Performance of Yaskawa Motoman Industrial Robot under Loaded Conditions and Various Distances

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***Abstract*—Introducing robotics into the manufacturing process brings benefits such as an increase in productivity, cost reduction and waste minimization. Robotic equipment is highly accurate with repeatability capability to perform various works. It is important for robot users to know the robot's current performance compared to its technical specification to ensure its suitability for the current task. Yaskawa Motoman MH5F is an industrial robot commonly used in material handling application. The aim of this project is to investigate the accuracy and repeatability of this robot for different payload and various distances using laser interferometry method. An interferometer is a clear-cut instrument designed to measure objects accurately. Laser interferometry uses the interference method of two or more waves for the purpose of recognizing contrasts between them. There were 12 sets of experiments conducted. For each set of load and distance, the experiment was repeated for 30 times. Results show that the robot repeatability and accuracy value obtained are ±0.0047 mm and ±0.237 mm respectively. Hence, this proved that Yaskawa Motoman MH5F robot has better repeatability compared to the robot's technical specification, which is ±0.02 mm. Regression analysis carried out using Microsoft Excel displayed the only repeatability against distance factor showing positive linear correlation. For further improvement, this experiment can be carried out with various weight and different distances to identify the machine's maximum capability.**

***Keywords*—Industrial Robots; Accuracy; Repeatability; Yaskawa Motoman MH5F Robot; Laser Interferometry**

I. INTRODUCTION

Robot is a powerful element, which is capable of performing many various tasks and operations accurately without requiring common safety and comfort elements humans need[1]. An industrial robot is a manipulator configuration to move materials or parts and execute a selection of modified tasks in manufacturing and production settings. Robots can be customized to do an extraordinary number of various motions and work with the speed and effectiveness of automated specific purpose machine [2].

The Robot Institute of America defines the industrial robot as a programmable, multi-purpose manipulator intended to transfer material, tools or specified devices through variant programmed movements for the performance of various jobs [3]. It is also called as a robotic manipulator or arm because of the popular appearance of the industrial robot, which is the same as an arm with waist, shoulder, elbow and wrist. The payload or weight lifted by the robot affects the accuracy and repeatability of the robots. Repeatability is considered much more important compared to accuracy because the robot has been set or programmed to perform a task and to repeat it. However, due to some factors, the positional errors occurred and affect the production performance [4].

The main obstacle in robotics applications is the positional errors that always occur, when it is under real working conditions. This implies that robots have to perform accurately under loaded conditions at any location within the working envelope. The aim of this study is to evaluate the performance of an industrial robot under payload and various distances within its working envelope. The first objective is to investigate the accuracy and repeatability of the Yaskawa Motoman MH5F robot using laser interferometry method. The second objective is to analyse the performance of Yaskawa Motoman MH5F robot in terms of accuracy and repeatability for different payload and various distances.

II. LITERATURE REVIEW

A. Industrial Robot

The industrial robot manipulators are the modern handling machines that display better accuracy and repeatability. Compared with the human arm, robot manipulators utilize the initial three joints (arm) to position the structure, and the rest of the joints (wrist) are utilized to situate the end-effector. There are five common types of industrial robot manipulators such as the cartesian, cylindrical, polar, articulated or joint arm and SCARA robot [5].

The science fiction author, Isaac Asimov had introduced the Three Laws of Robotics [6]:

- A robot may not injure a human being or its inaction allowed humans to be in harm.
- A robot must obey the orders given to it, except where such orders would conflict with the First Law.
- A robot must protect its own existence as long as such protection does not conflict the First and Second Law.

In the industrial world, some of the tasks are unrealistic for humans to perform due to the danger of the occupation such as casting and welding work with the extraordinary temperature environment that would be unsafe for a person.

B. Accuracy

Accuracy is defined as the precision movements of the robot capable to make to a specific point in 3-D space [7]. Accuracy is the most extreme position or orientation fault gain when moving to any point characterized in Cartesian space. This amount is reliant upon a totally characterized frame of reference. This is a set reference point on the frame commonly for robots. Hence, to link up with a different part of the work cell, this point is utilized.

