Modelling and proportional-integral-derivative controller design for position analysis of the 3-degree of freedom

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ABSTRACT

A closed-loop system or which can also be known as a feedback system helps the system to achieve the desired output by comparing the input and the output values. If any difference is detected, the closed-loop system will create an error signal and automatically responds to it. Other than that, the proportional-integral-derivative (PID) controller has a feedback mechanism. Thus, this creates the curiosity whether the closed-loop system and PID which both have the characteristic of a feedback system, can give the same. In this paper, the comparison of the model of 3 degree of freedom (DOF) Mitsubishi RV2-AJ is being made between two models of a robot arm that has a closed-loop system but only one that is embedded with PID controller while the other one is not, these two are simulated for different positions. The new model is created by using Solidworks which is later exported to Matlab-Simulink. The results from MATLAB-Simulink show that the model which is equipped with a PID controller has better results in terms of the rise time and percentage of overshoot. These results confirm the effectiveness of PID controller in producing smaller errors in the systems even when both models are created together with closed-loop systems.

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1. INTRODUCTION

An industrial robot is a specialized machine tool that best for the task of repetition and suitable whether the task is needed to be handled skilled or semi-skilled and the task that needs precision [1]. The robot has taken over the job from humans that include repetitive and dangerous tasks. Such dangerous tasks may include working with radioactive materials, toxic chemicals, cotton lint, coal dust, asbestos fibres or working under conditions in outer space, undersea or even in deep mines. These unfit working scenarios may give dangers, side effects or bring fatality if being carried out by humans, thus making the robot as substitutions in this working area is a good move [2], [3]. Mostly, industrial robotics are used in the applications of die casting, forging, investment casting, machine tool loading and unloading, parts transferring, spray painting, small parts assembling, electronic assembling, finishing, plastic molding, spot welding, arc welding, machining and inspecting. The characteristics of the industrial robot consist of hand, wrist, arm, base, lifting power, repeatability, manual control, automatic control, memory, a library of programs (programmed by the user), safety interlocks, speed of operation, computer interface, reliability and easy maintenance.

There are five types of industrial robotics in total which are cartesian, cylindrical, selective compliance assembly robot arm (SCARA), polar and anthropomorphic. The industrial robotic arm that is used in this paper is Mitsubishi RV2-AJ that has five degree of freedom (DOF) as it has five joints which makes the robotic arms fall under the type of anthropomorphic robot arm where anthropomorphic means human-shaped by its definition. Mitsubishi RV2-AJ is one small and compact robot arm however offers the maximum speed of 2000 mm/sec and position repeatability of ±0.02 mm [4]. As mentioned earlier, Mitsubishi RV2-AJ is small, thus the maximum load that Mitsubishi RV 2-AJ can handle is only 2 kg which is suitable for the task of handling a small workload, placing and separating small parts. Figure 1 shows the dimensions of 5-axis of Mitsubishi RV2-AJ while Table 1 shows clearer data on the rotation angle.

