Advances in Social Science, Education and Humanities Research, volume 242
2nd International Conference on Vocational Education and Training (ICOVET 2018)

A 2-DoF Robot Arm Simulation for Kinematics Learning

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Abstract.--Most of the robotics research papers are focused on robot competition and only a few papers discuss on robot education and robot teaching. This research is focused on robot education with the help of simulation to give students more freedom to determine the robot movement so that the trial and error cycle can be avoided during the lesson. The simulation is developed for simple 2-DoF robot arm kinematics and can be used to simulate the movement of SCARA robot. The simulation was tested on industrial robotics class of 22 students. The student response for subject, interface and benefits aspects show positive results with the summary of all aspect is 80 %, indicating this simulation is acceptable.

Keywords--robot arm, simulation, 2-DoF, kinematics

I. INTRODUCTION

The development of robotics technology nowadays is growing very rapidly. Especially in the industrial revolution 4.0 era, the robots will be more utilized than ever [1]. Many industries are switching the role of the human with the robot because it can be programmed to do a repetitive task without weariness [2]. Consequently, robotics becomes a more important subject, especially for engineering students.

However, in Indonesia, students' knowledge in robotics are used mainly for competition with more than 40 universities took a part in Indonesian robot contest [3]. Moreover, 93% of robotics research papers worldwide are also focused on robot competition [4]. Only a few papers discuss robot education and robot teaching. Therefore, there are many open problems that can be explored on how to teach robotics effectively.

Learning robot arm, used in the industrial robot, requires a comprehensive understanding of kinematics theory [5]. It includes the forward kinematics and inverse kinematics theory. With many equations, kinematics become a very challenging subject for an engineering student. The practical implementation of robot arm also requires the calculation of each movement. Thus, the utilization of simulation for calculating and visualizing in kinematics can be beneficial for students.

This research is focused on robot education with the help of simulation in Matlab. A 2-Degree-of-Freedom (DoF) Robot Arm simulation is developed to give students more freedom to determine the robot movement so that the trial and error cycle can be avoided during a lesson. Furthermore, the results of the simulation can be applied to SCARA robot for practical implementation.

Robot Arm Kinematics

Kinematics is a branch of mechanics that describes the motion of objects without reference to the forces that cause the motion. Kinematics in industrial robot concerned with the position and orientation of the robot end effector relative to the robot joints angle. There are two kinematics analyses on robot manipulator, forward kinematics and inverse kinematics. Forward kinematics is the process of calculating the position and orientation of end effector based the angle of joints. On the other hand, inverse kinematics is the calculation of the angle of joints when given the end effector position and orientation. The latter term is more useful in practice since the working space on human perception is usually mapped in a Cartesian coordinate system.

However, inverse kinematics requires complex mathematical analysis, especially in the higher degree of freedom (DoF). Taking an example of 2-DoF forward kinematics analysis depicted with a kinematic trigonometric diagram on figure 1. The equation to calculate the end effector point are given in equation 1 through equation 4.

$$x_1 = L_1 \cos\theta_1 \tag{1}$$

$$y_1 = L_1 \sin\theta_1 \tag{2}$$

$$x_2 = x_1 + L_2 \cos(\theta_1 + \theta_2) \tag{3}$$

$$y_2 = y_1 + L_2 \sin(\theta_1 + \theta_2) \tag{4}$$

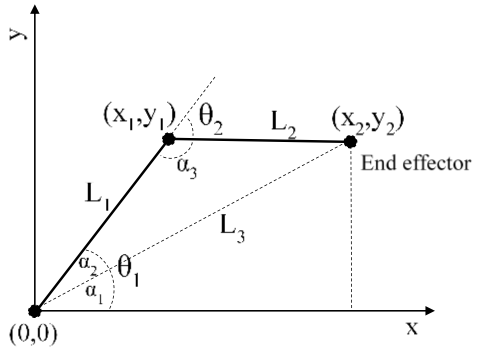

Figure 1. Kinematic Trigonometric Diagram for 2-DoF Manipulator

Furthermore, the inverse kinematics equations to calculate the angle of joints based on the end effector point are given in equation 5 through equation 9.

$$\alpha_1 = \tan^{-1}\frac{y_2}{x_2} \tag{5}$$

$$\alpha_2 = \cos^{-1}\left(\frac{L_1^{\,2} + L_3^{\,2} - L_2^{\,2}}{2L_1L_3}\right) \tag{6}$$

$$\alpha_3 = \cos^{-1}\left(\frac{L_1^{\,2} + L_2^{\,2} - L_3^{\,2}}{2L_1L_2}\right) \tag{7}$$

with $L_3 = \sqrt{x_2^{\,2} + y_2^{\,2}}$, the results are as follows:

$$\theta_1 = \alpha_1 + \alpha_2 \tag{8}$$

$$\theta_2 = \alpha_3 - 180^o \tag{9}$$

The complexity of the above equations is relatively lower than 6-DoF robot arm kinematics. In conclusion, the more degree of freedom a robot has, the more complex the kinematics calculation.

