Visual-Based Pick and Place on 6 DoF Robot Manipulator

Ryan Satria Wijaya[1*], Adhitya Pratama[1], Rifqi Amalya Fatekha[1], Hendawan Soebhakti[1], dan Senanjung Prayoga[1]

[1]Jurusan Teknik Elektro, Politeknik Negeri Batam, Batam, Indonesia

*Email: ryan@polibatam.ac.id

***Abstract*— This paper discusses the application of visual servoing on a 6 DOF robotic manipulator for industrial automation. With visual feedback, the manipulator can perform pick and place operations accurately and efficiently. We explore feature- and model-based visual servoing methods and object detection techniques, including deep learning algorithms. The experimental results show that the integration of visual servoing with pick and place method as well as object detection improves the performance of manipulators in industry. This research contributes to the understanding of visual servoing technology in industrial automation. The conclusion shows that the manipulator is more precise in controlling the X-axis shift in the first two experiments, but faces challenges in the third experiment. The success of the system is affected by environmental factors such as lighting. For further development, research is recommended to improve robustness to environmental variations as well as evaluation of execution speed and object positioning accuracy.**

Keywords: Pick and place, Robot manipulator, Visual servoing

I. INTRODUCTION

THE use of robots in today's world is not only to facilitate human activities, but also to increase the anticipation of life and economic growth [1]. Industrial robots are an efficient solution to carry out industrial tasks such as painting, welding, soldering and more without the need for human intervention [2]. The use of robots in the industrial field encourages the rapid development of industrial robots. Industrial robots develop when they are utilized in the production process. In the 1990s, the market opened up opportunities for renewal of industrial forms that were integrated with technological developments [3]. Industrial robots are robot technology that is widely used to meet industrial needs. Industrial robots function as human assistants who have the advantage of working without stopping. Clear evidence of the development of industrial robots is the increase in robot purchases by 59% or 183,000 units in 2016 in Asia [4]. One type of robot that is developing and utilized in industry is the robot manipulator.

Robot manipulators use the mechanism of mathematical method of modeling to show the geometry and dynamic aspects. The obstacle that often occurs when learning a robot manipulator is analyzing and deriving the inverse kinematic equations of the robot manipulator [4]. From the control point of view, a robot manipulator is a multidimensional non-linear dynamic system [5]. To move the robot manipulator, the relative position, direction between objects, and end effector of the robot must be in the correct condition. If there is an error, an accurate method of correction is required. The feedback sensor method is used in this process in order to get accurate correction.

A system that combines robot vision using kinematic analysis of robots and images as well as the accuracy of the target object's position [6]. Visual servoing is a method for control the position and direction of a robot's end effector with respect to a target position by taking into account the image given by the camera [7]. The visual information utilized for such robot manipulators is known as servo visual. Visual servo methods are already commonly applied to control industrial robots and field robots [8]. Visual Servo Control was invented by Chaumette and Hutchinson [9]. Visual servoing consists of two types, namely image based visual servoing (IBVS) and Pose Based Visual Servoing (PBVS) [10]. But in its development, there are also those that use a hybrid approach between the two types [11]. IBVS uses information and images as a direct degree controller for the robot manipulator. Meanwhile, PBVS is a technique that uses geometric interpretation of camera feature extraction, such as analyzing object force and camera distance [12]. Visual sensor-based manipulation robots rely on visual feedback as position or motion control of the manipulator [13].

To apply the visual servoing method, a camera is needed as an object detection tool. The pixy camera is a camera that is commonly used in the application of the method. This pixy camera is able to detect and recognize objects based on patterns and colors [14]. The pixy camera filters the color algorithm at 50 Hz which is used to track objects [15]. The pixy camera can also be used in many lighting conditions such as infrared, behavior monitoring can be done in almost all aspects of biological settings [16]. The many uses of the pixy camera show that this camera is very multifunctional [17].

Therefore, this paper describes the operation of a robot manipulator that utilizes the visual servoing method as a servo controller and a camera as a target object detector. The scope of the discussion is devoted to a robot manipulator with a 6-DOF structure with an object color detection method. The pick and place method not only improves the efficiency of human-like movements, but also automatically improves safety by generating movements that can be detected and anticipated by humans. This approach not only optimizes time, but also stresses the priority on safety through mimicking gestures that are familiar and easy for human users to understand [18]. The pick and place process are needed in all stages of the manufacturing process [19]. Robotic pick and place have many applications in the industrial field, for example handling and transporting goods in logistics and intelligent warehouses, as well as grasping and categorizing objects in good conditions [20]. The pick and place method are a robot control method that is useful for picking up objects from one location and placing them in another location. This task is a common one performed on industrial robots [21]. The pick and place method in robot manipulators usually involves motion planning and control to move the robot to the position of the object to be picked (pick) and then move it to the destination position to place the object (place). In robotic manipulators with multiple joints operating in three-dimensional space, the cosine rule is used in inverse kinematics, especially in manipulators with two arms and known link lengths [22].

