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A Robotic Ball Catcher with Embedded Visual Servo Processor

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

Abstract—**In this work we present a robotic ball catcher with embedded visual servo processor. The embedded visual servo processor with powerful parallel computing capability is used as the computation platform to track and triangulate a flying ball's position in 3D based on stereo vision. A recursive least squares algorithm for model-based path prediction of the flying ball is used to determine the catch time and position. Experimental results for real time catching of a flying ball are presented by a 6-DOF robot arm. The percentage of success rate of the robotic ball catcher was found to be approximately 60% for the ball thrown to it from five meters away.**

I. INTRODUCTION

VISUAL servoing has been applied widely in robotics area because cameras are useful robotic sensors since they mimic the human sense of vision and allow the robots to locate and inspect the environment without contact. Catching objects attracts much attention in visual servoing. To catch an object with a robot arm, the system generates the motion of the arm based on theobject's position information. Following are three approaches for catching objects:

(a) To calibrate the relations of the robot arm and cameras.
(b) To track the current object position by vision system.
(c) To move the robot arm to the position at particular time which is predicted using current position and velocity of the object.

A robotic ball catcher with embedded visual servo processor is presented in the video. The flying ball in 3D space is tracking by a stereo vision system which is a FPGA used as the computation platform. The 3D spatial position of the ball was estimated by triangulation which took the image coordinates of the ball's centroid as input. The catch time and position of the flying ball are determined by a recursive least squares algorithm for model-based path prediction[1]. Experimental results for real time catching of a flying ball are presented by a 6-DOF robot arm. The percentage of success rate of the robotics ball catcher was found to be approximately 60% for the ball thrown to it from five meter away.

II. METHODS

A. Stereo Vision and Robot Arm Calibration

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[2]. Furthermore, the relation between the cameras and the robot arm should be determined to transform the 3D position of the ball in the stereo vision coordinate to the robot coordinate.

To avoid the movement of robot arm affecting the accuracy of stereo vision, the two cameras of stereo vision is set not to see the robot arm. Hence, another camera which can see the robot arm is used in calibration step and the relation of stereo camera and robot arm can be determined through this third camera. The relations in the system are shown in Fig.1. 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**.

A hand-held chess board (pattern #1 in Fig. 1) is used to calibrate the stereo vision including the intrinsic parameters and $\mathbf{B}_{Cl,Cr}$, the relation of the left and right camera. This chess board is also used to calibrate the intrinsic parameters of the third camera and $\mathbf{B}_{Cl,C3}$. Another chess board (pattern #2 in Fig. 1) 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. Moreover, the transformation from the base of robot to the end-effector, $\mathbf{B}_{R,E}$, can be determined according to all joints, the position of each corner on the chess board in the robot coordinate can be calculated in each frame. With intrinsic parameters of the third camera descried above, the transformation from the third camera to the robot arm, $\mathbf{B}_{C3,R}$, is determined by minimizing the differences of points in images and the corresponding projected points. Since $\mathbf{B}_{C3,R}$ and $\mathbf{B}_{Cl,C3}$ are obtained, $\mathbf{B}_{Cl,R}$ can be calculated for transforming the 3D position of the ball in the stereo vision coordinate to the robot coordinate. The third camera can be removed after calibration.

Providing samples for each calibration step is simple and convenient in this system. Only two patterns and one third camera are required for calibration.

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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.

Y.C. Chang, S.H. Su, and J.J. Yang are 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.