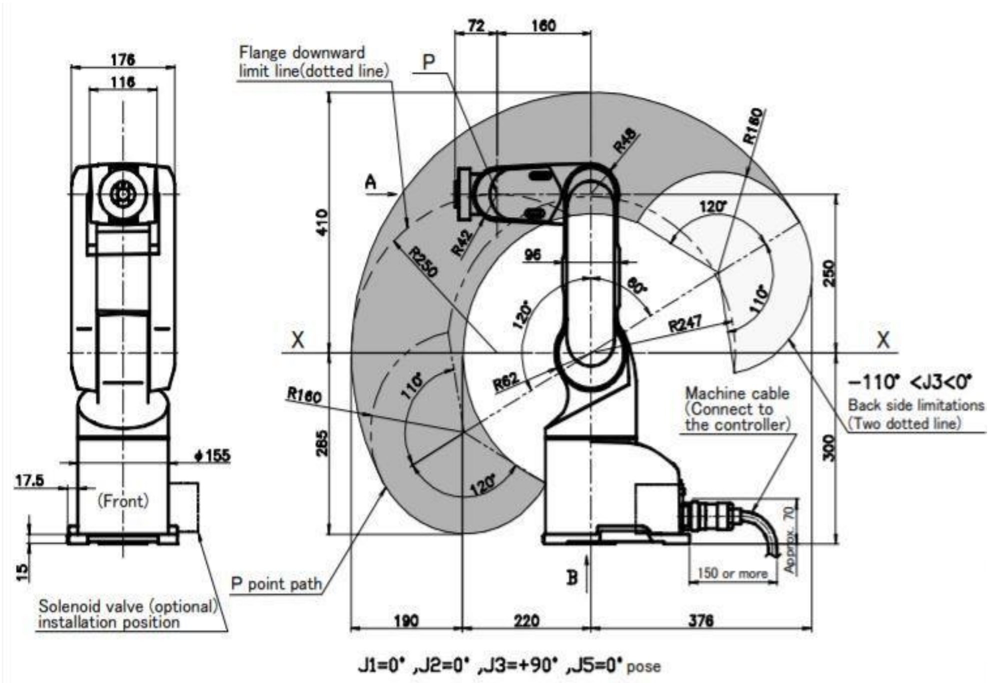


Figure 1. The dimensions of 5-axis Mitsubishi RV2-AJ [5]

Table 1. Rotation range for RV-2 AJ [6]

Joint	Range of Angle
Base rotation	-150° to +150°
Shoulder rotation	-60° to +120°
Elbow rotation	-110° to +120°
Wrist pitch	-90° to +90°
Wrist roll	-200° to +200°

Modelling can be done mathematically [7]–[9], virtual geometric using software such as solidworks [10], [11] and Dymola [12]. When modelling using virtual geometric, the real dimensions are used to build a model. However, smaller parts which does not affect much towards the dynamics of the robot is not modelled together, as it would be difficult and require excessive processing power for a personal computer (PC) [11].

Simulation is an imitation of a process or situation, which is usually run in the virtual environment. Implementation of the simulation in the testing of the robotic arm is helpful in the industry as the simulation enables the robot arm to be tested in hazardous and endless complicated situations without having to worry about the danger that could be potentially received by both humans and the industrial robot arm. The advantage of applying simulation is that the simulation makes the troubleshooting process easier. The simulation can be made using the application OpenGL [13], MATLAB [6], [11], [14]–[16] and Dymola [12], [17], [18].

A controller is the brain for the robot. Over time, there are many embedded controllers built and proportional-integral-derivative (PID) controllers have been around for many years in the industry and are still valid to be used in current technologies. PID controller may be the simplest to be designed and implemented and also inexpensive if being compared to the other controller. However, it still can provide an efficient solution towards the industrial applications [8].

PID stands for proportional-integral-derivative and as there are three actions comprised in one controller thus the name, PID [18]. PID law has been to design control input where it will provide stability towards the system as it has a feedback control loop mechanism and has been used as a feedback controller [7], [15], [19], [20]. This is actually how it works, P will determine the reaction to the current error which can lead to improvement of rise time while I, determine the reaction of the summation towards the recently appeared error which can reduce the steady-state error and as for D, determine the reaction following the rate of error changing which means D can predict the future error based on the rate of the current changed which can reduce the overshoot [21]–[23]. PID can be used on its own or even hybrid with another algorithm such as genetic algorithm (GA), particle swarm optimization (PSO), bat algorithm (BA), fuzzy logic et cetera [8], [21], [24]–[29].

2. METHOD

The method are starts with the modelling in Solidwork which later be converted into MATLAB-Simulink. The schematic drawing is achieved by the conversion and later proceed with embedding the PID controller. Two schematic drawings are shown to show the difference between the model with and without PID controller that affects towards the position of the robotic arm.