The example of accuracy without precision can be seen in Figure 1. It shows the four black dots that almost hit the target point but those dots are not close to each other. Meanwhile, Figure 2 shows the four black dots are located far from the target area, but next to each other, which represent the example for precision without accuracy.

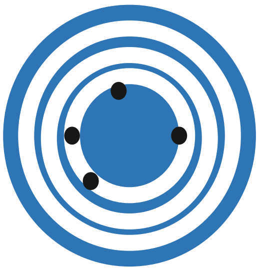

Figure 1: High accuracy, but low precision

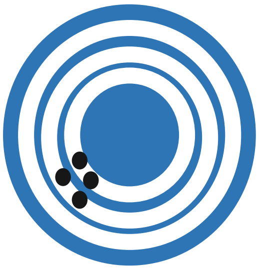

Figure 2: Low accuracy, but high precision

C. Repeatability

Repeatability shows the capacity of a robot to come back to the desired point again and again [8]. This point is normally put away as an arrangement of joint orientation, not really characterized in Cartesian space. As a two-dimensional robot is a move to a similar position in a certain time, the diameter of the least circle enclosing a set of points that show the real end point of each motion is measured as the repeatability. Thus, to apply a level of certainty to this amount, it is necessary to identify the actual procedure for its acquisition.

This may incorporate a standard deviation for the point fixed, the quantity of points drawn, a specification of the external tool used for estimation, the quantity of areas inside the work envelope considered, the quantity of axes utilized as a part of the motion, payload size utilized during testing and so on. For higher dimensional area, it turns out to be more complex. Without a clarification of how the particular is derived, a single repeatability detail given for a six-level flexibility robot has minimal importance. Likewise, the movements utilized as a part of the test may have basically been joint-based moves requiring no kinematic calculations. This thus gives no measure of the precision of the kinematic model. The repeatability description basically determines the maximum error.

The term repeatability had been characterized as a factual term connected with exactness; it portrays how a point is replicated [9]. A research found that a robot joint is told to move by a similar edge from a specific point of various circumstances, all with equivalent natural conditions. It will be found that the resultant movements prompt to contrasting removals. Figure 3 shows an example of a representation of resolution, accuracy and repeatability of a robot arm.

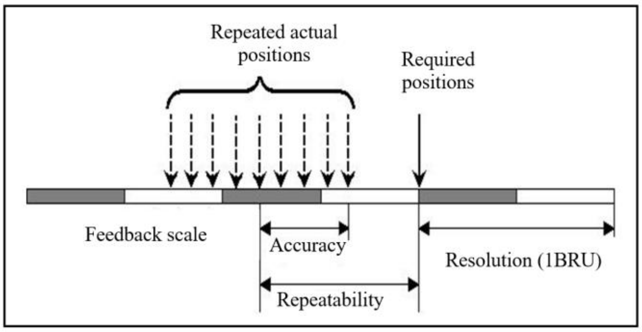

Figure 3: Example of representation of resolution, accuracy and repeatability [9]

D. Laser Interferometry

Interferometry is the method of interfering two or more waves, which are utilized to recognize the contrasts between them. This works are based on the principle that two waves with a similar recurrence and have a similar stage will add to each other, while two waves that have inverse stage will subtract [10]. Regularly, in an interferometer, a wave is separated into (at least two) sound parts, which travel distinctive ways and the parts are then consolidated to make interference.

The main exhibit of utilizing light impedance standards as an estimation instrument was accomplished by Albert A. Michelson in the 1880’s by building up the main interferometer. A Michelson interferometer comprises of a beam splitter (half-silvered mirror) and two mirrors.