II. METHOD

A. Pick and Place

In this case, the robot manipulator is designed to recognize, pick up, and place objects from one location to another, as illustrated in Figure 1. In the initial step, the 6 degree-of-freedom (DOF) robot manipulator begins the process in its initial position. Subsequently, the camera positioned atop the robot performs object detection in its surroundings. If the camera fails to detect an object, the robot returns to its initial position to await further instructions. However, if the camera successfully detects the object, the robot initiates the movement to pick up the object, particularly the green object. After successfully grasping the object, the camera resumes detecting the appropriate location to place the object previously picked up. If the camera fails to detect the correct position, the robot returns to the initial location to pick up the object. Conversely, if the camera successfully identifies the appropriate position, the robot proceeds with the movement to place the object in a location indicated by blue color. After successfully placing the object, the robot returns to its initial position, completing the task cycle. Thus, this visual servoing system enables the robot manipulator to automatically pick up and place objects according to predefined conditions.

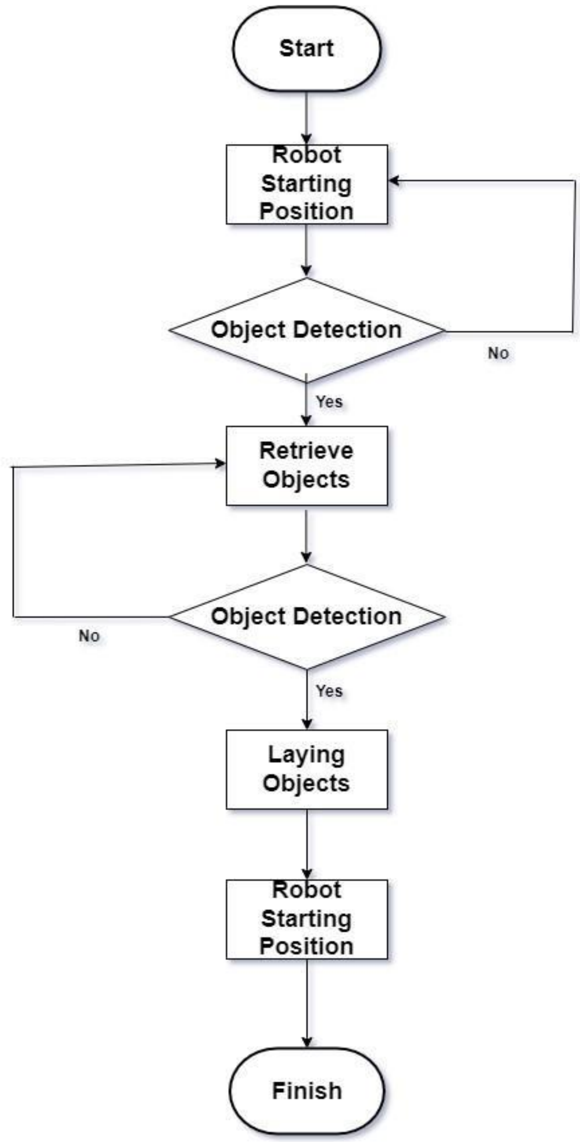

Fig. 1. Flowchart of The Pick and place System.

. In the implementation of visual servoing using a robot manipulator, two Arduino devices are employed to achieve the desired task. The first Arduino serves as a controller for the camera, equipped with a built-in program responsible for data acquisition by XY, acquiring data by pixel angle from the surrounding environment. The data acquired by the first Arduino is then transmitted to the second Arduino through the communication interface. The second Arduino functions as a controller for the servo motors that drive the mechanical parts of the robot manipulator. Each degree of freedom (DOF) utilizes existing inverse kinematics for its movement. After receiving the XY pixel angle data from the first Arduino, the second Arduino interprets the information and drives the servo motor, enabling the robot manipulator to orient itself toward the intended object. Refer to the block diagram of the visual servoing system in Figure 2.

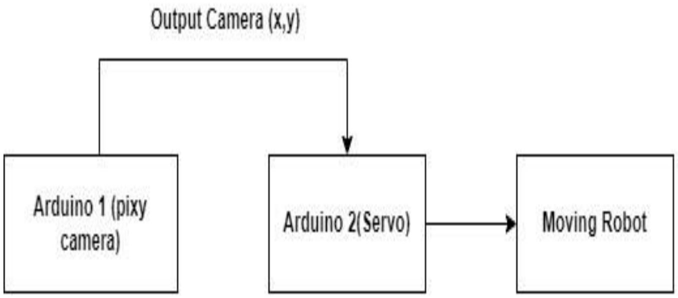

Fig. 2. Visual Servoing Hardware Block Diagram

B. Object Detection

Color-based object detection method in robotic manipulators is a commonly used approach to identify objects based on their color characteristics [23]. In the implementation of pick and place using pixy camera as object detection [24]. To use the Pixy camera, connect the camera to a computer or microcontroller via a USB cable. Open PixyMon, select the operation mode (color or object signature), and set the configuration of the color or object you want to detect. Adjust the parameters, and then save the configuration. Object detection methods in robot manipulators are essential to improve the robot's ability to interact with the surrounding environment [25]. Previously, in the pick and place method, the steps or methods of object detection were described in Figure 1. Subsequently, an implementation of color-based object detection is presented in Figure 3, where the object to be picked up by the robot is green, and the designated placement area for the object is indicated in blue.