2.1. Modelling of industrial robotic arm

The model of the Mitsubishi RV2-AJ industrial robotic arm is built-in Solidworks using the dimension that is shown in Figure 1. However, for this paper, Mitsubishi RV2-AJ is modeled only for 3 joints as this paper only focused on 3 DOF. Each part of the body is modelled separately where small parts like screws and later each part of the modelled robotic arm is assembled later at the end to make the robotic arm as a whole. Figure 2 shows the model of Mitsubishi RV 2-AJ that is built in 3 DOF using Solidworks which consist of Joint 1 (J1), Joint 2 (J2) and Joint 3 (J3).

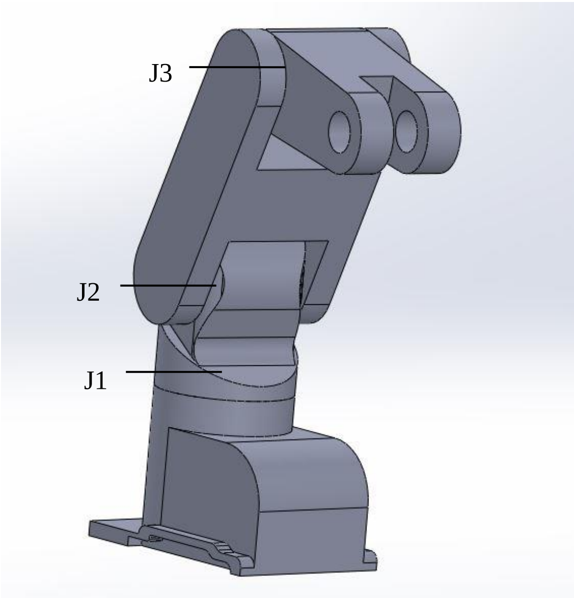
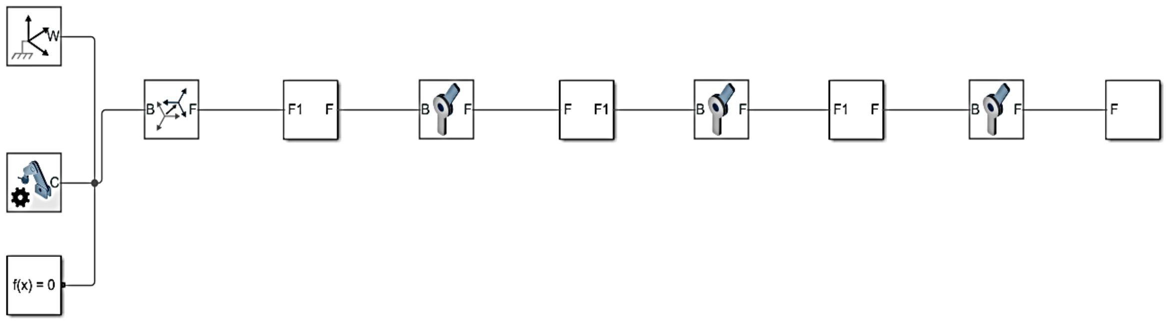


