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POSITION CONTROL OF ARM MECHANISM USING PID CONTROLLER

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ABSTRACT

This paper presents the application of rotary encoder for a motion of a gripper mechanism using PID controller. The approach consists of a robotic arm's whose movement are controlled by a brush DC motor. The brush DC motor shaft was mounted to the rotating wheels where a rope and pulley system was used to lift the robotic arm. The strategy of feedback compensation is used when controlling a system using a PID controller. With the presence of rotary encoder enables the microcontroller to control the speed of the robotic arm with the PID controller. As results, the robotic arm can be operated smoothly and achieved the desired position compared to the ON and OFF controller. The program using PID controller has been created with the microcontroller as the controller for the system. The robotic arm has been interface with rotary encoder and implemented with PID controller and it is possible for any robotic application if the feedback signal is provided.

Keywords: *Gripper Mechanism, PID Controller, Rotary Encoder, Robotic Motion*

1. INTRODUCTION

Robotic Arm controller is the challenging and demanding activity in industrial field as well as military and other applications. Robots are generally used to do unsafe, dangerous, highly repetitive, and unpleasant tasks which have many different functions such as material handling, assembly, arc welding, resistance welding, machines tool load and unload functions, painting, spraying, etc [1].

A robotic arm is a robot manipulator, normally programmable with analogous functions to a human arm. Usually robots are set up for a task by the teach-and-repeat technique. Therefore, a portable control device (a teach pendant) is used to teach a robot its task manually by a trained operator (programmer). Robot speeds during these programming sessions are slow [2].

Robot localization has been acknowledged as one of the problem in robotic [3]. Positioning technique such as odometry still seems to be effective and relatively cheap method of providing robot with current position. Basically, the method of estimation for a wheel-type robot's position employ the rotation encoder (also called odometry system) of a wheel, etc. as shown in works of [4], [5], [6] and [7].

The requirement for precision position sensors is based on a diversity of industries that need precision motion. Normally, a rotary electromagnetic motor actuates using gearing arrangement. The measurement of a gearing ratio is calculated between the motor and the motion stage. When the gearing ratio is high, then a relatively low resolution rotary position sensor at the motor will result in high resolution motion measurements at the motion stage [8].

The demands for advanced technology in various fields have inspired the development of small or uncomplicated systems. For instance, the direct-drive motion systems will obtained very high positioning resolution. The absence of gearing in these systems denotes that higher resolution position sensors are required to achieve the greater positioning precision.

Direct drive rotary motors can generate high torque and enable precision servo control over very small angles. The load of rotary motor is coupled directly to the drive as a result reducing the need for transmission components that introduce backlash, hysteresis, gear tooth error or belt stretch. Therefore, their dynamic reaction is excellent. A ring encoder provides an appropriate solution, better than the frameless format of torque motors with great internal diameter offers no obvious

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coupling to fit a shaft encoder. Additionally, the ring encoder is coupled rigidly to the drive, eliminating "play" in the system. Whatever the application, reliable direct position feedback is the key [9].

The most recognizable position feedback solution is a rotary encoder. In tuning and selecting the correct rotary encoder, it is depends on a convincing requirement specification, knowledge of the factors affecting encoder precision and a good understanding of how performance shortfalls may be overcome to get an accurate position of a motion mechanism. In this project, the rotary encoder is used to get an accurate position of an arm mechanism and it is applied to a robot application.

2. METHODOLOGY

The project starts by design and constructing of arm mechanism and electronic circuit for the mechanism. Then it continues with program development and tuning the PID controller. Finally, demonstrate rotary encoder application on the arm mechanism using the tuned PID controller to locate the arm at the desired position. The entire project development is illustrated in Figure 1.

