
Applied System Innovation for Modern Technology

Editors

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National Formosa University, Taiwan

Stephen D. Prior
The University of Southampton, UK

Artde Donald Kin-Tak Lam
Fujian University of Technology, China

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Applied System Innovation for Modern Technology

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Editorial

This volume represents the proceedings of the 2017 IEEE International Conference on Applied System Innovation (IEEE-ICASI 2017). This conference was organized by the IEEE Tainan Section Sensors Council (IEEE TSSC) and the Taiwanese Institute of Knowledge Innovation (TIKI), and held May 13-17, 2017 in Sapporo, Japan. The conference received 1800+ submitted papers from 8 countries, whereby 500+ papers were selected by the committees. These papers on various topics are divided into 29 sessions (14 regular sessions & 15 invited sessions) and presented in several parallel sessions in the conference. The conference provided a unified communication platform for researchers in a wide range of discipline. This proceedings volume enables interdisciplinary collaboration between science and engineering technologists in the academic and industry fields as well as networking internationally.

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Abstract

Object pose estimation is one of the crucial parts in vision-based object manipulation system using standard industrial robot manipulator, particularly in pose estimation of the end effector of the robot arm to grasp the object targeted. This paper presents the utilization of stereo vision system to estimate the 3D (3 dimensional) object position and orientation to pick up and place the object targeted in an arbitrary location within the workspace. In order to accomplish this task, a calibrated stereo camera in the eye to hand configuration is used to capture the images of the object on the left and right camera. Then, the specific object feature is extracted and the 3D position and orientation of the object are calculated using image processing algorithm. Finally, the end effector of robot arm equipped with gripper will pick up the object targeted according to the object pose estimation output, and then place it to the desired location. The experimental results using 6 DOF robot arm are demonstrated and show the effectiveness of the proposed approach with good performance.

Key words: Object Pose Estimation; Stereo Vision System; 6 DOF Robot Arm; Image Processing

Introduction

Vision based object manipulation system that utilize a standard robot manipulator such as bin picking [1] and feeding robot [2] are commonly requires to know the object position and its orientation in the workspace. This information is important to determine the proper grasping mode and avoid the object from damages due to inappropriate of gripper pose estimation. This requirement leads to develop the various methods in improving the performance of object manipulation system.

Several researchers have been applied the stereo vision to obtain the 3D object pose estimation as mentioned in [3, 4]. However, their estimation algorithms were using many formulae to calculate the position and orientation of the object with respect to the robot arm coordinate frame. Hence, our proposed method only uses the data provided by Matlab function, and calibrates using an adaptive artificial network based fuzzy interference system (ANFIS) method to reduce the complex algorithm and computation.

This study presents the 3D object pose estimation including position and its orientation using calibrated stereo vision system, that is, one of the most popular vision sensor in robotic field particularly in 3D object position detection due to the advantages among other method [5]. The 3D object position was estimated using the triangulation algorithm based on the centroid of the object targeted as described in [6]. While, the object orientation is obtained by extracting the image region properties resulted by Matlab function. An ANFIS method is used to obtain the object pose estimation with respect to the robot arm coordinate frame. Finally, the 3D object pose estimation results can be used to move the robot arm equipped with gripper and grasp the object in proper position and orientation.

For demonstration, we apply the proposed object pose estimation system for object-grasping tasks and analyze the performance. The rest of this paper is structured as follows. Section 2 is the summary of the object detection and pose estimation using stereo vision, including the camera to robot arm coordinate transformation and a robot manipulator are also described. Section 3 explains the experimental results. Finally, a brief conclusion and future work are presented in Section 4.

Methods

In this study, some environments which are used to implement the 3D object pose estimation system are shown in Fig. 1. A calibrated stereo camera that consists of two identical cameras Logitech C310 was placed toward the workspace and 6 DOF robot arm with equipped gripper. While, a blue color object as a target to be manipulated was placed in arbitrary location within the workspace. On the other side, Personal computer (PC) connected to robot arm controller was used to develop a Graphic user interface (GUI) in Matlab platform and implement the proposed method.

