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A Ball-Throwing Robot with Visual Feedback

Jwu-Sheng Hu, Ming-Chih Chien, Yung-Jung Chang, Shyh-Haur Su, and Chen-Yu Kai

***Abstract*—This work presents a robot system for throwing a ball into a basket. A stereo vision system is used to measure the position of the target in 3D space. The ball-throwing transformation between the input command of the robot system and the target position is built by cubic polynomial. Through ball-throwing transformation with visual feedback for target position, the robot throws the ball toward the target which can randomly move to everywhere in visible field. The percentage of successful ball-throwing for target within three meters was found to be approximately 99%.**

I. Introduction

RECENT years, robotics systems work everywhere in our life and intelligent robots require sensor-based control and learning ability to perform complex operations and to deal with uncertainty in the environment. An example of a sensor-based feedback is a visual feedback that utilizes information from camera images. Desired information can be extracted from the images to observe, recognize, and locate stationary parts. In this video, we present a robot system for throwing a ball. A stereo vision system is used to measure the position of the target in 3D space. A cubic polynomial is used to build the ball-throwing transformation between the input command of robot system and target position. Through ball-throwing transformation, the robot throws the ball toward the target which can randomly move to everywhere in visible field.

Calibration is essential to acquire precise intrinsic parameters of the two cameras and geometry relations between these two cameras in stereo vision. Bouguet provides a powerful toolbox named Camera Calibration Toolbox for Matlab [1], which is inspired from Zhang's work [2] and can not only calibrates monocular camera but also calibrates stereo camera. Furthermore, in order to obtain the transformation from the robot to the stereo vision, a calibration board is installed on the end-effector.

The robot is set to throw a toy basketball into a basket with a backboard and the square on the backboard is the target for automatic detection in the stereo vision system. The center of the basket is determined through the square of backboard in three-dimensional space in robot coordinate.

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J.S. Hu is with the Mechanical and Systems Research Laboratories, Industrial Technology Research Institute and Department of electrical and Control Engineering, National Chiao-Tung University.

M.C. Chien is with the Mechanical and Systems Research Laboratories, Industrial Technology Research Institute, No. 195, Sec. 4, Chung-Hsing Rd., Chutung, Hsinchu, 310, Taiwan, R.O.C. (corresponding author, phone: 886-3-591-8630;fax:886-3-591-3607;e-mail: D9203401@mail.ntust.edu.tw).

Y.J. Chang is with the Department of electrical and Control Engineering, National Chiao-Tung University.

S.H. Su is with the Mechanical and Systems Research Laboratories, Industrial Technology Research Institute.

C.Y. Kai is with the Department of Mechanical Engineering, National Taiwan University of Science and Technology.

II. Methods

A. Visual Feedback

Accurate 3D position estimation of stereo vision depends on proper calibration. The parameters of each camera in pin-hole model are focal lengths, skew coefficient, principle points, and distortion coefficients. The rotation and translation between left and right camera are also needed for precise 3D positioning. These parameters and relations can be obtained by applying a chess board and utilizing Camera Calibration Toolbox for Matlab[1]. Moreover, the relation between the cameras and the robot should be determined. The relations in the system are shown in Fig. 1. A chess board installed on the end-effector and each corner of the chess board relative to the coordinate of end-effector can be obtained from the design. In Fig. 1, **B**s' are defined as

$$\mathbf{B} = \left[\ \mathbf{R} \,|\, \mathbf{T}\ \right] \tag{1}$$

which is a transformation including a rotation matrix **R** and a translation vector **T**. $\mathbf{B}_{Cl,Cr}$ is the transformation from the left camera to the right camera and is obtained in stereo calibration. $\mathbf{B}_{R,E}$ is the transformation from the base of robot to the end-effector and is determined according to all joints. $\mathbf{B}_{R,E}$ is the transformation from the end-effector to the chess board and is determined in the mechanical design. Then, in each frame, the position of each corner on the chess board in the robot coordinate can be calculated. With intrinsic parameters and the transformations described above, the transformation from left camera to the robot is calculated by minimizing the differences of points in images and the corresponding projected points. Providing samples for calibration is simple and convenient in this system.

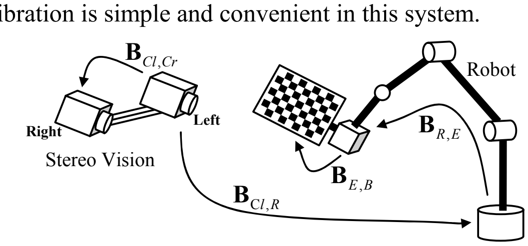

Fig. 1 Relations of stereo cameras and the robot

Stereo triangulation is applied to locate a specific point in a pair of images. The basket to throw the ball into also can be located in the vision system. The throwing target is the basket; however, detecting the square on its backboard is more reliable. Firstly, contours are found in an image. Each contour is illustrated by a point sequence. Then, each contour is approximated by using least points and the convex contours with four points are remained for following processes. The contours with too large or too small area are not desired. Variances of pixel values in contours are utilized to choose inner ones on the square. Based on these conditions, the objective square can be found successfully in images. The four corners of the square from 1 to 4 are marked according to their relative position in the image. In each pair of images, four corners are detected in the left and right images and consequently the 3D position of each corner can be obtained. Using these four corners can calculate the 3D position of the center of the basket. Fig. 2 shows an example of detecting the square and the basket center. The circles in Fig.2 are the projections from the 3D position to each image. For computer vision, the OpenCV [3] library is used for some related tasks.