A. MECHANICAL MODULE

The design concept of the arm is to pick the object from one place and place it to another place. From initial study, the gripper is designed to grip the object from the allocation of the starting gripper is on the open grip which the gripper then will grip the object if only it the arm arrive at object location and the gripper design consist of movable part. Figure 2 shows the constructed lifting mechanism for the robotic arm

The designed structure of the arm mechanism consists of two poles connected each other with the lifting system. The lifting movement of the arm mechanism was design using the three rollers to move along each pole. The pulley system have to be used in order to lift the robotic arm since direct mounting of the brush DC motor to the robotic arm results in the brush DC motor unable to lift the robotic arm due to insufficient torque. Two DC motor was used for the lifting system rather than one DC motor such to increase the lifting speed and torque. Figure 3 shows the pulley system used in the lifting system of robot arm.

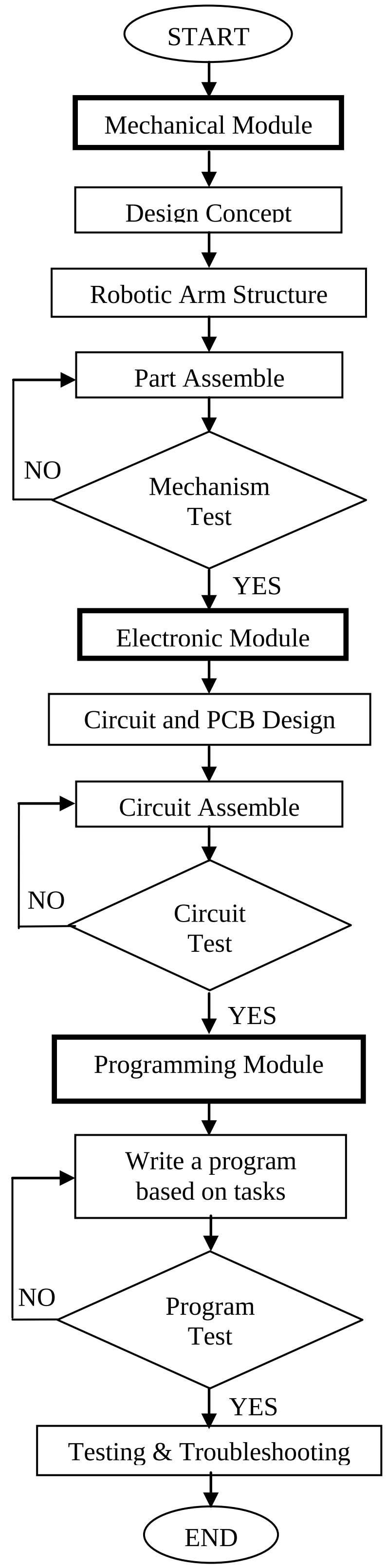

Figure 1: Robotic Arm Development

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Figure 2: Robotic Arm Structure

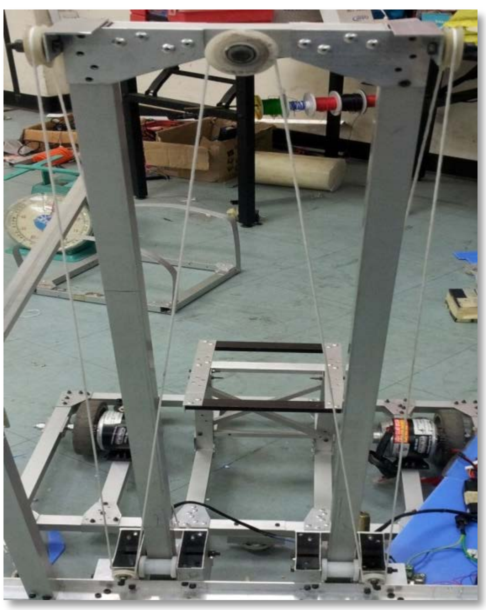

Figure 3: Pulley System For Lifting System.

The rotary encoder was mounted directly on the lifting structure in such way that when the arm is lift up or down, the roller of the encoder will rotate and the pulse was generated according to the distance of the movement of the arm. The encoder was attached such that the roller of the encoder will move on the pole of the lifting system since the pole has linear and smooth surface.

