International Journal of Engineering & Technology, 7 (4.37) (2018) 103-109

International Journal of Engineering & Technology

Website: Www.Sciencepubco.Com/Index.Php/IJET

Paper Research

Design and Analysis of Robot PID Controller Using Digital Signal Processing Techniques

Mshari A. Asker[1], Khalaf S. Gaeid[2*], Nada N. Tawfeeq[3], Humam K. Zain[4], Ali I. Kauther[5], Thamir Q Abdullah[6]

[1]Computer Department/Tikrit University, Tikrit, Iraq
[2,3,4,5,6]Electrical Engineering Department/Tikrit University, Tikrit, Iraq
**Corresponding author E-mail: gaeidkhalaf@gmail.com*

Abstract

Recently robotic is a playing vital role in the life In our modern society, the usage of robotic arms are increasing and much of the work in the industry is now performed by robots. As robots begin to behave like humans in an intelligent manner, control system becomes a major concern. In this paper, design and analyses of the pick and place robot due to control, the forearm, wrist, desired turntable and desired bicep is introduced to construct a closed system with four degrees of freedom (4DOFs). The main performance specifications are the accuracy and stability of the input system for obtaining a good system performance. Implementation of the control system using PID parameters for stability, minimum steady state error, minimum overshoot and faster system response has been carried out. The design of two degree of freedom PID(2DoFPID) to control robotic arm along with first order low pass filter(LPF) to compensate the unwanted signal is improved. To be able to implement such a precise and effective system, feedback system has to be made to improve the overall performance specifications. The digital signal processing controller (Arduino Uno) is used as it is active, cheap , it has open source code and easy to use in the software and hardware applications.
Experimental set up developed in addition to the Matlab/Simulink implementation of the complete system. The results and the communication signals test ensure smooth operation of the control system and the effectiveness of the proposed algorithm.

Keywords: *Arduino, Bicep, DC motors, Forearm, PID controller, Robotic arm, Turntable, Wrist.*

1. Introduction

The robots can be considered as the most important machines in the field of industry, the education and the field of artificial intelligence as well(Jaffar S. et al.,2018).They are smart machines, programmed and can be used in many areas such as production lines, manufacturing, medicine and space (Sivakumar B. G.,2018). The interested specifications of the robots suck as high precision, works any time anywhere to improve the hard life. The DSP techniques for real time systems is an introduction to DSP software development for real-time developers giving details on how to use digital signal processors (Arduino Uno in this work) efficiently in real time systems(Oshana R.,2006). The functions of a human arm can be used to be as a platform of the robotic arm manipulator which are connected by joints to perform either rotational motion or translational displacement to construct the kinematic chain. The manipulator can be defined as a device used to manipulate material without direct contact. The final goal of the manipulator kinematic chain ends effectors and it's operation is the same the human hand. The specified application will locate the end effectors job such as spinning, welding, gripping. Robots can be classified as autonomous, semi-autonomous and remotely controlled and can be used to perform a variety of tasks with great accuracy (Russell S.,2016). The fixed and mobile are the main kinds of robotic arm and can be designed for variety types of applications. The parallel PID controller schemes are used in this paper to obtain best response of the system. The main purpose is to use the reaction torque generated by the motor to counter balance the robotic specific arm. Control the angle and get the best response to balance the operation of the movable. The tuning of PID is to get a smoother response which main is to get short settling time, and minimum overshoot. Higher proportional gain give a faster response rate but will increase the overshoot and accelerates the DC motors used in this robot(Yaw Y, et al.,2018). PID is a three terms algorithm used for control systems to ensure the stability of an instrumentation system with feedback characteristics on the system (Neola R. et al., 2018). A hybrid fuzzy (H-fuzzy) design and implementation architecture for intelligent navigation of a mobile robot in all environments is given in (Anish P. et al.,2017). Robot operating system (ROS) framework and Arduino introduced in (Adrian I. et al., 2017). Neural network based controller of robotics actuators and sensors with DSP is used in (Fernandez A.J. et al., 2012). PID controller for robot motors is used to obtain highly precision response using adaptive radio frequency communication signal processing module is presented in (Baikar P.,2014). The contribution of this paper deals with a robotic arm using Arduino as sensors and digital signal processing controller for the data acquisition of the natural arm movements. The robot uses four DC motor driven robot arm with a few joints. Besides the base, upper arm, the forearm, wrist, desired turntable and desired bicep, there are a lot of joints and four servo robot arm to form the complete mechanical structure. The control system with the Arduino used to displayed the 4-DOF robot arm movements control principle LPF is used as a good compensator for any noise in the control system.
The proposed control algorithm allows greater flexibility in controlling the four robotic arms instead of using a scheme to control each part separately.