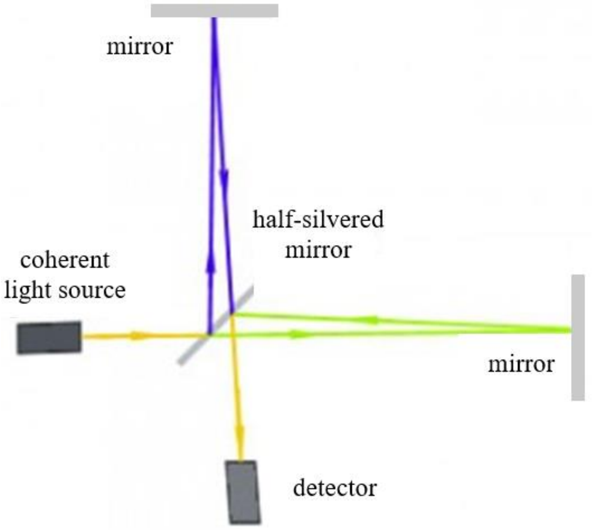

Figure 4: Basic Michelson interferometry diagram

At the point when the light experiences the half-silvered reflect/bar splitter (which is incompletely reflecting), it is divided into two shafts with various optical ways (one going to mirror 1 and the other going to mirror 2). After being reflected back at the mirrors, these bars recombine again at the pillar splitter before touching the base at the finder. The contrast of these two bars causes a stage distinction, which makes an impedance periphery design. The basic Michelson interferometry diagram is shown in Figure 4.

III. METHODOLOGY

The preparation of the methodology is to make sure the result for the performance of the Yaskawa Motoman MH5F (Figure 5) robot, including the accuracy and repeatability of planning and expected. The procedure is set up according to the scopes of the project for the purpose of achieving the objective stated. This robot has a maximum allowable payload of 5 kg and its specified repeatability is ± 0.02 mm. The maximum horizontal and vertical reach in its working envelope is 706 mm and 1193 mm respectively.

Figure 5: Yaskawa Motoman MH5F robot

The flowchart showed in Figure 6 describes the overall process involved to obtain the final results, starting from the preliminary study on literature review, experimental setup and process, experimental method and data analysis. The methodology also covers the equipment or apparatus used in the experiment and the setup of apparatus before starting the experiment.

The first stage explains the preliminary study related to the project scopes from reviewing the articles and journals. The reviews on the previous studies cover the industrial robot’s application, industrial robot components, robot performance characteristics, robot calibration methods and comparison for significant findings in each journal and articles. The preliminary studies give a clear view and knowledge of the project title and scope as well as the procedure or experimental setup in using laser interferometry method. This will help to determine the best method in conducting the experimental work in order to gain the best possible results.

The second stage describes the setup for the experiment from the beginning until the end of the experimental work. The setup starts with the robot programming to determine the linear movement of the robot along its specific axis, and then continues with the laser interferometer setup. The laser interferometer system requires perfect alignment of the laser from the source to the measurement optic placed at the end effector of the robot. Next, the distance is set, and the load is added to the robot arm. The experiment started for the first set and continue its performance by changing the distances and loads for each subsequent set.

The final stage shows the result and data gathered from the completed experiment. The data were analyzed and arranged into tabulated form using a statistical software, which is the Microsoft Excel before generating a graph from the results.

