x^2 + y^2 + (z-d)^2}$ .

### 3. Object Recognition

If object recognition is performed based on color information, miss-detection is unavoidable as light condition may affect the color of an object or it is impossible to segment images of deferent objects with the same color. Consequently, the object to be grasped should be recognized based on shape information. Geometrical components such as circle and straight line, etc. of the object are retrieved from the edge image. Of course, whenever color information is available, it will be exploited to augment object recognition results. Figure 3 shows the flowchart of object recognition.

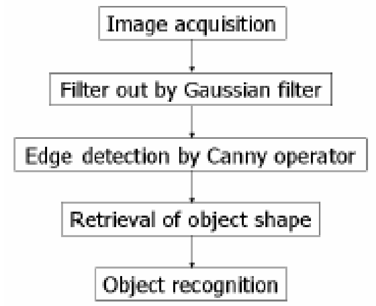



**Figure.3 Flowchart of Object Recognition**

### 4. Motion Stereo

It is difficult to acquire the position of an object because only a single camera is mounted inside the hand. Therefore, the stereo view must be obtained by moving the camera in horizontal or perpendicular direction. A three-dimensional position of the object is calculated by using the principle of triangulation (Fig.4).

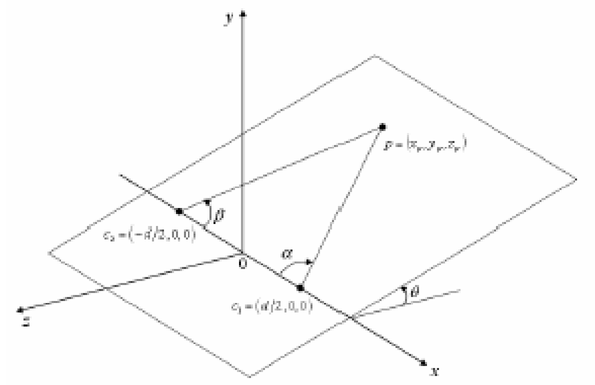


**Figure.4 Principle of Triangulation**

Let assume the position of the physical object to be at a point *p*, and angle between the x-z plane and the plane consisting of three points $C_1$, $C_2$ and $p$ to be $\theta$. Let $l$ be the length of a perpendicular line drawn from point $p$ into $x$ axis, we have:

$$\tan\alpha = \frac{l}{d/2 - x_p} \quad (8)$$

$$\tan\beta = \frac{l}{d/2 + x_p} \quad (9)$$

It follows that:

$$x_p = \frac{d(\tan\alpha - \tan\beta)}{2(\tan\alpha + \tan\beta)} \quad (10)$$

$$l = \frac{d\tan\alpha\tan\beta}{\tan\alpha + \tan\beta} \quad (11)$$

For $y_p = l\sin\theta$ and $z_p = -l\cos\theta$, coordinates of the target object and the distance can be obtained as follows:

$$y_p = \frac{d\tan\alpha\tan\beta\sin\theta}{\tan\alpha + \tan\beta} \quad (12)$$

$$z_p = \frac{d\tan\alpha\tan\beta\cos\theta}{\tan\alpha + \tan\beta} \quad (13)$$

### 5. Tactile Sensor

The tactile sensor judges whether a target object can be grasped appropriately. The tactile sensor was devised newly using a positional sensor used in the optical mouse and LED. [3] A grayscale image of a skin under a positional sensor is obtained with a LED, and is converted into the sense of touch (Fig.5).

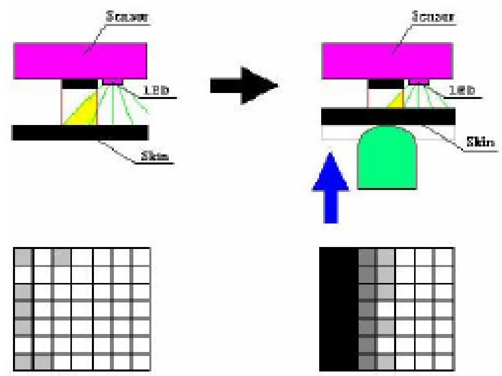



**Figure.5 Contact Judgment**

## IV. Experiment and Result

### 1. Verification of Arm Control Program

We verified the correctness of a torque controlling arm program by comparing a specified goal position with the position attained with an arm. The experiment was conducted in the environment with no obstacles. Figure 6 shows the difference between a specified target coordinates and actual attainment coordinates.