The structure of this paper follows: Robotic design in Section II, Methodology overview in section III. Modelling of Robotic Arm in Section IV, Results is given in section V. Finally, Section VI gives a conclusion.

2. Materials And Methods

Four degree of freedom (4DOF) robotic arm is a robotic arm with four degrees of freedom joints. It's actuated using four DC motors. There are different types of robotic arm such as Bluetooth module, Atmega328 Controller, controlled by PC and Arduino microcontrollers.
The input power source is a battery or an AC power supply for the robotic arm between (5-6) volts with a current rating up to DC 10 Amp.
The transfer function of the DC motor without friction force as in (Syukriyadin S. et al.,2018).

$$G_{dc\_motor} = \frac{K}{(Js+b)*(Ls+R)*K^2} \quad (1)$$

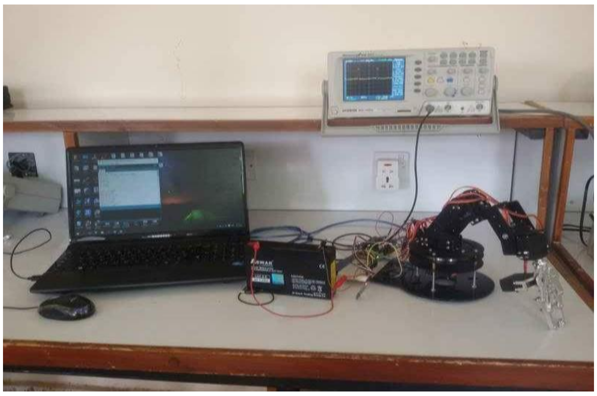
Where
J, b, K, R, L is the rotor inertia [kg·m2], motor viscous friction constant [Nms], torque constant [Nm/A], electric resistance [Ω], electric inductance [H] respectively.
The closed loop system of motor PID controller circuit with a unity feedback is:

$$G_{CL} = \frac{(PID)_{TF} * G_{dc\_motor}}{1+(PID)_{TF} * G_{dc\_motor}} \quad (2)$$

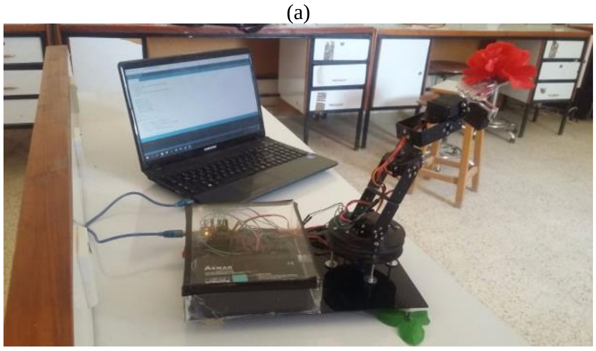
The PID controller transfer function can be written as:

$$(PID)_{TF} = \frac{Ps + Ds^s + I}{s} \quad (3)$$

After constructing the robotic arm we will be able to control it from Matlab/Simulink as will be shown later or from Windows. Next step is to connect it with a microcontroller to generate a code for the control of the arm.
The generated source code is directly programmable to the Arduino or through Simulink embedded control downloaded from Mathwork web site.
The robot arm is controlled by an Arduino UNO controller circuit board as mentioned earlier. The Arduino controller board will be connected to the serial port of a PC operated with windows operating system(Wan M. et al,2012).
The software programming of Atmega-328 microcontroller is obtained by using Arduino UNO. The angle recognition of the rotation and the signals potentiometers signals are fed to the microcontroller(Mohamed N.,2007).
A pick and place robotic arm construction and design of using a PID microcontroller is one of the objectives to get more compact and reliable robotic arm operation.
Different analyses have been done to check the distance, speed and load that can be picked of the robot to know its stability and reliability (Khalaf S. Gaeid, 2013). The complete setup can be shown in Fig.1.