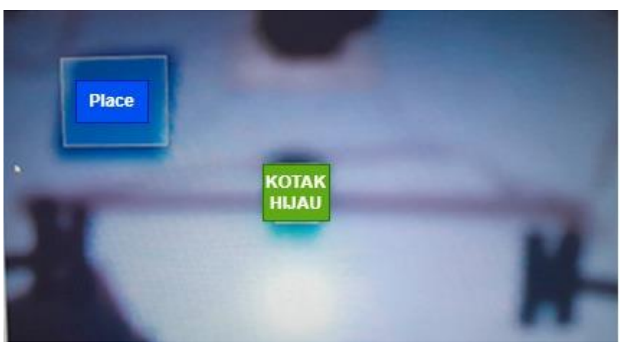

Fig. 3. Color Detection Test

We used Mean Absolute Error (MAE) to calculate the accuracy error between the x and y values of the camera angle and the actual position. Mean Absolute Error (MAE) is a metric for measuring the error of model predictions against actual values (1). Percentage Error (% Error) measures the relative error of the MAE to the average actual value (2).

$$MAE = \frac{1}{n}\sum_{i=1}^{n} \quad |Approximation_i - Actual_i| \qquad (1)$$

$$\%Error = \left(\frac{MAE}{Mean\ of\ Actual\ Values}\right) \times 100 \qquad (2)$$

III. RESULT AND DISCUSSION

In this research, the main focus is placed on testing a robot manipulator that is directed to execute a pick and place task by utilizing visual servoing techniques. Figure 2 served as the main guide in determining the manipulator's aim based on the angular data from the servo and xy values from the camera. The test procedure was carefully designed to create a situation that reflects real field conditions. The robot manipulator was programmed to respond to the angular data received from the servo, which is a key element in regulating the robot's motion and orientation.

The test data on the Pixy camera includes three objects with detected position information and the object's reference position. The first object has coordinates (405.00, 52.00) and a reference position (x_p, y_p) of (112.00, 205.00). The second object has coordinates (251.00, 106.00) with a reference position (x_p, y_p) of (270.00, 51.00). While the third object has coordinates (289.00, 114.00) with a reference position (x_p, y_p) of (278.00, 89.00). This test aims to verify the Pixy camera's ability to detect and track objects, and ensure that the detected position is close to the expected reference position. The results of this test can be used to optimize settings and ensure the accuracy of object detection by the Pixy camera... Object position (x,y) is the angle seen on the pixy camera that is communicated to the robot and object reference position (x p, y p) is the angle seen on the pixy camera but not communicated to the robot..

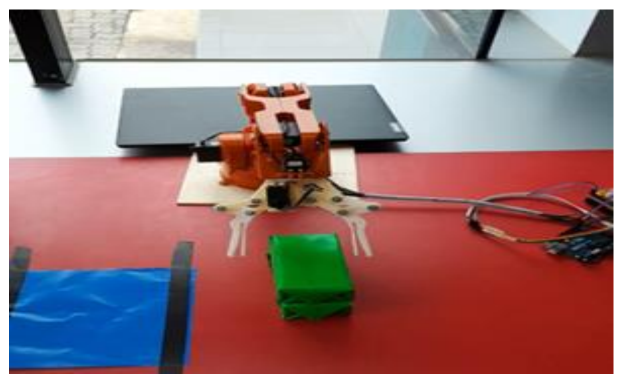

Fig. 4. Pick and place Data Collection

The results of this experiment are expected to provide better insight into the capabilities of the robot manipulator in pick and place operations as well as assist in the development and performance improvement of the manipulator. The test was conducted with a green colored object and a blue colored place holder, with the camera above the object. The pick and place test on the robot manipulator can be seen in Figure 4.

Table 1 shows that in the ten trials on the camera, there were three trials that showed slightly higher values in x-angle and slightly lower values in y-angle as expected. With an average error of 0.2469% for x and 7.6923% for y, which shows the accuracy of the visual servoing system or method. The servo pickup in the table is the servo angle value when the robot picks up the object and the servo place is the angle value when the robot attaches the object. An in-depth analysis of the experimental results shows that there are differences between the expected data and the observed data in three specific cases.