This section presents the method of the object pose estimation in both camera and robot arm coordinate frames and
also describes the robot arm that used in the experiment. The detailed explanations of each subsystem will elaborated in following section.

A. Object detection and pose estimation using stereo camera

In order to determine the object position and orientation in camera coordinate frame, a calibrated stereo camera in the eye to hand configuration as shown in Fig. 3, is used to capture the images of the object on the left and right camera. Then, the colored object targeted was recognized through the HSV color thresholding and some filter algorithm was applied to differentiate the object with the background. After that, the blob analysis was used to determine the position and orientation of the object in two dimensions image plane coordinates. According to the centroid of the object, the 3D object position can be estimated using triangulation algorithm as described detail in [6]. While the object orientation is extracted from the object region properties that provided in Matlab function, ranged from -90 to 90 degrees. The object orientation is the angle between the x-axis and the major axis of the ellipse that has the same second-moments as the region as described in [7].

B. Camera to robot arm coordinate calibration

The ANFIS method is used to calibrate the stereo camera and robot arm coordinate frames as shown in Fig. 4. The ANFIS structures are expanded from three layers with 3 inputs and 3 outputs of the object position with respect to stereo camera and the object position with respect to the base frame, became four layers with 4 inputs and 4 outputs of the object position and orientation with respect to stereo camera coordinate and the object position and orientation with respect to the base frame.

The four-ANFIS structure consists of first-order Sugeno fuzzy system for three axes in camera to robot arm 3D coordinate transformation and one object orientation. 5 Gaussian membership functions with product inference rule are used at the fuzzification layer, and hybrid learning algorithm is used to adjust the premise and consequent parameter.

C. Robot manipulator

The Mitsubishi RV-3SD manipulator considered in this study is made up by joining a number of rigid bodies which has 6 degrees of freedom (DOF). The robot arm is equipped with a gripper and controller that can be connected to the PC via the serial communication standard which allows users to move the robot by sending command with the required command format[8]. The DH (Denavit-Hartenberg) parameters of the robot arm are shown in Table 1. These parameters \(a_i, \alpha_i, d_i\), and \(\theta_i\) are the link length, link twist, link offset, and joint angle, respectively.

<table>
<thead>
<tr>
<th>Joint no. (i)</th>
<th>Joint angle (\theta_i)</th>
<th>Link offset (d_i)</th>
<th>Link length (a_i)</th>
<th>Link twist (\alpha_i)</th>
<th>Joint</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(\theta_1)</td>
<td>(d_1)</td>
<td>(a_1)</td>
<td>-90°</td>
<td>Waist</td>
</tr>
<tr>
<td>2</td>
<td>(\theta_2)</td>
<td>0</td>
<td>(a_2)</td>
<td>0°</td>
<td>Shoulder</td>
</tr>
<tr>
<td>3</td>
<td>(\theta_3)</td>
<td>0</td>
<td>(a_3)</td>
<td>90°</td>
<td>Elbow</td>
</tr>
<tr>
<td>4</td>
<td>(\theta_4)</td>
<td>(d_4)</td>
<td>0</td>
<td>-90°</td>
<td>Fore arm</td>
</tr>
<tr>
<td>5</td>
<td>(\theta_5)</td>
<td>0</td>
<td>0</td>
<td>90°</td>
<td>Wrist</td>
</tr>
<tr>
<td>6</td>
<td>(\theta_6)</td>
<td>(d_6)</td>
<td>0</td>
<td>0°</td>
<td>Tool</td>
</tr>
</tbody>
</table>

Based on the DH parameters the forward kinematics can be calculated through equation (1),

\[
^{0}T_{6} = ^{0}T_{1}^{1}T_{2}^{2}T_{3}^{3}T_{4}^{4}T_{5}^{5}T
\]

where \(^i T_j\) denotes the homogenous transformation from frame \(i\) to frame \(j\) and
By substituting these parameters listed in Table 1 to (1), we can obtain the transformation matrix as shown in (2),

$$\begin{align*}
T_j &= 
\begin{bmatrix}
\cos(\theta) & -\sin(\theta) & 0 & a_j \\
\sin(\theta) & \cos(\theta) & 0 & b_j \\
0 & 0 & 1 & c_j \\
0 & 0 & 0 & 1
\end{bmatrix}, i = 1, \ldots, 6.
\end{align*}$$

The first three columns in the matrix represent the orientation of the end effector, whereas the last column represents the position of the end effector.