Therefore, the encoder can generate pulse more accurate on the linear surface rather than on the rough surface or surface with obstacle since rough or non-linear surface can cause miss counting of the encoder pulse that will interrupt the precision and accuracy of the encoder. Figure 3 shows the mounted rotary encoder on the robotic arm lifting system.

The mounting of the encoder was constructed in a way that the roller or encoder wheel can move through the lifting pole smoothly. Figure 4 shows the encoder mounting that had constructed. The mounting was design in such way that the roller of the encoder always touch the pole and when there are obstacle on the pole, the mounting will slightly adjusted to allowed the roller can still move through the pole since the spring was used with the encoder mounting to make the encoder wheel always contacted with the lifting pole.

The encoder wheel is constructed as shown in Figure 5. The small size of wheel used in this project to reduce the load on the encoder shaft and to reduce the friction between the wheel and pole surface which can reduce the accuracy of the encoder.

Figure 4: Mounted Rotary Encoder On The Robotic Arm Lifting System

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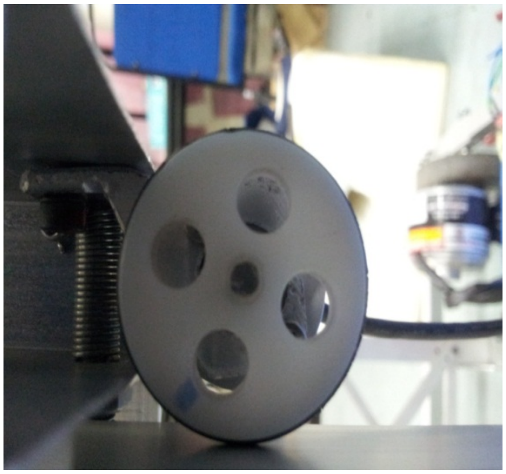

Figure 5: The Encoder Wheel.

B. ELECTRONIC CIRCUIT MODULE

The configuration of the electronic circuit for the arm system is shown in Figure 6. The microcontroller used in this project is PIC microcontroller. Therefore the microcontroller board was design using Proteus software and fabricate for the application of the PIC microcontroller.

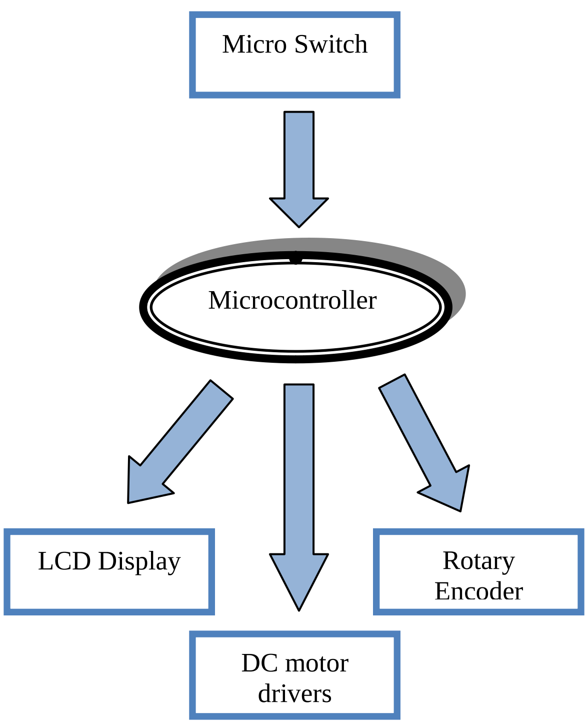

Figure 6: Electronic Configuration

Overview of the electronic circuit constructed is display in Figure 7. The electronic circuit consist of microcontroller board, liquid crystal display (LCD) circuit, DC motor drivers circuit and encoder circuit.

Figure 8 shows the development of microcontroller board. This microcontroller board was developed based on two side tracks which is upper and bottom side of the printed circuit board (PCB). This board was used as master or main board where all the command or instruction that the user applies to the project was through the microcontroller on this board. All the variable was varied in this controller based on the programming apply to the microcontroller. In addition, the microcontroller board is used to interface to the rotary encoder.