TABLE I
RESULT OF THE FIRST EXPERIMENT ON SERVO ANGLE AND CAMERA XY ANGLE

No.	Object Position (x, y)	Error X	Error Y	Object Reference Position (x_p, y_p)	Servo pick angle (a0, a1, a2, a3)	Servo angle place (a0, a1, a2, a3)
1	(405.00,52.00)	0	0	(112.00,205.00)	(97.32,85.85,0.73,49.41)	(126.87,57.78,37.48,40.73)
2	(405.00,52.00)	0	0	(112.00,205.00)	(97.32,85.85,0.73,49.41)	(126.87,57.78,37.48,40.73)
3	(406.00,48.00)	-1	-4	(116.00,206.00)	(96.74,85.71,0.89,49.40)	(126.87,57.78,37.48,40.73)
4	(405.00,52.00)	0	0	(112.00,205.00)	(97.32,85.85,0.73,49.41)	(126.87,57.78,37.48,40.73)
5	(405.00,52.00)	0	0	(112.00,205.00)	(97.32,85.85,0.73,49.41)	(126.87,57.78,37.48,40.73)
6	(405.00,52.00)	0	0	(112.00,205.00)	(97.32,85.85,0.73,49.41)	(126.87,57.78,37.48,40.73)
7	(405.00,52.00)	0	0	(112.00,205.00)	(97.32,85.85,0.73,49.41)	(126.87,57.78,37.48,40.73)
8	(405.00,52.00)	0	0	(112.00,205.00)	(97.32,85.85,0.73,49.41)	(126.87,57.78,37.48,40.73)
9	(406.00,48.00)	-1	-4	(116.00,206.00)	(96.74,85.71,0.89,49.40)	(126.87,57.78,37.48,40.73)
10	(406.00,48.00)	-1	-4	(116.00,206.00)	(96.74,85.71,0.89,49.40)	(126.87,57.78,37.48,40.73)

Table 1 shows that in the ten trials on the camera, there were three trials that showed slightly higher values in x-angle and slightly lower values in y-angle as expected. With an average error of 0.2469% for x and 7.6923% for y, which shows the accuracy of the visual servoing system or method. The servo pickup in the table is the servo angle value when the robot picks up the object and the servo place is the angle value when the robot attaches the object. An in-depth analysis of the experimental results shows that there are differences between the expected data and the observed data in three specific cases.

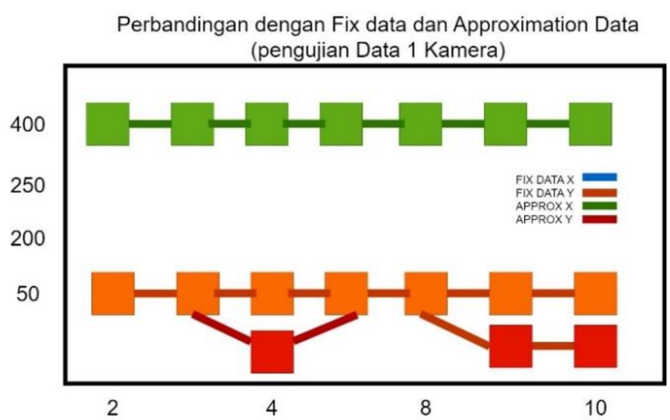

Fig. 5. Error Data Graph of The First Attempt on The Camera.

My research is supported by the significant data graph shown in Figure 5, which illustrates the comparison between the fixed and approximate data generated from the camera test. This graph visualizes four data sets with colors distinguishing each element, where blue and orange represent fixed data x and fixed data y, while green and red represent approximate data x and approximate data y, respectively. fix data is the data to be tested or the exact value and approximation is the error value of the camera. With camera fix data values x=405 and y=52.