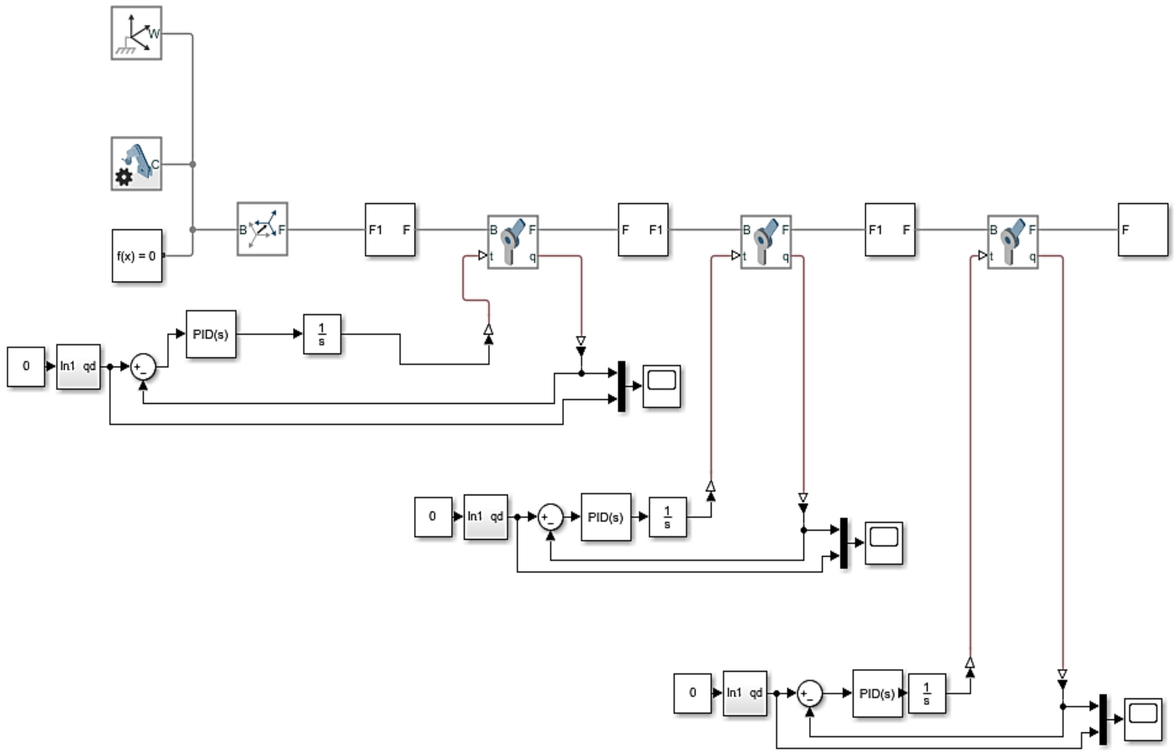
Figure 2. The model of Mitsubishi RV2-AJ built-in 3 DOF using Solidworks

2.2. Comparison towards the response of the joints with and without embedded PID controller

After the completion of the whole model in Solidworks, the model are then converted into the format of (.xml) file using the Solidworks extension, “Simscape Multibody Link”. This is due for the the Matlab-Simulink to open the file as schematic diagram in Figure 3. Figure 3(a) below shows the result of the model robot arm after conversion while Figure 3(b) shows the PID controller are embedded to the model robot arm.



(a)



(b)

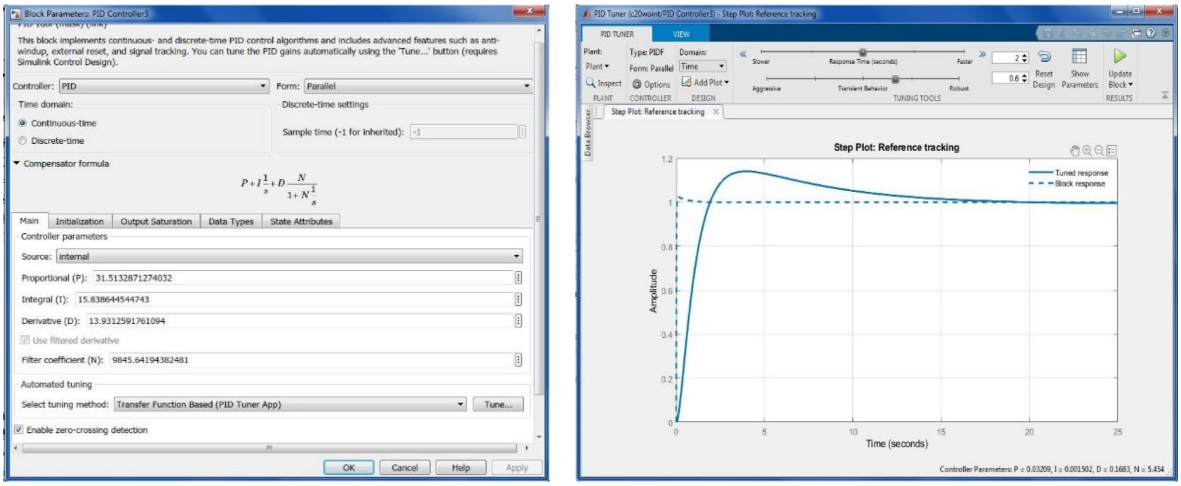
Figure 3. The schematic diagram for the modelled robot arm in (a) MATLAB-Simulink after conversion and (b) with PID attached to each joints