Next, Figure 9 illustrates the LCD display which shows the pulse count, error, PWM and different speed. The first line showing the speed and error value, while in the second line there are two values corresponding to the pulses count and motor PWM speed.

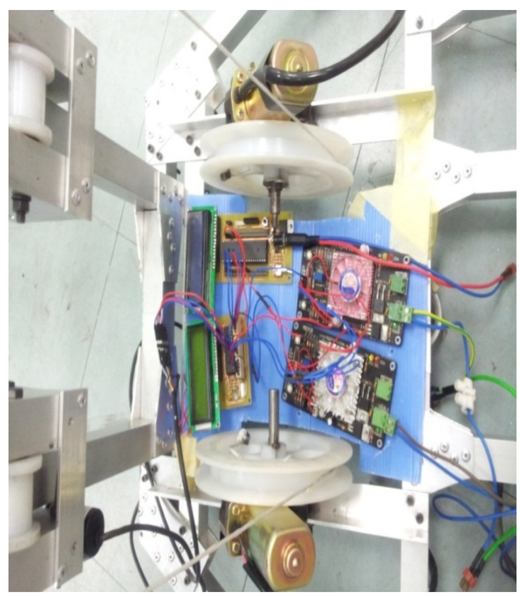

Figure 7: Overview Of The Electronic Circuit For Lifting Of Robotic Arm

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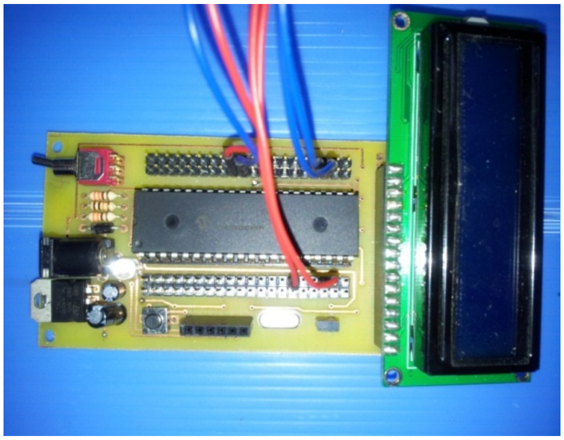

Figure 8: Microcontroller As A Main Board

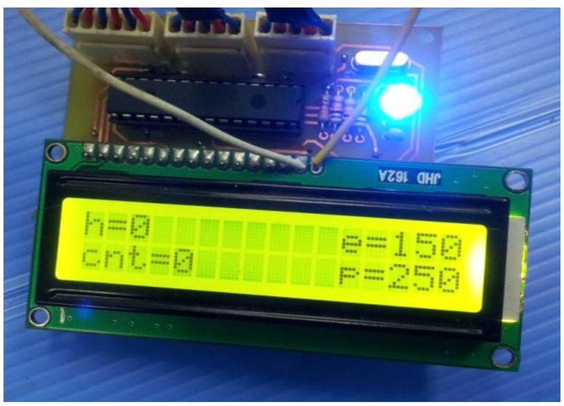

Figure 9: LCD Circuit

C. PROGRAMMING MODULE

This module discusses on the development of the program for data transfer into microcontroller. There are two programs consisting of two modes which are named as teaching mode and run mode. During the teaching mode, the robotic arm was moved manually until it reaches the desired location. Figure 10 showing the deliberate flowchart for the programming part of the robot's arm interfacing with rotary encoder. While in the run mode, the program is run with the predefined set point value previously obtained from the teaching mode. The importance of the first program which is the teaching mode program is to get the set point value which could be manually done while the second program which is run mode program is the main program using the set point obtained.