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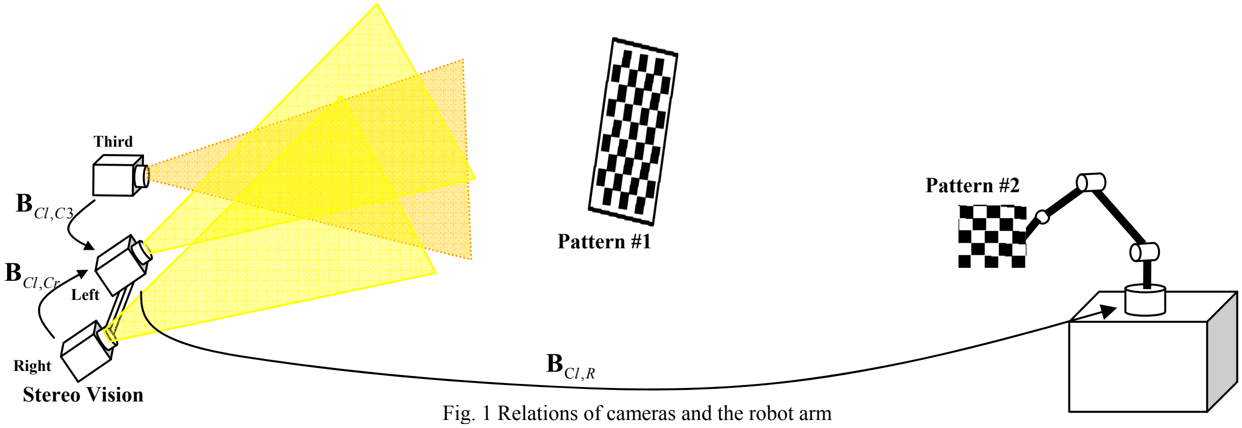

Fig. 1 Relations of cameras and the robot arm

B. FPGA Visual Servo Processor

The 3D spatial position of a flying ball was estimated by an embedded FPGA-based visual servo processor to provide high enough visual update frequency for the ball catching task. The visual servo processor estimates the 3D position of a ball by triangulation. The triangulation used the image coordinates of a ball's center-of-mass in the left and right cameras to estimate the ball's position. The image coordinates of a ball's center-of-mass were determined through background subtraction, morphological filtering, center-of-mass computation. These operations are both computation intensive and must be accelerated by parallel computing hardware to satisfy the processing speed required for the ball catching task. Our visual servo processor took at most 17 ms to update the position of a flying ball. This gave a visual update frequency of 58 Hz. The estimated 3D spatial position of the ball is encoded with time stamp and sent to path prediction to determine the interception point.

C. Object Path Prediction and Catch Time/Point Determination

Once the ball has been tossed, data storage, fitting and prediction begin. The path prediction of the flying ball is used a recursive least squares algorithm assuming a parabolic model for the trajectory. The computation required for each new data point is independent of the number of data points already collected because the algorithm is recursive[1]. Similarly, each data point is weighted equally, the last having as much effect as the first. A satisfactory catch time/point is updated with each change (approximately 58Hz) and determined by using the predicted parabolic constants. Once a satisfactory catch point is determined, the robot arm attempts to intercept and match position with the flying ball.

III. EXPERIMENTS

The embedded visual servo processor was designed based on a Xilinx Virtex-5 FPGA. The FPGA implemented an embedded system with a high performance object tracking IP developed by Industrial Technology Research Institute. The robot applied is TX60 with a controller, CS8, which is manufactured by Stäubli Inc. The cameras are Panasonic WV-CP 480 CCD. Cameras are connected to a FPGA and the computer communicates with the CS8 through RS232. The robotic ball catching system is shown in Fig.2. The percentage of success rate of the robotics ball catcher was found to be approximately 60% for the ball thrown to it from 5m away.

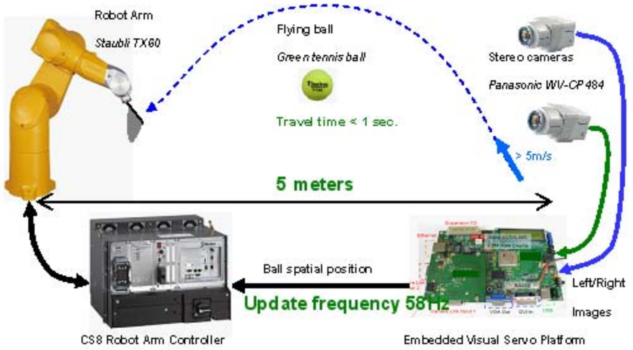

Fig. 2 The robotic ball catching system

IV. CONCLUSION

A robotic ball catcher with embedded visual servo processor is presented in the video. The flying ball in 3D space is tracking by a stereo vision system which is a FPGA used as the computation platform. The 3D spatial position of the ball was estimated by triangulation which took the image coordinates of the ball's centroid as input. The catch time and position of the flying ball are determined by a recursive least squares algorithm for model-based path prediction. Experimental results for real time catching of a flying ball are presented by a 6-DOF robot arm. The percentage of success rate of the robotics ball catcher was found to be approximately 60% for the ball thrown to it from five meters away.

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