Grasping and Positioning Tasks for Selective Compliant Articulated Robotic Arm Using Object Detection and Localization: Preliminary Results

Mohannad Farag[1], Abdul Nasir Abd Ghafar[2]
[1,2]Faculty of Engineering Technology
Universiti Malaysia Pahang
26300 Gambang, Pahang, Malaysia
e-mail: mohanadfaraj@gmail.com,
abdnasir@ump.edu.my

Mohammed Hayyan Alsibai
Faculty of Engineering & Technology
International University for Science and Technology
Damascus, Syria
e-mail: mhdhayyan@gmail.com

***Abstract*—Vision guided robots have more ability, functionality and adaptivity in industrial assembly lines than normal robots. This research attempts to increase the impact of computer vision on robotic positioning and grasping applications. Therefore, we addressed object detection and localization to perform robotic grasping and positioning using Selective Compliant Assembly Robot Arm (SCARA). The target position of SCARA robot is determined based on information obtained from object detection and position measurement process. This process is implemented on a circular object to simplify the task. For accurate position measurement, the distortion of camera lens is removed using camera calibration technique. In object detection, several methods are compared to detect circular holes in an input image. The most successful methods with 100% Precision, Recall and F-measure are used to detect the circular object. The position of this object is measured in world coordinate unit for pick-and-place operation. Then, the experiment is designed to move SCARA robot to the measured position of the detected circular object. The result showed that the robot is successfully moved to the measured position of the detected object with average positioning error (0.314, 0.155) *mm*.**

Keywords-object detection; object localization; edge detection; robotic arm; robot positioning, robot grasping

I. INTRODUCTION

Robotic arm is the most important part of the industrial robotic system as it manipulates objects or products directly. Two major types of robotic arms in assembly lines can be considered [1], first is the Cartesian robot which also called rectangular, rectilinear or gantry robot. This robot could move its gripper to any position within the cube or rectangle defined as its work envelope. Second, is the Selective Compliant Assembly Robot Arm (SCARA) provides a circular work envelope. SCARA robot was developed as a new concept for assembly robots by Prof. Hiroshi Makino at University of Yamanashi in 1981 [2]. SCARA robot is generally faster and cleaner than Cartesian robot. As it is built based on a serial architecture, which means that the first motor carries the other motors, it requires a small footprint. On the other hand, SCARA controlling software requires inverse kinematics for linear movement and therefore it could be more expensive than Cartesian robotic systems [1].

SCARA robots are most adept in pick-and-place tasks in industrial assembly lines that need speed and precision [3]. Despite huge researches on computer vision, yet their impact on the robotic applications in industry is not very significant [4]. SCARA's capability can be improved to perform vision guided grasping and positioning using computer vision techniques. For this purpose, object detection and localization are addressed in this work. We used GLOBOT KSS-1500 SCARA robot equipped with Chameleon3 USB3 camera to perform pick-and-place operations by guidance of the vision system. To achieve a precise robot positioning, it is required to provide the topology and structural information of relevant object in an image and measure its position accurately [5]. Therefore, we used edge detection technique to analyze the image and applied the concept of image filtering based on image extracted features [6]. In addition, camera calibration process for removing lens distortion is implemented for proper position measurement [7], [8].

Edge detection is an image processing technique where the edges in an image are identified according to the sudden change in image intensity. In this process, the places where the first derivative of the intensity is larger in magnitude than some threshold or where the second derivative of the intensity has a zero crossing are considered as edges. Thus, the result will be a binary image containing ones where edges are found and zeros elsewhere [9], [10]. This technique simplifies the analysis of images by extremely reducing the amount of processing data, while maintains useful structural information about object boundaries for further image processing [11], [12]. The target position of SCARA robot is determined based on information obtained from object detection and position measurement process implemented on a circular object. The experiment is designed to move SCARA robot to the measured position. This sequence is repeated for 50 time with calculating of positioning error.

Seven methods are compared to detect circular holes in input images. These operators are Sobel, Prewitt and Roberts, which use first derivative to obtain the image gradient, and Log, Zero-cross, Canny and Approxcanny. The last four methods use the second derivative of the image where the edges are determined based on these zero crossing areas [10]. Edge detection results are evaluated based on Recall, Precision and F-measure [13]–[15].