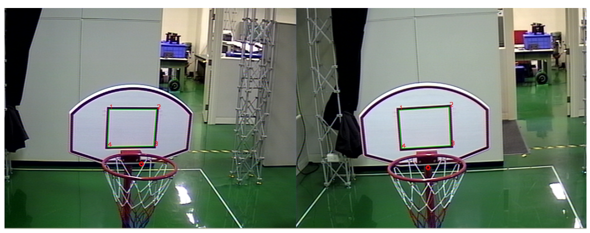

Fig. 2 A sample of a processed image pair of the basket.

A. Ball-Throwing Transformation

The ball-throwing motion can be considered as a mapping between input command of robot system and target position feedback by stereo vision system. A transform mapping to describe this motion is:

$$\mathbf{y}=\mathbf{f}(\mathbf{x}) \tag{2}$$

where $\mathbf{x}$ is the target position feedback by stereo vision system and $\mathbf{y}$ is the input command state of robot system. The $\mathbf{x}$ and $\mathbf{y}$ are defined as

$$\mathbf{x}=\begin{bmatrix}\theta_{\text{target}} & r_{\text{target}}\end{bmatrix}^T \tag{3}$$

$$\mathbf{y}=\begin{bmatrix}\theta_{\text{release}} & s_{\text{release}}\end{bmatrix}^T \tag{4}$$

where $\theta_{\text{target}} \in \mathbb{R}$ and $r_{\text{target}} \in \mathbb{R}$ are the target positions , and $\theta_{\text{release}} \in \mathbb{R}$ and $s_{\text{release}} = |\mathbf{v}_{\text{release}}| \in \mathbb{R}$ are ball-release angle and speed(Fig.3). $\mathbf{f}(\bullet)=\begin{bmatrix}f_1(\bullet) & f_2(\bullet)\end{bmatrix}^T$ is a transform vector function of ball-throwing motion. $f_1(\bullet)$ is the mapping between θ_{release} and θ_{target} which is

$$\theta_{\text{release}} = 90^{\text{o}} - \theta_{\text{target}} \tag{5}$$

$f_2(\bullet)$ is the mapping between s_{release} and r_{target} is described by a cubic polynomial,

$$s_{\text{release}} = a_3 r_{\text{target}}^3 + a_2 r_{\text{target}}^2 + a_1 r_{\text{target}} + a_0 \tag{6}$$

where $a_{(\bullet)}$ are polynomial constant coefficients which are determined by least squares method with off-line collecting date.

Through eq.(5) and eq.(6) with visual feedback for θ_{target} and r_{target}, the robot throws a ball toward the target which can move to everywhere in its visible field.

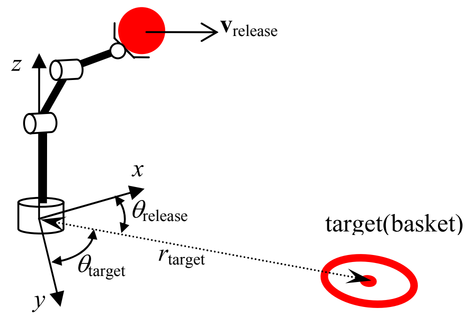

Fig.3 Relation of the basket and the robot

III. Experimental Hardware

The robot applied is TX60 with a controller, CS8, which is manufactured by Stäubli Inc. and the robot hand is Barrett Technology Inc.'s BH8-series BarrettHand™ for catching the ball. The cameras are Panasonic WV-CP 480 CCD. Cameras are connected to a multiple channel capture card in a computer and the computer communicates with the CS8 through ethernet. The ball-throwing robot system is shown in Fig.4. The percentage of successful ball-throwing for $r_{\text{target}} \leq 3m$ was found to be approximately 99%.

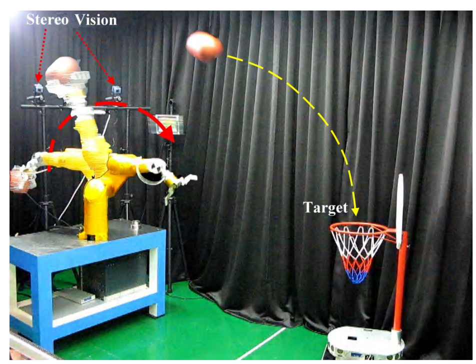

Fig. 4 The experimental setup.

IV. Conclusion

A robot system for throwing a ball is demonstrated in this video. The position of randomly moving target is detected by a stereo vision system. The ball-throwing transformation is build by cubic polynomial. Via ball-throwing transformation with visual feedback for target position, the robot throws a ball toward the target which can move to everywhere in visible field.

References

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[3] G. R. Bradski and A. Kaehler, Learning OpenCV - Computer Vision with the OpenCV Library. O'Reilly, 2008.