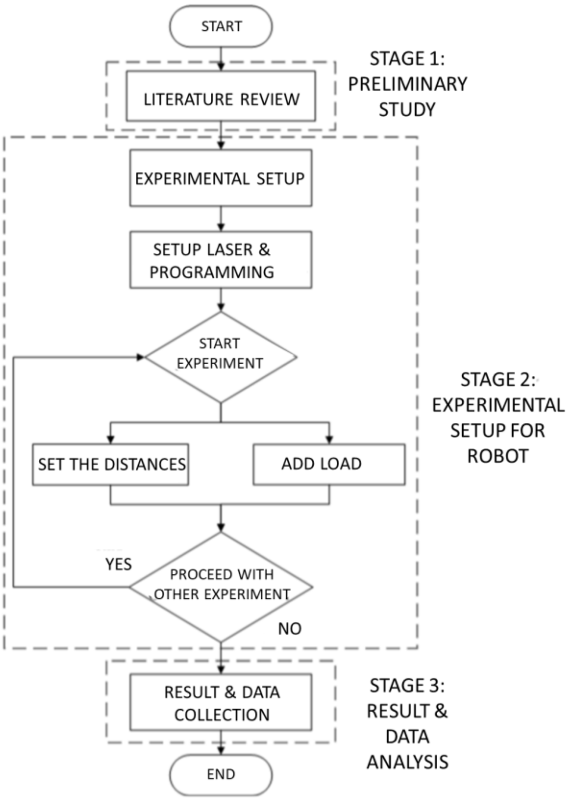

Figure 6: Methodology flowchart

A. *Renishaw’s Laser Interferometer System*

The set of Renishaw’s Laser Interferometer System showed in Figure 7 consists of XC80 compensator with a temperature sensor and XL80 laser. The Renishaw’s Laser Interferometer System utilizes a non-contact method to measure the slight movement and vibrations on the object’s mirror reflection. Once the object had moved, the wavelength of laser change was recorded and can be observed in the QuickViewXLTM

Figure 7: Renishaw’s laser interferometer system

software. Laser interferometer position measurement systems provide a very precise position or distance information for dimensional measurements or motion control. The laser system gives a great accuracy and dynamic performance of linear measurement accuracy, which is an assured ± 0.5 ppm.

B. *Microsoft Excel Software*

Microsoft Excel is the statistical software used to conduct the correlation analysis to determine the performance of the robot by analyzing the experimental data. The first step is to find the relationship between the load with the repeatability and accuracy of the robot. The second step is to investigate the relationship between robot repeatability and accuracy with respect to various distances travelled by the robot. Then, the results obtained from the correlation analysis were compared with the robot specifications from the manufacturer.

C. *Loads and Distances*

The experiment was conducted using the loads of 10N, 25N and 40N, which were added to the robot. However, the robot also will be carrying no load as the comparable value with each of the three loads. The experiment has been set into three different distances; 100 mm, 300 mm and 500 mm.

For this experiment, the Yaskawa Motoman MH5F robot has been programmed to move in a linear movement on the x-axis which will be separated into three distances: 100mm, 300mm and 500mm. The delay around 15 seconds at the end point is needed in considering the ability of the XL80 Renishaw's Laser System to record the constant data. Hence, the robot will move from the starting point (point A) and delay for 15 seconds at endpoint (point B).

The XL80 Renishaw's Laser System starts recording the data during the delay time. After that, the robot will return back to the point A where it first starts. The laser has been a program to measure a unidirectional direction, which means the data is being recorded only from point A to point B.

Figure 8 shows the position of the linear reflector on the table and laser interferometer mounted at the end-effector. Loads used are mounted using F-clipper on top of the robot's link.

Figure 8: The actual experimental setup in the laboratory.

IV. RESULTS AND DISCUSSION

At the end of the experiment, results have been gathered and managed. The summarized data for linear repeatability and linear accuracy were arranged and presented in Table 2 and Table 3 respectively.

A. *Repeatability Data*

The repeatability value is calculated using this equation:

$$Repeatability = \frac{\sum_{i=1}^{N} \sqrt{(x_i - \bar{x}\,)}^{\,2}}{N} \qquad (1)$$

Where the number of experiment are 30 and represent by N, x_i shows experiment reading and $\bar{x}$ equals to the mean.

Table 2
Repeatability data

Distance	Load				Average
	0 N	10 N	25 N	40 N	
100 mm	0.0039	0.0045	0.0045	0.0029	0.0040
300 mm	0.0046	0.0053	0.0050	0.0045	0.0049
500 mm	0.0063	0.0054	0.0054	0.0045	0.0054
Average	0.0049	0.0051	0.0050	0.0040	**0.0047**

B. *Accuracy Data*

The data captured by the laser system had been calculated using this equation:

$$Accuracy = \frac{\sum_{i=1}^{N} \sqrt{(x_i - x_{comanded})}^{2}}{N} \qquad (2)$$

where N represents the number of experiment with totalof 30, xi signifies actual reading and $x_{commanded}$ equals to the target Value