978-1-7281-3910-4/19/$31.00 ©2019 IEEE
DOI 10.1109/ICEEE2019.2019.00061

The rest of the paper is organized as follows. The vision guided selective compliant articulated robotic arm is provided in Section II. Section III provides the camera calibration process while Section IV describes the design of vision guided pick-and-place robot task. The experimental results are provided in Section V while the conclusion is included in Section VI

II. Vision Guided SCARA Robot

The SCARA we used is the GLOBOT KSS-1500 (Korea Standard SCARA) manufactured by DMBH CO., LTD. [16]. It is a horizontally articulated robot with two angular positioning movements (X and Y axes) and one linear movement (Z axis). KSS-1500 robot is equipped with 2-finger gripper which rotates around θ axis to place the grasped object in a proper direction as shown in Fig. 1. The arm has 4 degree-of-freedom (DOF) driven by four brushless direct current (BLDC) motors with encoders. In addition, KSS1500 robot controller enables users to use eight exterior isolated input/output devices to interact with the robot directly.

The vision system uses FLIR Point Grey Chameleon3 1.3 MP Color USB3 camera (model CM3-U3-13S2C-CS-SET). Chameleon3 camera is supported by USB3 Vision toolbox and image acquisition toolbox in MATLAB and Simulink [17]. Thirty image acquisition formats are supported using 'pointgrey' adapter in MATLAB including BayerGB, Mono, RGB and YUV format. As shown in Fig. 1, the camera is mounted near the gripper in parallel with robot z axis. This design allows SCARA robot to generate motion and position the gripper based on object detection and localization then perform pick-and-place tasks.

III. Camera Calibration

As edges are often associated with the boundaries of an object, edge detection will be a useful technique for the object position measurement purpose. The essential step toward that is to remove the lens distortion using camera calibration which is a process of estimating the parameters of the lens and the camera sensor [7], [8]. Removing lens distortion is very important especially for wide angle cameras to get a proper pixel to millimeter conversion for accurate measurement. A standard checkboard with an asymmetric pattern is used for the calibration process [18]. In our case the square size is 21.70 *mm*. Forty images of the calibration pattern are used for accurate calibration.

Once the calibration is done, the detected points in the image (green cycled corners), and the corresponding projected points (red plus signed corners) can be visualized as in Fig. 2. The distances between these points are called reprojection errors [19]. The overall reprojection error of calibration images is 0.05 pixels. The calibrated camera parameters can be exported and being used to remove lens distortion. Fig. 3 (a) and (b) show the checkboard before and after remove distortion respectively. The detected checkboard origin (0,0), marked in Fig. 2 with a yellow square, is considered as the origin point of the world unit coordinate measurements.

Figure 1. Vision guided KSS-1500 robot with 4 DOF

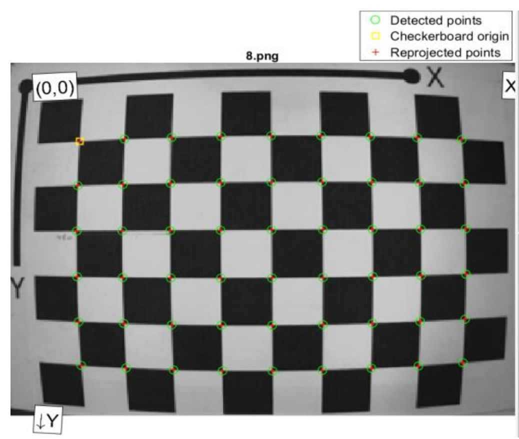
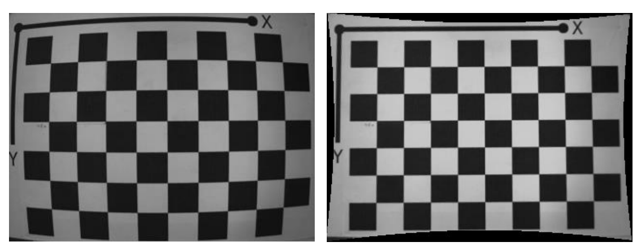


Figure 2. Detected and reprojected points of the sample calibration image



(a) (b)

Figure 3. Sample of the calibration images (a) before remove distortion (b) after remove distortion

IV. Design of Vision Guided Robot Positioning and Grasping

The main focus of this study is to calibrate SCARA robot movement with the coordinates retrieved by the vision system. Therefor a simple task is designed to perform a vision guided pick-and-place for a cylindrical object from Region A to Region B as shown in Fig. 4.