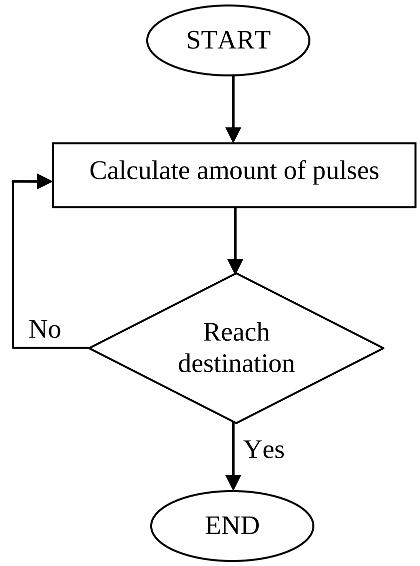

Figure 10: Flow Chart Of Programming Module

D. PID CONTROLLER

The PID (proportional integral derivative) controller is utilized to control a robot arm. By selecting the PID gains, the robot can move along the designed trajectory. The PID provides robust and reliable performance for most systems if the PID parameters are determined or tuned to ensure a satisfactory closed-loop performance. The PID control is one of the earlier control strategies [10]. The basic idea behind a PID controller is to read a sensor, then compute the desired actuator output by calculating proportional, integral, and derivative responses and summing those three components to compute the output [11].

In the PID controller, the proportional component depends only on the difference between the set point and the process variable. It reduces error but does not eliminate it. Meanwhile, integral mode corrects for any offset that may occur between the desired value and the process output automatically over time. Derivative action anticipates where the process is heading by looking at the time rate of change of the controlled variable. Derivative action depends on the slope of the error, unlike P and I. If the error is constant, derivative action has no effect [12].

Generally, there are few variables required to complete the equation of the PID controller system. For the programming of the PID controller, the PID terms have been converted to a simpler form as listed in Equation (1) until (4) below [13]:

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e = SV – PV (1)
Integral = Integral + e (2)
Derivative = $e - e_p$ (3)
Output = (K_P x e) + (K_I x Integral) + (K_D x Derivative) (4)

where e is error, SV is set value, PV is process value, e_p is previous error, K_P is proportional gain, K_I is integral gain while K_D is derivative gain

In the PID control program, the controller measured the error signal by subtracting the set value with the feedback value. Then the program calculates the proportional, integral and derivative term. The proportional term is the multiplication of the error or feedback value with the proportional gain that has set. The integral term is multiplication of the integral gain with the addition of previous value of integral with the feedback value. Meanwhile, the derivative term is the multiplication of derivative gain with the result of the subtractive of error value with the last error. Note that the last error is the previous value of the error signal. It means that in the iteration process, the error value of the nth iteration used as the last error of the iteration of (n + 1).

3. SIMULATION

Simulation of the PID controller was done with the Proteus ISIS software as shown in Figure 11. The function of the simulation is to verify the program developed in order to debug any error occurs from the program. The program load for this simulation contain of quadrature encoder interface (QEI) module to operate the encoder. The timer interrupt function was used to display the current value of the PWM value supplied to the motor with predefined time.