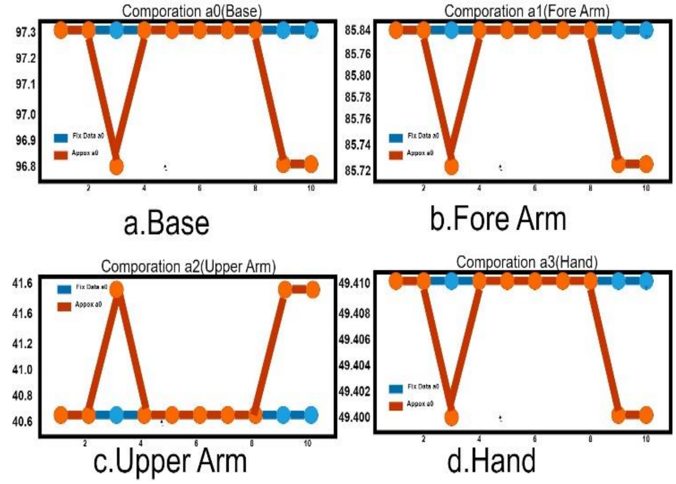

Fig. 6. Angle Graph During Object Capture

TABLE II
RESULT OF THE SECOND EXPERIMENT ON SERVO ANGLE AND CAMERA XY ANGLE

No.	Object Position (x, y)	Error X	Error Y	Object Reference Position (x_p, y_p)	Servo pick angle (a0, a1, a2, a3)	Servo angle place (a0, a1, a2, a3)
1	(250.00,104.00)	0	0	(270.00, 51.00)	(45.00,81.29, 5.81,48.90)	(126.87,57.78, 37.48,40.73)
2	(251.00,106.00)	-1	-2	(270.00, 51.00)	(45.00,81.29, 5.81,48.90)	(126.87,57.78, 37.48,40.73)
3	(250.00,104.00)	0	0	(270.00, 51.00)	(45.00,81.29, 5.81,48.90)	(126.87,57.78, 37.48,40.73)
4	(250.00,104.00)	0	0	(270.00, 51.00)	(45.00,81.29, 5.81,48.90)	(126.87,57.78, 37.48,40.73)
5	(251.00,106.00)	-1	-2	(268.00, 50.00)	(45.10,81.39, 5.81,48.80)	(126.87,57.78, 37.48,40.73)
6	(251.00,106.00)	-1	-2	(270.00, 51.00)	(33.69,67.89, 41.62,1.49)	(126.87,57.78, 37.48,40.73)
7	(250.00,104.00)	0	0	(268.00, 50.00)	(45.10,81.39, 5.81,48.80)	(126.87,57.78, 37.48,40.73)
8	(251.00,106.00)	-1	-2	(268.00, 50.00)	(45.10,81.39, 5.81,48.80)	(126.87,57.78, 37.48,40.73)
9	(250.00,104.00)	0	0	(270.00, 51.00)	(43.39,67.89, 41.62,1.50)	(126.87,57.78, 37.48,40.73)
10	(250.00,104.00)	0	0	(270.00, 51.00)	(43.39,67.89, 41.62,1.50)	(126.87,57.78, 37.48,40.73)

Figure 6 is supported by the relevant data graph, which illustrates the comparison between the fix data and the approximation data generated from testing the servo angles of the robot manipulator components, namely a0 (base), a1 (upper arm), a2 (lower arm), and a3 (hand). Based on the data in Figure 5, it can be concluded that the majority of the servo angle measurement results (a0, a1, a2, a3) in 10 trials are consistent with the expected values, namely (97.32, 85.85, 0.73, 49.41). However, there are three values that show an error or deviation from the expected value, namely (96.74, 85.71, 0.89, 49.40). The expected servo angle should be 97.32, but the measurement data shows a value of 96.74, indicating a deviation or error in the measurement results as shown in Figure 6. (a) Base. The expected servo angle should be 85.85, but the measurement data shows a value of 85.71, indicating a deviation or error in the measurement results as shown in Figure 6. (b) Upper arm. The expected servo angle should be 0.73, but the measurement data shows a value of 0.89, indicating a deviation or error in the measurement results as shown in Figure 6(c) Fore Arm. The expected servo angle should be 49.41, but the measurement data shows a value of 49.40, indicating a deviation or error in the measurement results as shown in Figure 5. (d) Hand.

Table 2 shows that in ten trials on the camera, there were three trials that showed slightly lower than expected x and y angle values. To find the average error is the same as the explanation in Table 1. With an average error value of 0.3984% for x and 1.8886% for y, which indicates the accuracy of the system or visual servoing method. The servo pickup in the table is the servo angle value when the robot picks up the object and the servo place is the angle value when the robot attaches the object.

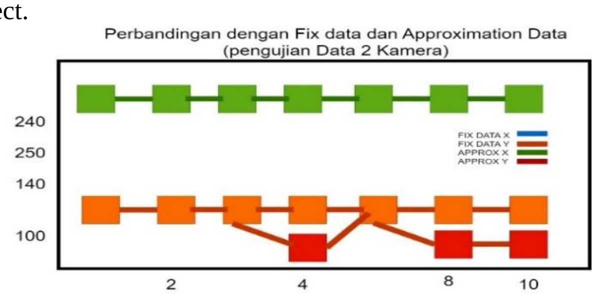

Fig. 7. Error Data Graph of The Second Experiment on The Camera.

My research is supported by the significant data graph shown in Figure 7, which illustrates the comparison between the fixed data and the estimated data generated from the camera test. This graph visualizes four data sets with colors distinguishing each element, where blue and orange represent fixed data x and fixed data y, while green and red represent approximate data x and approximate data y, respectively. fix data is the data to be tested or the exact value and appoximation is the error value of the camera. With camera fix data values x=251 and y=106.

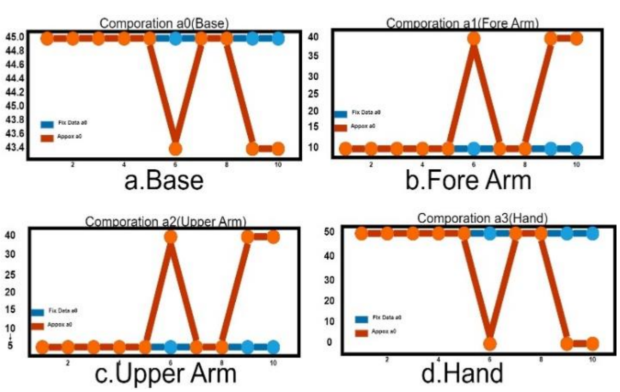

Fig. 8. Angle Graph During Object Capture

Figure 8 is supported by the relevant data graph, which illustrates the comparison between the fix data and the approximation data generated from testing the servo angles of the robot manipulator components, namely a0 (base), a1 (upper arm), a2 (lower arm), and a3 (hand).Based on the data in Figure 8, it can be concluded that the majority of the servo angle measurement results (a0, a1, a2, a3) in 10 experiments are consistent with the expected values, namely (45.00,81.29,5.81,48.90). However, there are three values that show an error or deviation from the expected value, namely (43.39,67.89,41.62,1.50). The expected servo angle should be 45.00, but the measurement data shows a value of 43.39, indicating a deviation or error in the measurement results as shown in Figure 8. (a) Base. The expected servo angle should be 81.29, but the measurement data shows a value of 67.89, indicating a deviation or error in the measurement results as shown in Figure 8. (b) Upper arm. The expected servo angle should be 5.81, but the measurement data shows a value of 41.62, indicating a deviation or error in the measurement results as shown in Figure 8(c) Fore Arm. The expected servo angle should be 48.90, but the measurement data shows a value of 1.50, indicating a deviation or error in the measurement results as shown in Figure 8. (d) Hand.