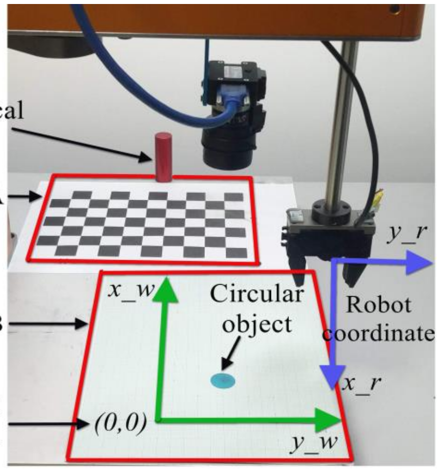


Figure 4. Design of the experiment platform

To obtain the preliminary results of this research the, the experiment is conducted under the following conditions.

- The cylindrical object position in Region A is fixed and predefined.
- The position where to convey the cylindrical object in Region B to be calculated by object detection and localization of a circle object.
- The circular object is selected to ease object detection task as the objective in this research stage is to proof the concept of the vision guided SCARA robot positioning. Also, it will be easy to measure positioning error accurately.
- The point of view of the camera is fixed when perform object detection in Region B.
- The detected object (circular object) is in the same plane of the calibration checkboard.
- The world coordinate origin point shown in Fig. 4 is identical with the checkboard origin shown in Fig. 2.

Once the target position is obtained in world coordinate, it will be translated to robot coordinate according the following translation rule.

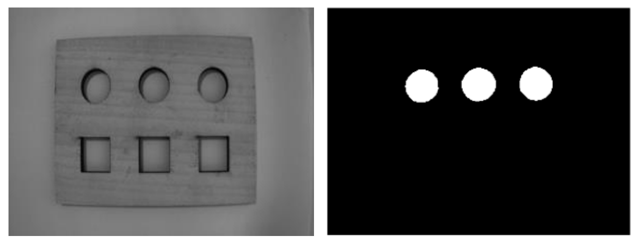
$$\begin{aligned} x_r &= 208.110 - x_w \\ y_r &= 229.255 + y_w \end{aligned} \tag{1}$$

where (x_w, y_w) is the world coordinate and (x_r, y_r) is the robot coordinate measured in millimeters. Finally, SCARA

V. EXPERIMENT RESULTS

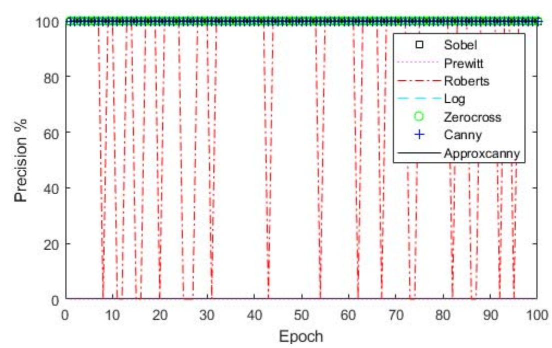
A. A comparison of Edge Detection Methods