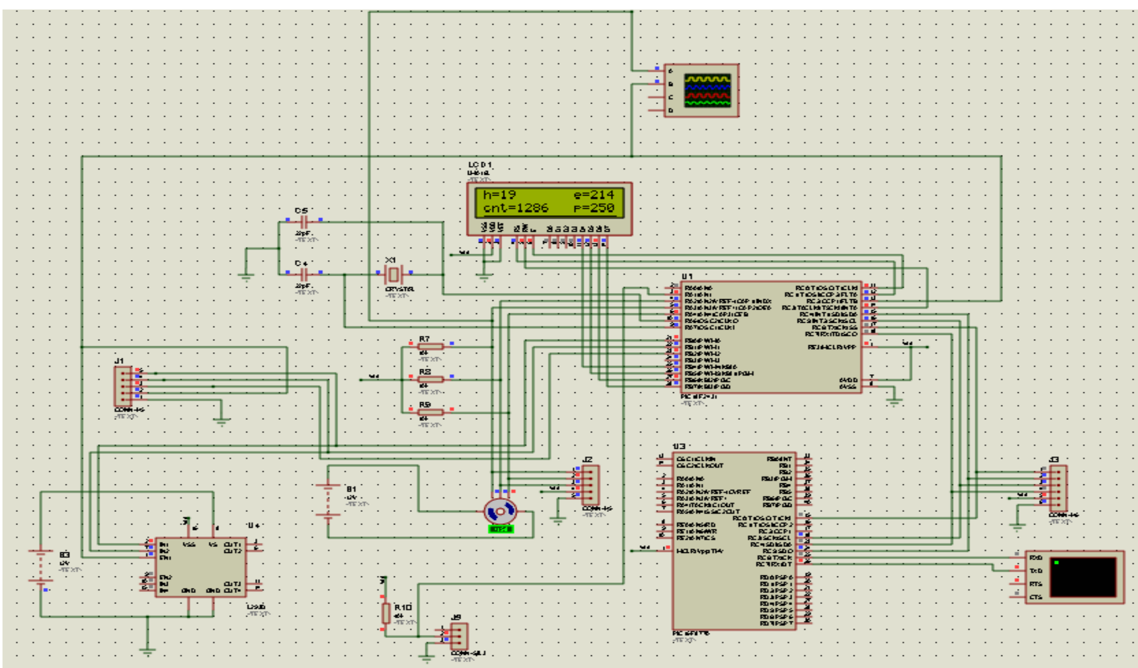

Figure 11: Response Of Changing Parameter K_P With K_I = 0.1, K_D = 1

Figure 12 shows the illustration of LCD display on the Proteus software on the simulation for testing the program had been developed. The set time for the timer interrupt function is 5 cycles. Meaning that, for every 5 cycles, the LCD will display the current value of the motor speed. The first line will display the speed and error value while the second line showing the current pulses value and the pulse width modulation (PWM) motor.

The PWM and pulse of the encoder during the simulation process are display in Figure 13. The top and the bottom on the display are the PWM and the encoder pulse respectively.

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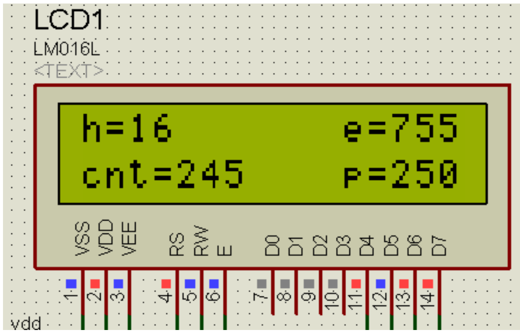

Figure 12: LCD Display On The Proteus Software For The Simulation

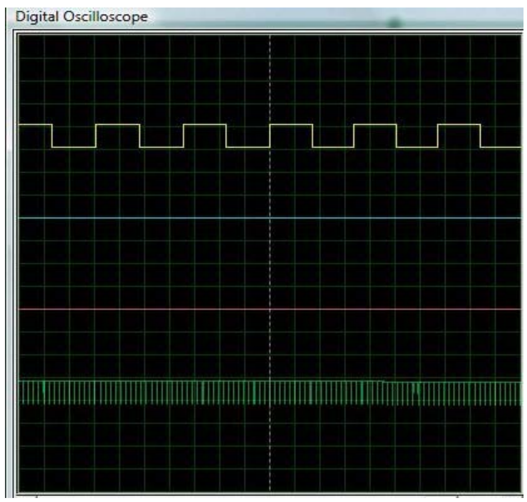

Figure 13: PWM And Encoder Pulse

4.RESULT AND DISCUSSION

The performance of PID controller was tested where some experiments were done in variation of PID parameter. The proportional constant (K_P), integral constant (K_I) and derivative constant (K_D) of the PID controller was based on Ziegler–Nichols tuning method until the satisfied results was obtained. The PID gain parameter such as K_P was chosen to decrease the rise time, K_D was chosen to reduce the overshoot and settling time and finally K_I was chosen to eliminate the steady state error.