Robot Arm Simulation

In order to program the robot arm manipulator, students are required to know the angle of joints on every move. Since calculating inverse kinematics manually is not a practical approach, a robot arm simulation is developed to calculate those problems automatically.

The purpose of this simulation is to give students more freedom to determine the robot movement so that the trial and error cycle can be avoided during a lesson. Moreover, programming a simulation also provides practical experience for students on implementing theoretical equations into a programming language.

A Matlab based simulation was developed to meet the challenge in robot kinematics. The flow chart of the simulation is shown in figure 2. There are three subfunctions in the simulation, invkin, forward kinematic and animation. Those functions are then used in the main simulation program of SCARA Robot.

The invkin function is used for converting the Cartesian point data into joint angles data. The joint angles data are then used for calculating the point of each joint and robot end effector by using forward kinematic function. Finally, the points of each joint and robot end effector are used for visualizing robot arm using animation function.

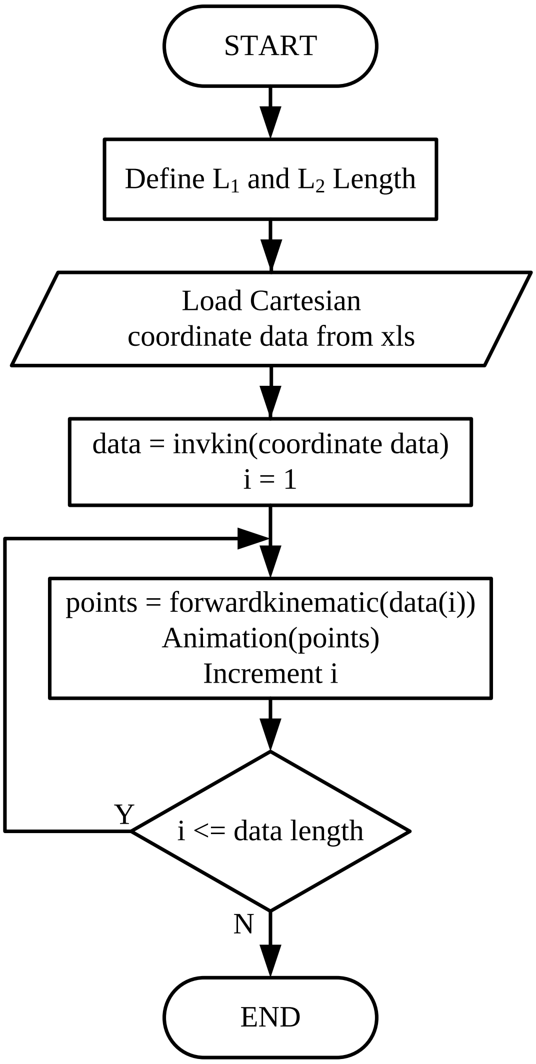

Figure 2. Simulation Flow Chart

The simulation was tested with several challenges including marks points, draws lines, creates 2D objects and writes letters. The simulation result for writing letters S is shown in figure 3. The simulation result shows a perfect S shape with many points. However, the simulation will slow down when drawing too many points. Therefore, for animation purpose, the points are reduced by sampling the points with an interval. The simulation can still produce many points for inverse kinematics to be used in the practical SCARA robot arm.

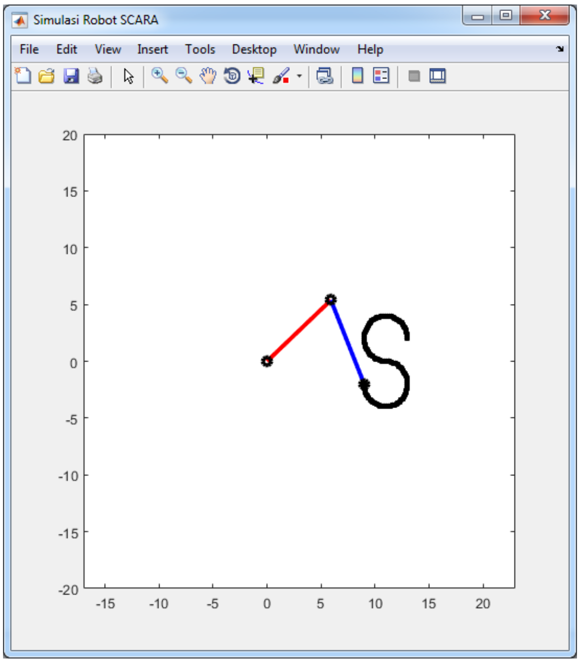

Figure 3. Simulation Result

II. METHOD

This research uses a quantitative approach, which is an inquiry employing operational definitions for generating numeric data to answer predetermined hypotheses [6]. The type of research used in this study is descriptive research. This study describes the students' response to kinematics simulation in industrial robotic class.