The objective of this section is to compare seven edge detection methods (Sobel, Prewitt, Roberts, Log, Zero-cross, Canny and Approxcanny) to detect the circular holes in the input image. In the next section, the circular object center will represent the position where the SCARA robot should place the object. Therefore, we designed six holes (in square and circle shapes) as an input image in Mono 8-bit and 1288x964 pixels format as shown in Fig. 5(a). The input image then is processed using the seven edge detection methods to result seven binary images. After that, the detected holes in these images are filled and filtered based on segmented image features, such as area, solidity and orientation, to recognize the circular object. Fig. 5(b) shows an example of a segmented and filtered image with three recognized circular objects. As the circular object is desired to be recognized, we can consider the object detection process as a binary classification for the circular object class. This process is repeated for 100 times. Precision, Recall and F-measure are calculated [13]–[15] for each object detection method as shown in Fig. 6 (a), (b) and (c) respectively. The averages of the calculated measures are listed in Table I. According the obtained results, Log, Zero-cross, and Canny methods have achieved the best performance at 100% of Precision, Recall and F-measure for circular object detection. These results are expected for a simple-shaped object detection. Thus, one of these three methods or a combination of 2 or 3 of them can be used for SCARA robot positioning in the next Section.

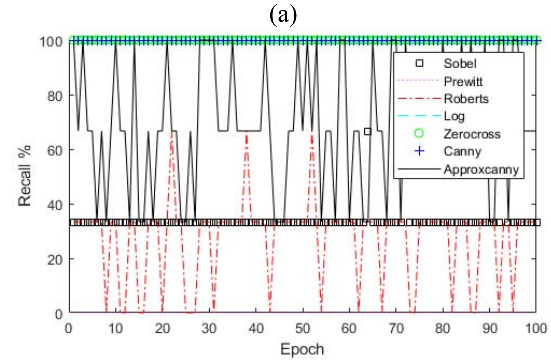


(a) (b)

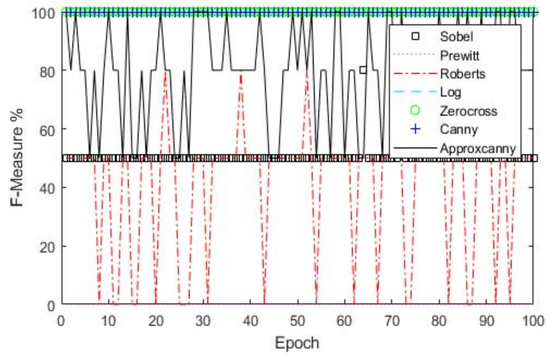
Figure 5. Designed six holes (a) Input image with (b) segmented image



(a)



(b)



(c)

Figure 6. Results of edge detection methods (a) Precision, (b) Recall, (c) F-measure

TABLE I. AVERAGE OF PRECISION, RECALL AND F-MEASURE

Edge Detector	Precision	Recall	F-measure
Sobel	100.00%	34.33%	50.90%
Prewitt	0.00%	0.00%	0.00%
Roberts	79.00%	27.33%	40.40%
Log	100.00%	100.00%	100.00%
Zero-cross	100.00%	100.00%	100.00%
Canny	100.00%	100.00%	100.00%
Approxcanny	100.00%	68.67%	79.00%

B. *Vision Guided Grasping and Positioning*

The designed vision guided pick-and-place platform in Section IV is used to obtain the experimental results for vision guided grasping and positioning. We defined fifty positions P_a in world coordinate unit (millimeters) in Region B marked as yellow points as shown in Fig. 7. These positions are considered as the actual positions P_a where the circular object is located and the cylindrical object should be placed by the SCARA robot. The experiment is conducted as described in the following steps.

- The circular object is located in the k^{th} actual position $P_a(k)$.
- SCARA robot is moved to the fixed point of view of the camera.
- Object detection is performed for the circular object.
- The position of the center of the detected hole is measured in world coordinate $P_d(k)$.
- The positioning error is calculated as follows.

$$e(k) = \left|P_a(k) - P_d(k)\right| \tag{2}$$

- The detected position $P_d(k)$ is translated to the robot coordinate $P_r(k)$ based on Eq. (1).