Two models of Mitsubishi RV2-AJ is created which both of them is created with closed-loop systems to make the systems stable as it can help to achieved and maintain the desired output. However, only one model is embedded with a PID controller while the other one is not as this is to create the comparison towards the presence of PID controller could make in the model. The initial position of the mode is set to be 0°. The model is moved to the position of 100° for the significant results to be seen for comparison purposes.

2.3. Varied position towards the model with PID controller

Each of the joints (J1, J2 and J3) has their own PID controller attached to them as the value of P, I, and D values are varied between those three joints. The approach used to determine the parameter of the P, I and D using transfer function based (PID Tuner App) which is shown in Figure 4. The 'Tune' button will bring out the step plot which is the reference tracking for tuned and block response that is shown in Figure 4. From the tuned response as a reference, the block response can be modified by sliding the response time by going slower or faster and as for the transient behaviour slide from the aggressive or robust until the block response nearly match the tuned response. Figure 4(a) shows the block parameter for PID controller while 4(b) is the reference tracking for both tuned and block response.

The position of the robot arm's model that is embedded with PID controller is varied from 0°, 20°, 40°, 60°, 80°, 100°, and 120° for three joints (J1, J2 and J3) according to the range of rotation on Table 1. This is to identify the stability of the system that is affected on J1, J2 and J3 with the presence of a PID controller that has been embedded to the system.



(a) (b)

Figure 4. PID tuner App for (a) block parameter for PID controller and (b) reference tracking for both tuned and block response

3. RESULTS AND DISCUSSION

3.1. Response of the joints with and without embedded PID controller

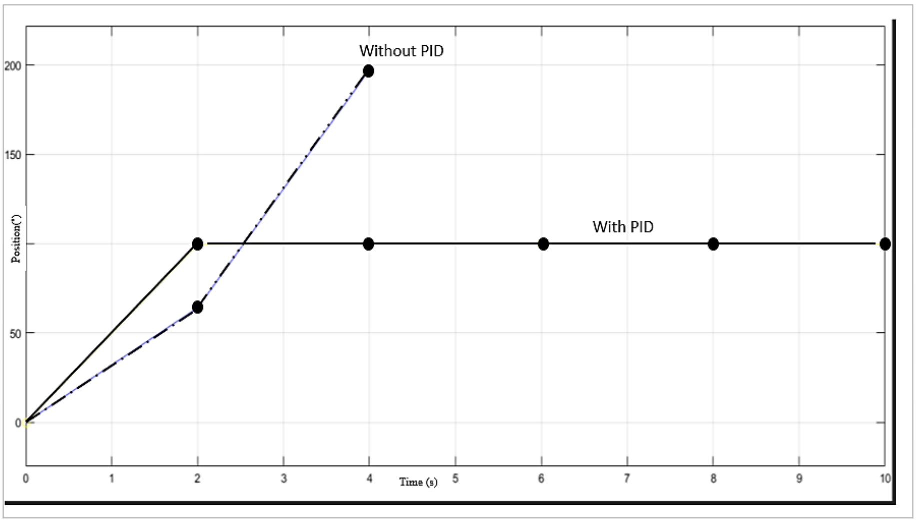
The three individual joints of the model arm are being tested with and without the PID controller. As the result of the joints response which are shown in Figure 5. Figures 5(a), 5(b) and 5(c) shows the output graph of response with and without PID at the position of 100° at different joints. From the graph reading, with the help of MATLAB-Simulink tools which can extract the value of overshoot percentage and rise time which can be seen in Table 2.