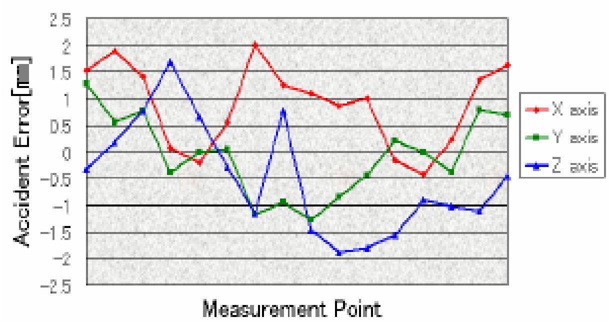



**Figure.6 Comparison of Coordinates**

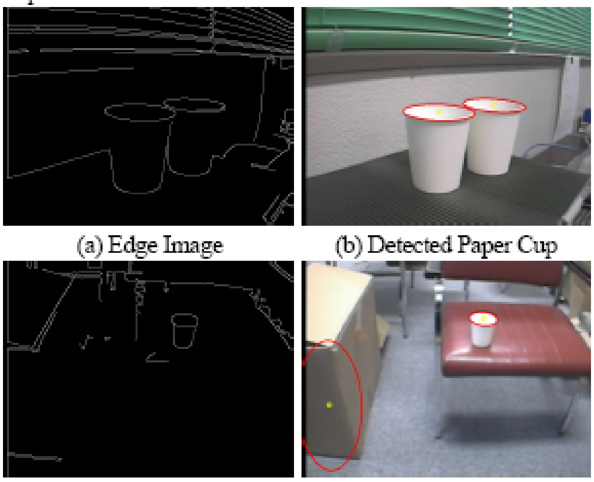
The maximum error was 2.01mm in *X* axis, -1.28mm in *Y* axis, and -1.88mm in *Z* axis, respectively.

### 2. Object Recognition

Whether the object to be grasped with the arm can be appropriately recognized is verified. The target object is a paper cup put within both the range of a camera and the reach of the arm.

The recognition result in a simple environment containing a few objects is shown in Figure 7 (a) and (b). The result in the environment with many objects is shown in Figure 7 (c) and (d).

In Figure 7 (d), an ellipse is successfully detected to find a paper cup but a wrong ellipse is also found. To reject the wrong one, shape and size information on a cup must be referred.



(a) Edge Image (b) Detected Paper Cup

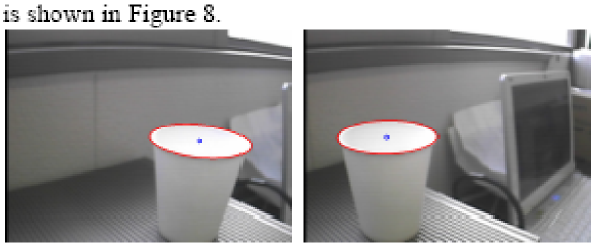
(c) Edge Image (d) Detected Paper Cup

**Figure.7 Recognition Result**

### 3. Distance Measurement

The distance between a target object and the end point of a robot arm was measured with a horizontal motion stereo measurement.

The acquired image captured with the motion stereo is shown in Figure 8.



(a) Left Image (b) Right Image

**Figure.7 Motion Stereo**

The distance from the camera to the front of the paper cup is 19 centimeters, and from the camera to the back of the paper cup is 25 centimeters. The principle of the triangulation is used, and the calculated distance to an ellipse center is 21 centimeters. This result is appropriate.

## V. CONCLUSION

In this research, we achieved followings: making a tactile sensor with a positional sensor used in the optical mouse, calculation of distance to the target object, object recognition based on shape information, and torque control important to drive a robot arm. However, the mis-detection of the object was caused in the environment including a lot of objects. At present it is difficult to grasp an object precisely.

As a rough distance between the target object and the arm is measured with a stereo camera mounted on a mobile robot though the method is not described here, it is possible to make a robot move within the reach of an arm. Then a motion stereo can calculate both distance to the target and its coordinates with a camera in the robot hand. Next, the target is grasped with a robot hand to bring it near a user to make the user grasp it with his hand.

Finally, we aim developing a mobile robot that can move to various places while recognizing and holding various objects with a hand mounted on the robot.

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