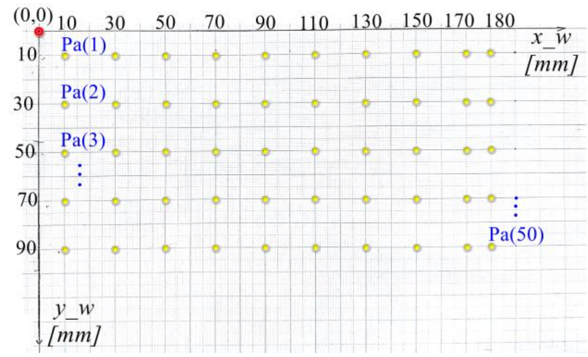
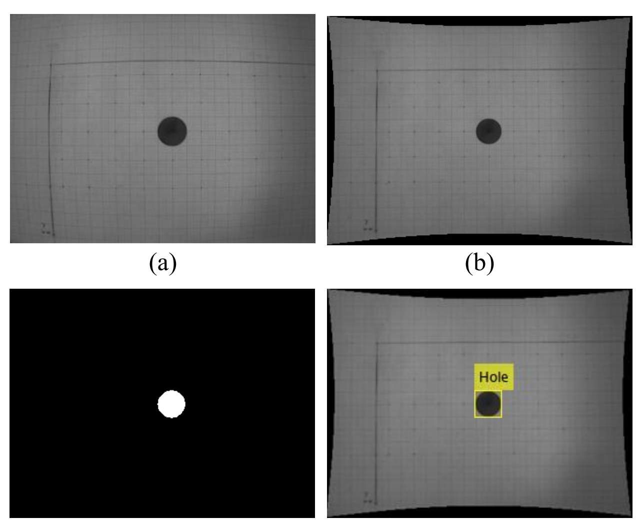


Figure 7. Fifty defined positions in Region B

- SCARA is moved to Region A and pick the cylindrical object.
- SCARA is moved to the detected position in robot coordinate $P_r(k)$ and the cylindrical object is placed.
- The above steps are repeated for all fifty positions shown in Fig. 7.

The average of positioning error can be calculated after that. Examples of input image, undistorted image, segmented image and detected hole, for experiment $k = 23$, are shown in Fig. 8 (a), (b), (c) and (d) respectively. In this experiment positioning error was (0.01,0.13) *mm*. Fig. 9 shows the results of positioning error for the fifty experiments where the average of these errors is $e_{av} = (0.314, 0.155)\,mm$. The obtained results reflect an accurate robotic positioning in pick-and-place operation. This accuracy could be improved by implementing more advanced edge detection and position measurement techniques.



(a) (b)

(c) (d)

Figure 8. The experiment result for $k = 23$, (a) input image, (b) undistorted image, (c) segmented image, (d) detected hole

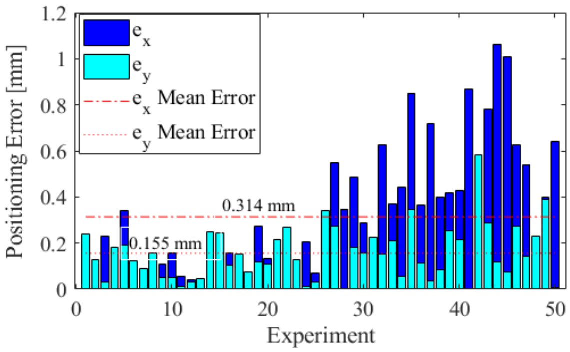


Figure 9. The results of positioning errors

VI. CONCLUSION AND FUTURE WORK

In this work, we addressed robotic grasping and positioning problem using object detection and localization technique. GLOBOT KSS-1500 SCARA robot was used as a hardware platform equipped with Chameleon3 USB3 camera. The target position of SCARA robot was determined based on information that obtained from object detection and position measurement process. Seven different methods of edge detection were compared to detect circular holes in the input image. The results have shown that Log, Zero-cross, and Canny, achieved the best performance with 100% Precision, Recall and F-measure. These methods were used to detect the circular object. The position of the detected object is measured in world unit coordinate after removing the lens distortion using camera calibration process. The robot is successfully positioned to the detected position, after translating it to the robot coordinate, with average positioning error $(0.314, 0.155)\,mm$. For future work, deep learning-based object detection model will be developed for SCARA robot grasp detection.

ACKNOWLEDGMENT

The authors would like to thank University Malaysia PAHANG to support this work under research grant RDU1703284 and post graduate research grant PGRS190359.