From the Figure 5 where are the response without the PID does not live up to the value input while the model robot that is equipped with PID controller are controlled and work at the specific value which has been set at 100° which shows the consistent and stable graph reading. With the help of Matlab-Simulink tools, the results of overshoot percentage and the rise time of the model that is equipped with PID controller are the only one that is managed to get extracted as for the model without PID controller cannot be extracted. This is because from Figure 5 itself, the graph reading without PID controller is inconsistent and unstable which shows instability towards the system and this proves with the presence of PID controller which has the feedback mechanism that can correct the output and came out to be stable.

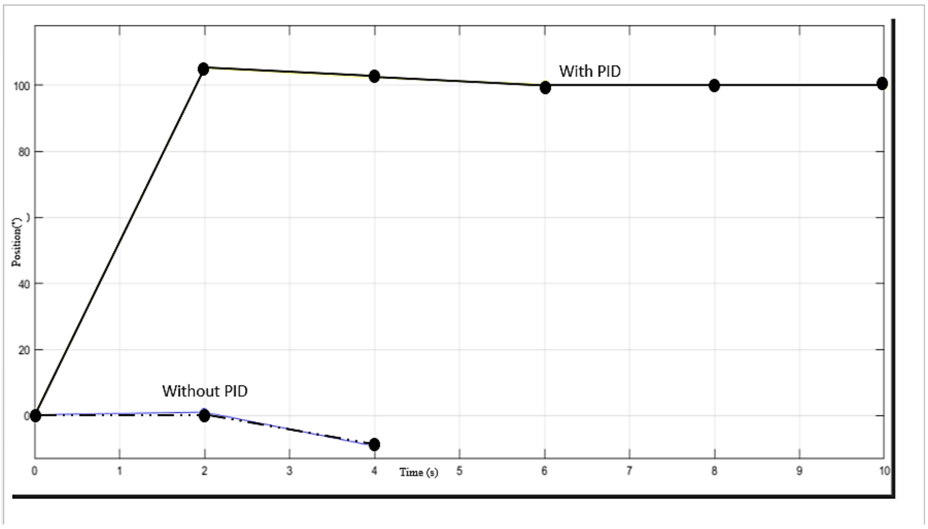
3.2. Value variation of position with PID controller

From Table 2, the redult are better in the model arm that is embedded with PID controller. In this section, the value of position is varied on the model arm that is embedded with PID controller. As the result, Figures 6(a), 6(b) and 6(c) are the graph reading when the position is varied at 0°, 20°, 40°, 60°, 80°, 100° and 120° while Table 3 show the response towards the rise time and the percentage of the overshoot at J1, J2 and J3 which is affected to the positions vary.