TABLE III
THRIED EXPERIMENT RESULT ON SERVO ANGLE AND CAMERA XY ANGLE

No.	Object Position (x, y)	Error X	Error Y	Object Reference Position (x_p, y_p)	Servo pick angle (a0, a1, a2, a3)	Servo angle place (a0, a1, a2, a3)
1	(289.00,114.00)	0	0	(278.00, 89.00)	(43.39,67.89,41.62,1.50)	(126.87,57.78,37.48,40.73)
2	(289.00,114.00)	0	0	(278.00, 89.00)	(43.39,67.89,41.62,1.50)	(126.87,57.78,37.48,40.73)
3	(289.00,114.00)	0	2	(278.00, 89.00)	(43.39,67.89,41.62,1.50)	(126.87,57.78,37.48,40.73)
4	(291.00,116.00)	-3	-2	(280.00, 91.00)	(33.69,67.89,41.62,1.49)	(126.87,57.78,37.48,40.73)
5	(291.00,116.00)	-3	-2	(280.00, 91.00)	(33.69,67.89,41.62,1.49)	(126.87,57.78,37.48,40.73)
6	(291.00,116.00)	-3	-2	(280.00, 91.00)	(33.69,67.89,41.62,1.49)	(126.87,57.78,37.48,40.73)
7	(291.00,116.00)	-3	-2	(280.00, 91.00)	(33.69,67.89,41.62,1.49)	(126.87,57.78,37.48,40.73)
8	(289.00,114.00)	0	0	(278.00, 89.00)	(43.39,67.89,41.62,1.50)	(126.87,57.78,37.48,40.73)
9	(289.00,114.00)	0	0	(278.00, 89.00)	(43.39,67.89,41.62,1.50)	(126.87,57.78,37.48,40.73)
10	(289.00,114.00)	0	0	(278.00, 89.00)	(43.39,67.89,41.62,1.50)	(126.87,57.78,37.48,40.73)

Table 3 shows that in the ten trials on the camera, there were three trials that showed slightly higher values in x and y angles than expected. To find the average value on the camera as described in table 1. With an average error value of 1.0380% for x and 1.7543% for y, which indicates the accuracy of the visual servoing system or method. The servo pickup in the table is the servo value when the robot picks up the object and the servo place is the angle value when the robot attaches the object. An in-depth analysis of the experimental results shows that there are differences between the expected data and the observed data in three specific cases.

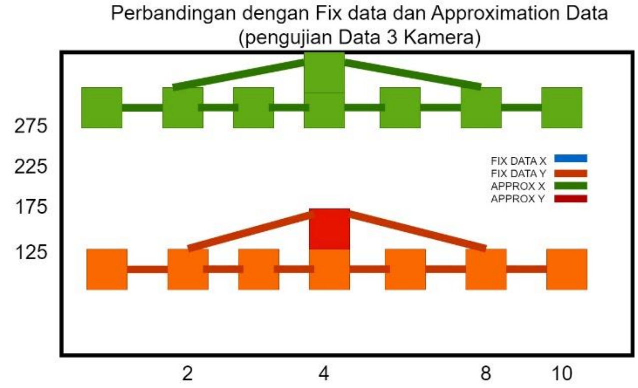

Fig. 9. Error Data Graph of The Third Trial on The Camera.

My research is supported by the significant data graph shown in Figure 9, which illustrates the comparison between the fixed data and the estimated data generated from the camera test. This graph visualizes four data sets with colors distinguishing each element, where blue and orange represent fixed data x and fixed data y, while green and red represent approximate data x and approximate data y, respectively. fix data is the data to be tested or the exact value and approximation is the error value of the camera. With camera fix data values x=289 and y=114.

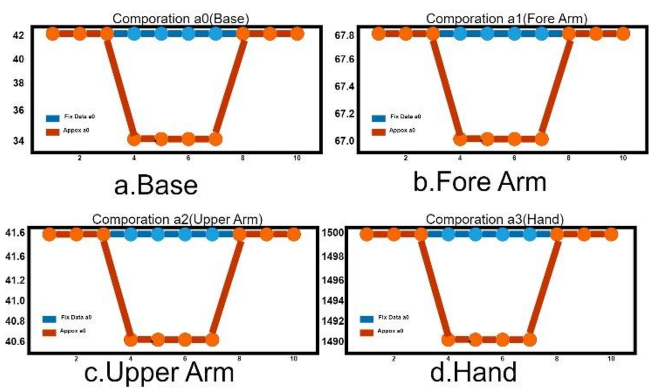

Fig. 10. Angle Graph During Object Capture.