REFERENCES

[1] D. McMorran, D. C. K. Chung, J. Li, M. Muradoglu, O. W. Liew, and T. W. Ng, “Adapting a Low-Cost Selective Compliant Articulated Robotic Arm for Spillage Avoidance,” *J. Lab. Autom.*, vol. 21, no. 6, pp. 799–805, Dec. 2016.

[2] L. Westerlund, *The Extended Arm of Man: A History of Industrial Robot*. Informationsförlaget, 2000.

[3] R. Alcala, Z. G. Arceo, J. N. Baterisna, J. O. Morada, and J. Oliver D. Ramirez, “Selective Compliance Articulated Robotic Arm (SCARA): Application of Inverse Kinematics on the Control of Pick and Place Using Microsoft Kinect Xbox 360,” *Res. Gate*, 2018.

[4] D. Hossain and G. Capi, “Object Recognition and Robot Grasping : A Deep Learning based Approach,” *Robot. Soc. Japan*, no. October, 2016.

[5] A. Zeng *et al.*, “Robotic Pick-and-Place of Novel Objects in Clutter with Multi-Affordance Grasping and Cross-Domain Image Matching,” *arxiv.org*, 2018.

[6] P. Amoako-yirenkyi, J. K. Appati, and I. K. Dontwi, “Performance Analysis of Image Smoothing Techniques on a New Fractional Convolution Mask for Image Edge Detection,” *Open J. Appl. Sci.*, vol. 06, no. July, pp. 478–488, Jul. 2016.

[7] Z. Zhang, “A flexible new technique for camera calibration,” *IEEE Trans. Pattern Anal. Mach. Intell.*, vol. 22, no. 11, pp. 1330–1334, 2000.

[8] S. Urban, J. Leitloff, and S. Hinz, “Improved wide-angle, fisheye and omnidirectional camera calibration,” *ISPRS J. Photogramm. Remote Sens.*, vol. 108, pp. 72–79, Oct. 2015.

[9] S. Wang, F. Ge, and T. Liu, “Evaluating edge detection through boundary detection,” *EURASIP J. Appl. Signal Processing*, vol. 2006, no. 1, pp. 1–15, Dec. 2006.

[10] R. M. Yousaf, H. A. Habib, H. Dawood, and S. Shafiq, “A Comparative Study of Various Edge Detection Methods,” in *2018 14th International Conference on Computational Intelligence and Security (CIS)*, 2018, pp. 96–99.

[11] J. Canny, “A Computational Approach to Edge Detection,” *IEEE Trans. Pattern Anal. Mach. Intell.*, vol. PAMI-8, no. 6, pp. 679–698, Nov. 1986.

[12] M. Brejl and M. Sonka, “Object localization and border detection criteria design in edge-based image segmentation: Automated learning from examples,” *IEEE Trans. Med. Imaging*, vol. 19, no. 10, pp. 973–985, 2000.

[13] POWERS and David M.W., “Evaluation: from Precision, Recall and F-measure to ROC, Informedness, Markedness and Correlation,” *J. Mach. Learn. Technol.*, vol. 2, no. 1, pp. 37–63, Dec. 2011.

[14] D. L. Olson and D. Delen, *Advanced data mining techniques*, 1st ed. Berlin, Heidelberg: Springer Berlin Heidelberg, 2008.

[15] X. Zhang, L. Wang, Y. Zhao, and Y. Su, “Graph-Based Place Recognition in Image Sequences with CNN Features,” *J. Intell. Robot. Syst.*, pp. 1–15, Aug. 2018.

[16] “DMBH Co., Ltd,” 2018. [Online]. Available: http://www.dmbh.co.kr/?ckattempt=1.

[17] “Point Grey Camera Support from Image Acquisition Toolbox,” 2019. [Online]. Available: https://www.mathworks.com/hardware-support/point-grey-camera.html.

[18] D. Scaramuzza, A. Martinelli, and R. Siegwart, “A toolbox for easily calibrating omnidirectional cameras,” in *IEEE International Conference on Intelligent Robots and Systems*, 2006, pp. 5695–5701.

[19] J. Heikkila and O. Silven, “A four-step camera calibration procedure with implicit image correction,” in *Proceedings of IEEE Computer Society Conference on Computer Vision and Pattern Recognition*, pp. 1106–1112.