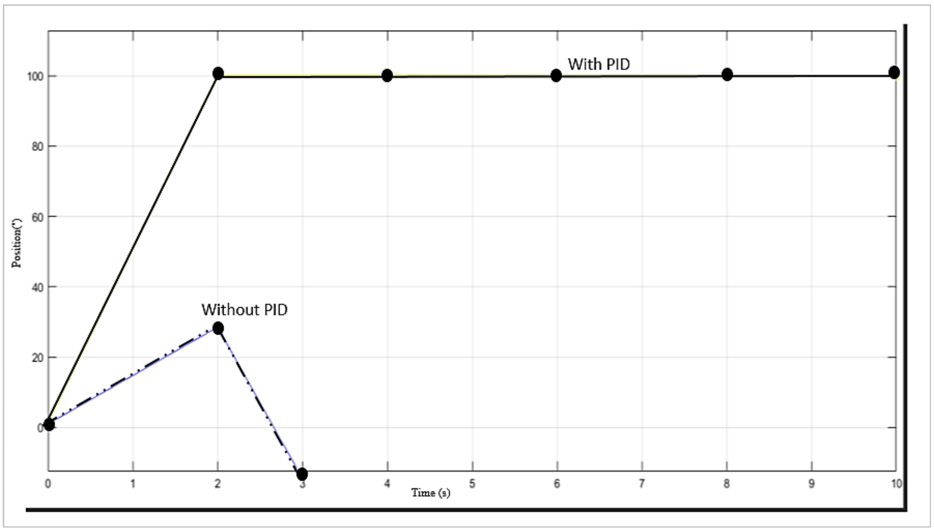
The graph also shows that the model that is embedded with the PID controller is consistent and stable even when the position is varied. The maximum rise time of three joints (J1, J2 and J3) in 1.59 s. However, the lower rise time is more desirable in the system as it will describe the system with the fastest response. The highest percentage of overshoot at J1 is 0.505% at the position of 60° and 80° while J2 is at 8.152% at the position of 120° and last but not least, J3 is at 1.531% at position 120°. A lower value of percentage of overshoot is also more desirable in a system as the output with the desired output does not have much difference.



(a)

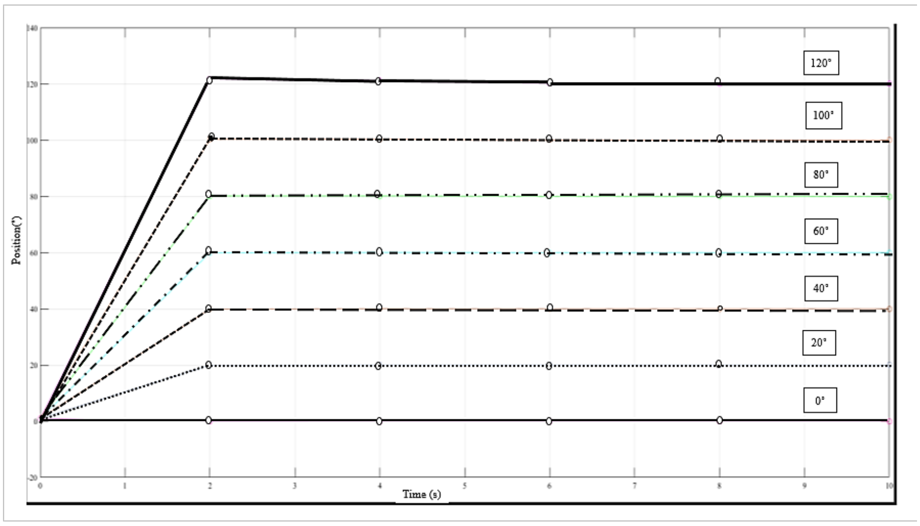


(b)

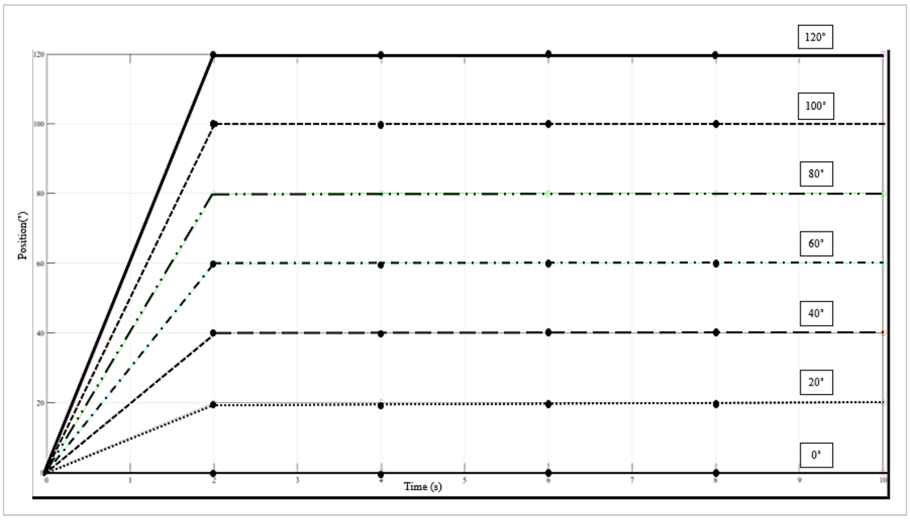


(c)