Figure 10 is supported by the relevant data graph, which illustrates the comparison between the fix data and the approximation data generated from testing the servo angles of the robot manipulator components, namely a0 (base), a1 (upper arm), a2 (lower arm), and a3 (hand).Based on the data in Figure 10, it can be concluded that the majority of the servo angle measurement results (a0, a1, a2, a3) in 10 experiments are consistent with the expected values, namely (43.39,67.89,41.62,1.50). However, there are three values that show an error or deviation from the expected value, namely (33.69,67.89,41.62,1.49). The expected servo angle should be 43.39, but the measurement data shows a value of 33.69, indicating a deviation or error in the measurement results as shown in Figure 10. (a) Base. The expected servo angle should be 67.89, but the measurement data shows a value of 67.89, indicating a deviation or error in the measurement results as shown in Figure 10. (b) Upper arm. The expected servo angle should be 41.62, but the measurement data shows a value of 41.62, indicating a deviation or error in the measurement results as shown in Figure 10(c) Fore Arm. The expected servo angle should be 1.50, but the measurement data shows a value of 1.49, indicating a deviation or error in the measurement results as shown in Figure 10. (d) Hand.

IV. CONCLUSION

Based on the test results, it can be concluded that the visual servoing system on the robot manipulator is capable of performing pick and place against variations in object position. Although there is still error data in ten trials when detecting objects and when performing pick and place. Analysis of the average error on the X and Y axes shows that the first experiment is 0.2469% x value and 7.6923% y value and the average error value for the second experiment x is 0.3984% and 0.3984% for y value. Meanwhile, the third experiment showed poor performance with an X error value of 1.0380% and Y error of 1.7543%. This conclusion shows that the manipulator tends to be more precise in controlling the X-axis shift in the first two experiments, but faces significant challenges in the third experiment. However, it should be noted that the success of this system could be affected by certain environmental factors, such as lighting. As a recommendation for further development, further research should be conducted to improve the system's robustness to environmental variations. Further evaluation of the execution speed and object positioning accuracy can also be focused on.

ACKNOWLEDGMENT

The authors gratefully acknowledge the financial support from Barelang Robotics and Artificial Intelligence (BRAIL) and the Electrical Engineering Department of Batam State Polytechnic. The authors express their sincere gratitude to the dedicated members of the Visual Servoing robotics research division at BRAIL for their invaluable guidance. Special thanks to Mr. Ryan Satria Wijaya, research leader and advisor, for his excellent teaching and guidance throughout the completion of this paper, and finally, the authors would like to acknowledge the unwavering support of the family, especially the parents, who have been inspiring role models in the pursuit of academic goals. Thanks, are also extended to seniors and colleagues who have always helped and inspired the author.

REFERENCES

[1] N. D. Rao and J. Min, "Decent Living Standards: Material Prerequisites for Human Wellbeing," *Soc. Indic. Res.*, vol. 138, no. 1, pp. 225–244, 2018, doi: 10.1007/s11205-017-1650-0.

[2] C. Li, L. Zhao, and Z. Xu, "Finite-Time Adaptive Event-Triggered Control for Robot Manipulators With Output Constraints," *IEEE Trans. Circuits Syst. II Express Briefs*, vol. 69, no. 9, pp. 3824–3828, 2022, doi: 10.1109/TCSII.2022.3170084.

[3] M. A. Arteaga-Peréz, J. Pliego-Jiménez, and J. G. Romero, "Experimental Results on the Robust and Adaptive Control of Robot Manipulators Without Velocity Measurements," *IEEE Trans. Control Syst. Technol.*, vol. 28, no. 6, pp. 2770–2773, 2020, doi: 10.1109/TCST.2019.2945915.

[4] X. Liu, S. S. Ge, F. Zhao, and X. Mei, "Optimized Interaction Control for Robot Manipulator Interacting With Flexible Environment," *IEEE/ASME Trans. Mechatronics*, vol. 26, no. 6, pp. 2888–2898, 2021, doi: 10.1109/TMECH.2020.3047919.

[5] J. Cvejn and M. Zapletal, "Feedback control of robot manipulators by using gravity and inertial effects compensation," *Proc. 2019 20th Int.*

Carpathian Control Conf. ICCC 2019, no. 2, pp. 1–6, 2019, doi: 10.1109/CarpathianCC.2019.8765975.

[6] N. T. Nguyen, T. N. T. Nguyen, H. N. Tong, H. V. A. Truong, and D. T. Tran, "Dynamic Parameter Identification based on the Least Squares method for a 6-DOF Manipulator," in *2023 International Conference on System Science and Engineering (ICSSE)*, 2023, pp. 301–305. doi: 10.1109/ICSSE58758.2023.10227164.