Table 3
Accuracy data

Distance	Load				Average
	0 N	10 N	25 N	40 N	
100 mm	0.425	0.418	0.407	0.404	0.413
300 mm	0.198	0.143	0.135	0.096	0.143
500 mm	0.236	0.185	0.131	0.070	0.156
Average	0.286	0.249	0.224	0.190	**0.237**

C. *Data Analysis*

The graph for repeatability and accuracy is developed by using the Microsoft Excel software by constructing the linear line to identify the correlation of repeatability and accuracy against the load and distance. On top of that, the equation that has been used is:

$$y = mx + C \qquad (3)$$

where y represents the value of y-axis, x represents the value of x-axis, m signifies gradient and C equals to point of the line crossed at the y-axis. From the equation shown, both repeatability and accuracy graph against load and distance is developed, including the linear line and the equation as well. The graph of different load and various distance data are plotted based on the results of the equation. Figure 9 below shows the plotted graph for linear accuracy against the different load placed on top of robot arm's link.

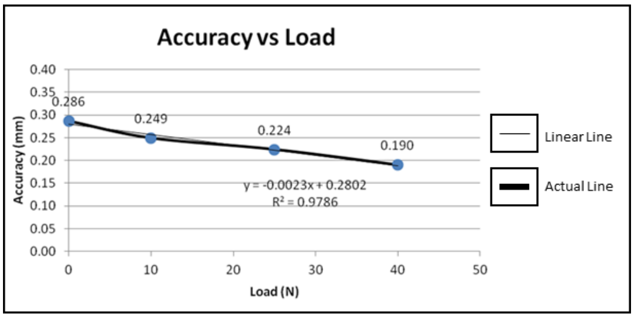

Figure 9: Accuracy against Load

From the graph constructed, it shows that the change in the load carried by the robot arm caused a significant change in accuracy of Yaskawa robot. The trend of the plotted data tends to be consistent, indicating the changes of accuracy error is consistent. The value of accuracy is decreased from 0.286 mm to 0.249 mm when the robot arm carried 10N loads from none before. When the load increased from 10N to 25N and 25N to 40N, it shows the accuracy error decreased with the value 0.025 mm and 0.034 mm respectively.

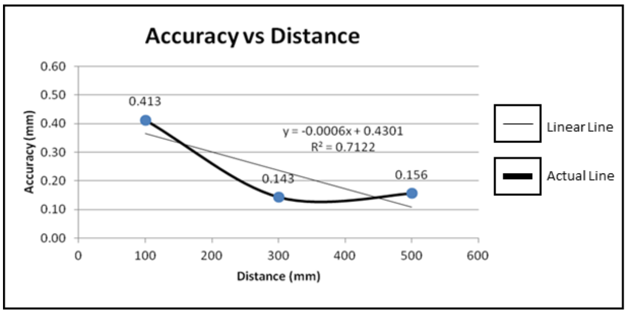

Figure 10: Accuracy against Distance

Figure 10 shows the plotted graph of accuracy against various distances. The trend of the plotted data shows inconsistently from one point of measurement to another.

Based on the graph, the distance travel by the robot arm shows there is a quite significant change in the accuracy of the robot. The change of error is found to be inconsistent. It shows that significant changes as much as 0.27 mm with the increasing distance travel of robot arm from 100 mm to 300 mm. As the robot arm travels from 300 mm to 500 mm, there is only a slight change of 0.013 mm in an accuracy error.