The system response from the experiments is plotted in a graphic so the performance of the system can be observed which the set point is 1500 pulse. Figure 14 shows the response of the lifting mechanism of robotic arm system when the value of proportional gain K_P was varied. Value of K_P is changed from 0.7, 1, 2, 3, and 5 while value of K_I and K_D is maintained at 0.1 and 1 respectively. Response shows that by increasing the value of K_P results in faster response or decrease the rise time of the robotic arm system decrease the steady state error but increase the overshoot of the system response.

In Figure 15, the response of changing parameter of K_I when K_P and K_D remain constant. The value of the K_I is responsible for the steady state error of the lifting mechanism of robotic arm system. When value of the K_I increased, it decreased the value of steady state error, increase the system response and increase the overshoot and settling time on the system. The selected value of K_I used in the performance test is the 0.1, 0.2, 0.4, 0.8 and 1 while the value of K_P and K_D remains constant at 1 and 1 respectively.

The response of changing parameter of K_D when K_P and K_I remain constant was illustrated in Figure16. From the figure, the value of the K_D is responsible for the handling the overshoot of the lifting mechanism of robotic arm system. As value of the K_D increased, it decreased the value of overshoot of the response and decrease the settling time on the system. From the figure, the selected value of K_D used in the performance test is the 0.2, 0.4, 0.8, 1.0 and 1.2 while the value of K_P and K_I remains constant at 1 and 0.1 respectively.

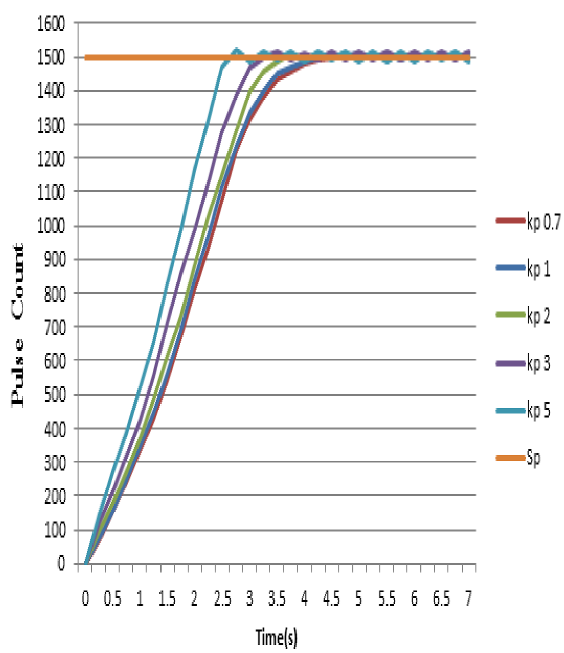

Figure 14: Response Of Changing Parameter K_P With K_I = 0.1, K_D = 1

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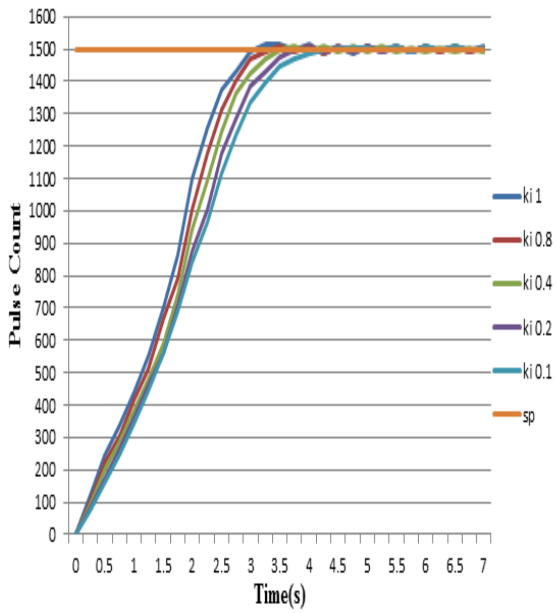