[7] T. Dewi, P. Risma, Y. Oktarina, and S. Muslimin, "Visual Servoing Design and Control for Agriculture Robot; A Review," *Proc. 2018 Int. Conf. Electr. Eng. Comput. Sci. ICECOS 2018*, vol. 17, pp. 57–62, 2019, doi: 10.1109/ICECOS.2018.8605209.

[8] X. Liang, J. Gao, X. Zhao, and G. Pan, "Visual Servoing of a Redundant Underwater Vehicle-Manipulator System Using Receding Horizon Control," *Ocean. 2019 - Marseille, Ocean. Marseille 2019*, vol. 2019-June, pp. 1–5, 2019, doi: 10.1109/OCEANSE.2019.8866879.

[9] M. F. Aqillah, R. Mardiati, and A. E. Setiawan, "Prototype of Robot Movement Navigation System Using Pixy Camera (CMUCAM 5)," *Proceeding 2022 8th Int. Conf. Wirel. Telemat. ICWT 2022*, no. Cmucam 5, 2022, doi: 10.1109/ICWT55831.2022.9935409.

[10] C. Sampedro, A. Rodriguez-Ramos, I. Gil, L. Mejias, and P. Campoy, "Image-Based Visual Servoing Controller for Multirotor Aerial Robots Using Deep Reinforcement Learning," in *2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, 2018, pp. 979–986. doi: 10.1109/IROS.2018.8594249.

[11] J. Dong and J. Zhang, "A new image-based visual servoing method with velocity direction control," *J. Franklin Inst.*, vol. 357, no. 7, pp. 3993–4007, 2020.

[12] F. Mangkusasmito, T. H. Nugroho, B. R. Trilaksono, and T. Indriyanto, "Visual servo strategies using linear quadratic Gaussian (LQG) for Yaw-Pitch camera platform," in *2018 International Conference on Signals and Systems (ICSigSys)*, IEEE, May 2018, pp. 146–150. doi: 10.1109/ICSIGSYS.2018.8372655.

[13] Z. Xungao, X. Min, G. Jiansheng, Z. Xunyu, and P. Xiafu, "Robot manipulation using image-based visual servoing control with robust state estimation," *Proc. 30th Chinese Control Decis. Conf. CCDC 2018*, pp. 445–449, 2018, doi: 10.1109/CCDC.2018.8407174.

[14] S. D. Perkasa, P. Megantoro, and H. A. Winarno, "Implementation of a camera sensor pixy 2 CMUcam5 to a two wheeled robot to follow colored object," *J. Robot. Control*, vol. 2, no. 6, pp. 469–501, 2021.

[15] D. Ji *et al.*, "Design and development of autonomous robotic fish for object detection and tracking," *Int. J. Adv. Robot. Syst.*, vol. 17, no. 3, p. 1729881420925284, 2020.

[16] G. M. Omosekeji, "Industrial Vision Robot with Raspberry Pi using Pixy Camera: Stereo Vision System," 2018.

[17] J. H. Li, Y. S. Ho, and J. J. Huang, "Line Tracking with Pixy Cameras on a Wheeled Robot Prototype," *2018 IEEE Int. Conf. Consum. Electron. ICCE-TW 2018*, pp. 1–2, 2018, doi: 10.1109/ICCE-China.2018.8448948.

[18] H.-A. Phan *et al.*, "Development of a vision system to enhance the reliability of the pick-and-place robot for autonomous testing of camera module used in smartphones," in *2021 International Conference on Engineering and Emerging Technologies (ICEET)*, 2021, pp. 1–6.

[19] F. Nagata, K. Miki, A. Otsuka, K. Yoshida, K. Watanabe, and M. K. Habib, "Pick and place robot using visual feedback control and transfer learning-based CNN," in *2020 IEEE International Conference on Mechatronics and Automation (ICMA)*, 2020, pp. 850–855.

[20] Y. Zhou *et al.*, "Robust Task-Oriented Markerless Extrinsic Calibration for Robotic Pick-and-Place Scenarios," *IEEE Access*, vol. 7, pp. 127932–127942, 2019, doi: 10.1109/ACCESS.2019.2913421.

[21] A. Lobbezoo, Y. Qian, and H.-J. Kwon, "Reinforcement learning for pick and place operations in robotics: A survey," *Robotics*, vol. 10, no. 3, p. 105, 2021.

[22] K. A. Abdullah *et al.*, "Algebraic models based on trigonometric and Cramer's rules for computing inverse kinematics of robotic arm," *Int. J. Mechatronics Autom.*, vol. 9, no. 1, pp. 1–11, 2022.

[23] J. Liu and Z. Liu, "The Vision-Based Target Recognition, Localization, and Control for Harvesting Robots: A Review," *Int. J. Precis. Eng. Manuf.*, pp. 1–20, 2023.

[24] Z. Bassyouni and I. H. Elhajj, "Augmented reality meets artificial intelligence in robotics: A systematic review," *Front. Robot. AI*, vol. 8, p. 724798, 2021.

[25] A. Bonci, P. D. Cen Cheng, M. Indri, G. Nabissi, and F. Sibona, "Human-robot perception in industrial environments: A survey," *Sensors*, vol. 21, no. 5, p. 1571, 2021.