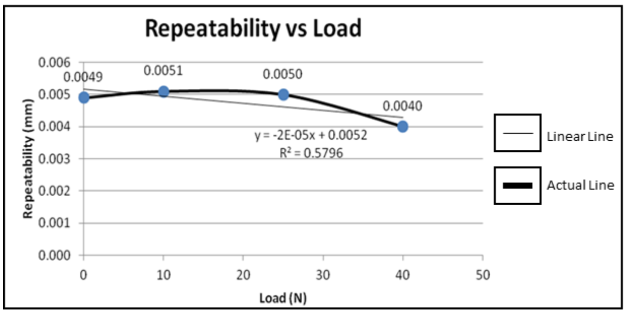

Figure 11: Repeatability of Load

Figure 11 below shows a graph of robot repeatability against load carried by the robot. This graph shows an inconsistent trend of plotted data between the robot repeatability and load. Based on the graph, it was found that the robot has good repeatability specification, where the load from 0 to 10N causes minor changes of 0.0002 mm. There is only a slight change in repeatability error, which is 0.0001 mm when adding a load of 10N to 25N. However, the accretion load of 25N to 40N results in major changes of the repeatability error of 0.001 mm.

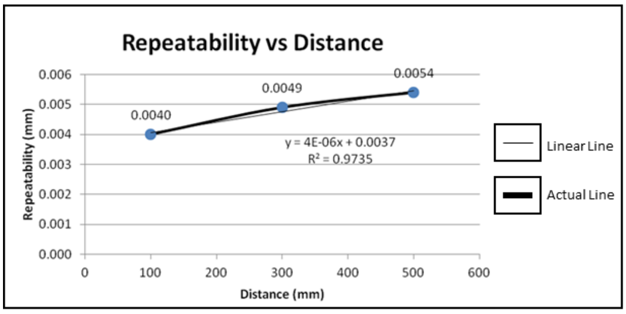

Figure 12: Repeatability against Distance

The graph for the repeatability of robot against distance is shown in Figure 12 below. This graph shows a linear relationship between the performance repeatability with the distance travelled by the robot arm. It was found that the robot has better repeatability performance where it only causes minor changes of 0.0009 mm during its movement from the distance of 100 mm to 300mm. However, the robot repeatability error decreased to 0.0005 mm when it travels to 500 mm distance. The regression analysis using Microsoft Excel showed that the factor of the robot has a positive linear correlation with the performance of this robot repeatability. From that, it can be concluded that the distance factor directly affects the repeatability of the robot.

The experimental results were compared with previous studies [11] [12]. Based on the studies that utilized laser interferometer to measure repeatability and accuracy, the robot FANUC Robot Arc Mate 100i reached the overall accuracy and repeatability of 2.215mm. The experimental results did not meet the technical specifications provided by the manufacturer, which quoted an accuracy and repeatability of ±1mm. In comparison to these studies, Yaskawa Motoman MH5F met the technical specification of ± 0.02 mm.

V. CONCLUSION

Based on the experiment, the Yaskawa Motoman MH5F robot shows good performance in terms of repeatability and accuracy. This is proven with the repeatability value that has been obtained from the experiment is better than the value provided by the Yaskawa manufacturer, which is ± 0.02 mm compared to the experimental value of ± 0.0047 mm.

Among the four-analysis conducted at the end of the experiment, it proves only robot repeatability against distance factor has the positive linear correlation. Meanwhile, another three pairs of repeatability and accuracy against load and distance factors have negative linear correlation.

As a conclusion, the project is a success considering the result and the analysis obtained had achieved the objectives of analyzing the performance of Yaskawa Motoman MH5F robot under loaded conditions and various distances.

The experiment provides insufficient information to obtain better analysis, even though this analysis can be concluded as a success. For future works, it is suggested to add more data for each of the factor in the experiment to obtain more plotted data on the graph. For instance, it is advised to add more loads such as 15N, 20N, 30N and 35N to the Yaskawa Motoman robot as long as the overall loads do not exceed the maximum payload. Similar actions should be made to the distance factor, in which more distances such as 200 mm and 400 mm during the experiment should be added. At the same time, the distance can be increased to see the maximum value of error in the robot.

In addition, a better way of mounting loads on the robot needs to be devised. In other words, the load should be mounted or placed at the end effector of the robot instead of its fifth joint. Then, an additional robot attachment can be invented so that it fits to the existing robot end effector.

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