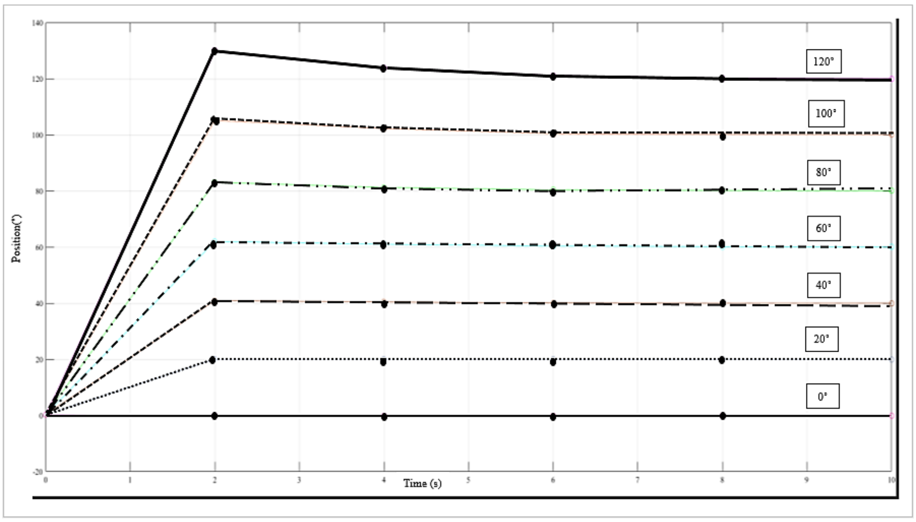
Figure 5. The differences of response with and without PID at the position of 100° located at (a) J1, (b) J2 and (c) J3



(a)



(b)



(c)

Figure 6. The result of (a) J1 (b) J2 and (c) J3 graph reading of the position against time of model RV2-AJ at 0°, 20°, 40°, 60°, 80°, 100° and 120°

Table 2. The result of percentage overshoot and rise time with and without PID at the position of 100° located at J1, J2 and J3

	Without PID		With PID	
Joint	Over-shoot (%)	Rise Time (s)	Over-shoot (%)	Rise Time (s)
J1	∞	∞	0.499	1.589
J2	∞	∞	4.737	1.520
J3	∞	∞	0.505	1.585

Table 3. The results of J1, J2 and J3 towards the overshoot and rise time against the position

Position (°)	Overshoot (%)			Rise Time (s)		
	J1	J2	J3	J1	J2	J3
0	-0.477	-13.259	-0.401	-	-	-
20	0.498	0.505	0.505	1.588	1.587	1.589
40	0.505	2.577	0.505	1.588	1.552	1.588
60	0.505	3.646	0.505	1.589	1.536	1.587
80	0.500	3.646	0.505	1.589	1.536	1.584s
100	0.499	4.737	0.505	1.589	1.520	1.585
120	0.496	8.152	1.531	1.589	1.472	1.567

4. CONCLUSION

In this paper, the simulation model of RV2-AJ is built into two where one is embedded with PID and one without the PID to make a comparison of the two outputs. The graph shows the model that is embedded with PID controller is more stable when compared to the model which is not. In conclusion, this shows even when the system that is equipped with a closed-loop system do not have the same or near to the system that has PID controller embedded to it even when both closed-loop and PID controller has the characteristic of a feedback system. Other than that, the stability of the system remained steady even when the position is varied. This proved that the feedback mechanism that the PID controller possessed can help to make the system stable.

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