The population of this study is electrical engineering education students in Surabaya state university. From this population, a group sample of 22 students who have an interest in robotics was drawn for pre-experiment. The students are then taught kinematics theory using programming simulation for 50 minutes. Then, they are required to fill a questionnaire about the simulation used for robotic learning.

A questionnaire was designed with 11 questions including three aspects which are subjects, interface, and benefits. Question number one until four are asking about the subject, question number five until eight are asking about interface and question nine until eleven are asking about benefits. The subject-related questions measure the suitability of the subjects. Then, the interface-related question measures the ease and the attractiveness of the simulation. Last, the benefits-related questions measure how much benefits of the simulation for students' learning process. All of those questions are given to the students after they learn using simulation.

III. ANALYSIS AND RESULT

The questionnaire results are presented in table 1. These results show that the students' response for robot arm simulation gives a positive result. Moreover, the numerical data show a normal distribution with an average score of 4 in every question. The score for subject-related questions provides clear conclusions that the robot arm simulation accords with the kinematics subject. It also simplifies learning kinematics, making the subject easier to understand. This is because the simulation can visualize how the robot works so that the information received by students is not in the form of abstract information [7].

The score for interface-related questions shows that this simulation is easy to use, interesting and clear. Moreover, the functions and how the learning media works can be understood easily. The robot arm motion is the key point in increasing students' interest in kinematics. The next point shows that this learning media has benefits in increasing the motivation of students and making the class more active.

Table 1. The Questionnaire Result.

No	Question	Answer				
		1	2	3	4	5
1	The robot arm simulation is in accordance with the subject			5	11	6
2	Robot arm simulation can simplify kinematics lessons			5	10	7
3	The subject is easier to be understood using the robot arm simulation			7	11	4
4	The robot arm simulation can shorten learning time		1	6	11	4
5	The robot arm simulation is easy to use			7	10	5
6	The robot arm simulation is interesting			4	13	5
7	The robot arm simulation appearance is easy to follow			5	12	5
8	The functions and the ways of working are clear and easy to understand			5	11	6
9	The robot arm simulation improves students' motivation and interest			3	15	4
10	The robot arm Simulation makes the student more active			4	14	4
11	The robot arm Simulation is useful for practical application			4	12	6

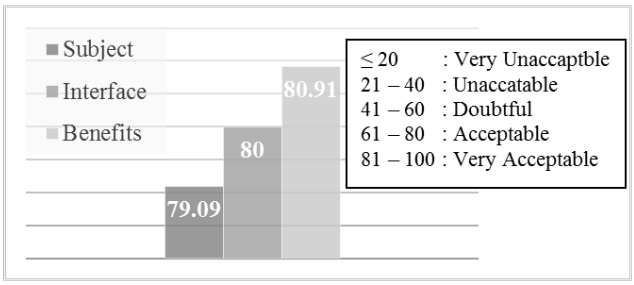

Figure 4. The result summary

The summary result for each aspect presented by figure 4. The bar graph shows that the aspect of subject and interface was acceptable and the aspect of benefits was very acceptable. The numerical data from the table are summed together using the formula below:

$$\text{Result} = \frac{\sum ObtainedPoin}{\sum MaxPoin} \times 100\% \qquad (10)$$

From table 1, the total points of the respondents' answer are 967 while the total maximum point for the questionnaire is 1210. Using the above formula, the result for the questionnaire is 80%, showing this media is acceptable.

IV. Conclusion

A 2-DoF robot arm simulation has been successfully implemented for kinematics learning. The simulation provides practical experience for students on implementing theoretical equations into a programming language. It also gives students more freedom to determine the robot movement, so that the trial and error cycle can be avoided during a lesson.

The students' response to the simulation shows that the simulation is easy to use, interesting and beneficial with the score of 79.09% for the subject, 80% for the interface and 80.91% for the benefits. In conclusion, the quantitative results show the average score for all aspects is 80%, indicating the simulation is acceptable.

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