Figure 15: Response Of Changing Parameter K_I With K_P = 1, K_D = 1

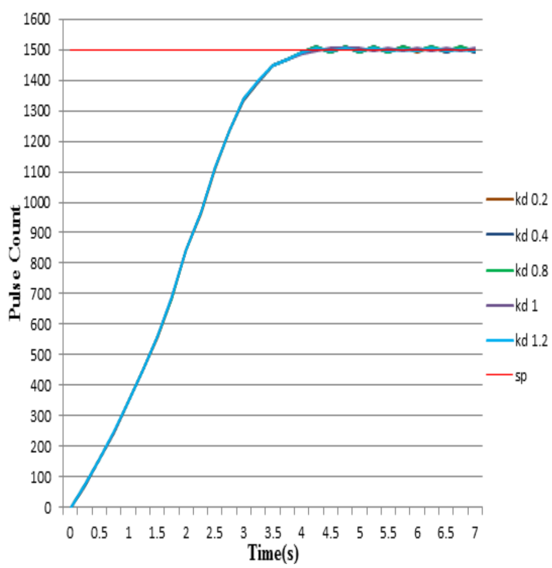

Figure 16: Response Of Changing Parameter K_D With K_P = 1, K_I = 0.1

Furthermore, the comparison between the PID controller and the ON and OFF controller was done as shown in Figure 17. It shown that for the ON and OFF controller, the final value is well above the set point. Compared with the PID controller, the lifting of the robot arm movement is smoother and precise. The K_P, K_I and K_D of the PID controller were changed heuristically with the lifting of robotic arm system. The value was chosen such that it provides the best possible outcome of the lifting system where the final value is as close possible to the set point value and the movement of the lifting of robotic arm is smooth. Most of all, the movement of the lifting should be smooth with the implementation of the PID controller. The final tuned value of the K_P, K_I and K_D is 1, 0.2 and 1 respectively.

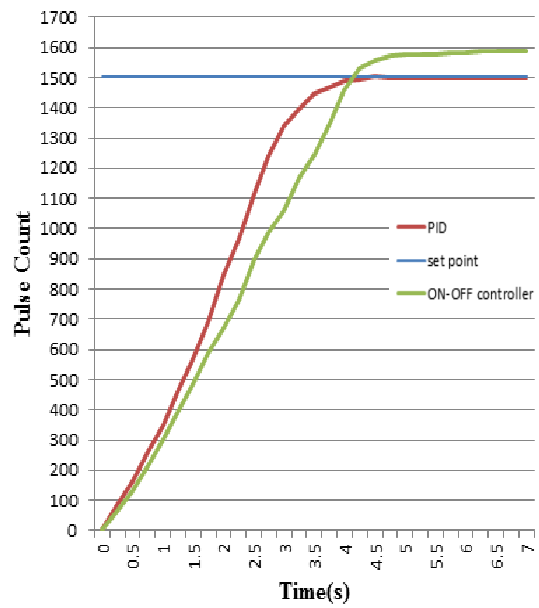

Figure 17: Response Of PID Controller And ON And OFF Controller

5. CONCLUSIONS

The rotary encoder was successfully used as the feedback signal to the PIC microcontroller. The pulse value generated using the rotary encoder was used as a measure between the process value and the set point producing error. The PID controller then compensated the lifting system for robotic arm to the appropriate speed.

PID controller was successfully applied in the lifting system of robotic arm and used to replace the ON and OFF controller. The program using PID controller has been created with the PIC microcontroller as the controller of the system. Through Ziegler–Nichols tuning method, the optimum gain of K_P, K_I and K_D obtained as 1, 0.2 and 1 respectively.

The PID controller system performs better than ON and OFF controller system which produced a more stable and consistent output compared to the ON and OFF controller system. With the PID controller system, the movement for lifting robotic arm is greatly smooth and reached to the desired position precisely. It also proves to be efficient as it

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compensated the lifting system to the appropriate speed as required by the robotic arm.

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