### Experimental results

In this section, several experiments are performed to evaluate the proposed method with the environmental setup as shown in Fig. 1 at the methods section. First, the object pose estimation in camera coordinate frame was carried out with the calibrated stereo vision system in eye to hand configuration. Then, the experiment of grasping preparation was performed using 6 DOF robot arm with equipped the 3 finger gripper to validate the performance of the 3D object pose estimation in robot arm coordinate frame.

#### A. Object pose estimation results in camera coordinate frame

The results of the object pose estimation in camera coordinate frame using stereo vision is shown in Fig. 5. It shows the blue color object was placed in arbitrary position and orientation within the workspace. The 3D object position \((X, Y, Z)\) and the orientation \(O\) are obtained after some image processing algorithm was applied as mentioned in section 2. Then, the orientation data were collected to be the ANFIS training data and the training error that shows the accuracy of orientation estimation result shown in Fig. 6.

![Fig. 5. Object pose estimation](image)

Table 2 shows the success of the object pose estimation in several position and orientation with the maximum average position absolute error of 3.59 mm, and 2.84° of the orientation absolute error.

![Fig. 6. Orientation data training error](image)

#### Table 2. The results of object position and orientation test

<table>
<thead>
<tr>
<th>No</th>
<th>Reference position and orientation</th>
<th>Measured position and orientation</th>
<th>Orientation absolute error (°)</th>
<th>Average Position absolute error (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Xr0, Yr0, Zr0, Cr0</td>
<td>Xr1, Yr1, Zr1, Cr1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>310.00, -320.00, 320.00, 180.00</td>
<td>314.26, -312.38, 318.89, 182.84</td>
<td>2.84</td>
<td>3.59</td>
</tr>
<tr>
<td>2</td>
<td>310.00, -480.00, 320.00, -120.00</td>
<td>308.49, -481.44, 320.57, -118.14</td>
<td>1.86</td>
<td>0.79</td>
</tr>
<tr>
<td>3</td>
<td>-10.00, -480.00, 320.00, 110.00</td>
<td>-13.27, -483.65, 325.75, 109.09</td>
<td>0.91</td>
<td>0.39</td>
</tr>
<tr>
<td>4</td>
<td>150.00, -400.00, 320.00, -90.00</td>
<td>152.80, -398.47, 316.06, -88.00</td>
<td>2.00</td>
<td>0.13</td>
</tr>
</tbody>
</table>

According to the results as shown in Fig. 5, the 3D object pose estimation has been successful to estimate the position and orientation of the object targeted with respect to the camera coordinate as follow: 44.1 mm (x axis), -26.0 mm (y axis), 1100.6 mm (z axis), -10.9° (orientation). These results will be calibrated in the next step to calculate the gripper position and orientation that attached in robot arm for grasping the object targeted.

Based on the results, the object targeted has been successful to be reached by the gripper according to the object position and orientation. It shows the good performance of 3D object pose estimation process and it can be implemented in object manipulation system application.

### Conclusion and future work

In this study, the 3D object pose estimation was successfully estimated using stereo vision system including both of the
object position and orientation. The robot arm with equipped the gripper can grasp the object targeted in arbitrary position within the workspace. According to the experimental results, it is concluded that the proposed method has achieved a good performance and it can be used in object manipulation system such as bin picking and object sorting. However, we assumed a non-cluttered background and without obstacle. Hence our future work will focus on improving this algorithm for cluttered setting.

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References