(a)



(b). Holding a red flower
Fig. 1: 4 DOF Robotic Arm

Methodology Overview: The 4DoF robotic arm consists of 4 joints labeled from base to tip to form the following angles:
1. Turntable,
2. Bicep,
3. Forearm,
4. Wrist

Each joint is actuated by a DC motor. The DC motor was chosen because it is easy to control speed and torque compared to servos or stepper motors(Goldy K.,2013). The Simulink model of the robot arm can be shown as in Fig.2.

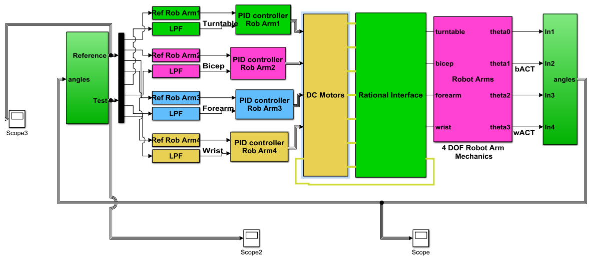


Fig.2: Simulink model

The controller design consists of four PID controllers which mean one per joint. The type of the PID controller is 2DOF-PID Controller (Mathwork, 2018). The structure of the controller is shown in Fig.3.

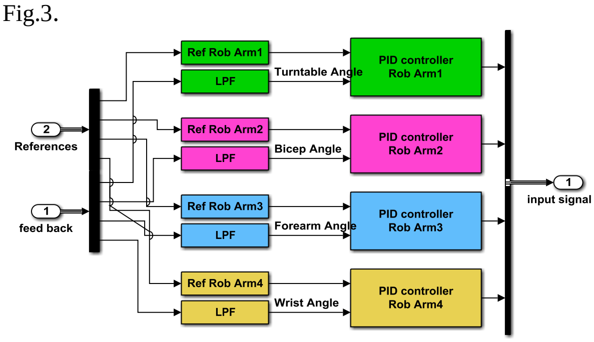


Fig.3: Controller Structure

The PID controllers are tuned using the Zeigler-Nichols second method at the time and cycling through the loops until the overall behavior is satisfactory due to the best values of Kp ,Ki and Kd. PID controller operation according to the following equation.

$$\frac{U}{E} = (K_p + \frac{k_i}{s} + k_d s) \quad (4)$$

This process can be time-consuming and is not guaranteed to converge to the best overall tuning. Alternatively, you can use (systune) instruction in the recent versions of the Matlab.

The Matlab systune command can jointly tune the gains of your control system regardless of its architecture and number of feedback loops to jointly tune all four PID loops subject to system level requirements such as response time and minimum cross-coupling. In one second each arm must move to a specific configuration with smooth angular motion at each joint. The arm starts in a fully extended vertical position with all joint angles at zero. The end configuration is specified by the angular positions as can be shown in table1.

Table 1: Robotic arm angular positions

parameter	angle	unit
Turntable	60	degree
Bicep	-10	degree
Forearm	60	degree
Wrist	90	degree

Modelling of Robotic arm: Modeling and analysis of robotic arm imply that it is a strongly nonlinear system (Haibin Y. et al., 2011). Flexibilities within the gearbox is modeled by a nonlinear spring and the friction of the system acts mainly on the first mass and is here modeled by a nonlinear friction torque as well (Erik W.& S. Gunnarsson,2006). The friction model links the slip speed v(t) of a body in contact with another body to the friction force f(t) via the static relationship(Makkar C.et al.,2005).

$$f(t) = g(1)*(tanh(g(2)*v(t)) - tanh(g(3)*v(t)) + g(4)*tanh(g(5)*v(t)) + g(6)*v(t) \quad (5)$$

Where

$g(1)$, $g(2)$, $g(3)$, $g(4)$, $g(5)$ and $g(6)$ are six unknown positive parameters

$$f_{stat\_friction} \approx g(1) + g(4)$$

The Striebeck effect will be:,

$$S_{tr} = (tanh(g(2)*v(t)) - tanh(g(3)*v(t)) \quad (6)$$

The friction term responsible about 10% drop with of 10 rad/sec speed near the origin.

The Coulombic friction effect is modeled by the term:

$$C_{fric} = g(4)*tanh(g(5)*v(t)) \quad (7)$$

The viscous friction dissipation is reflected by the last term,

$$V_{fric} = g(6)*v(t) \quad (8)$$

Linearization of the robotic arm along the trajectory makes it easy to control the system with one set of PID gains. The flowchart of a simulation using in this paper can be shown in Fig.4.

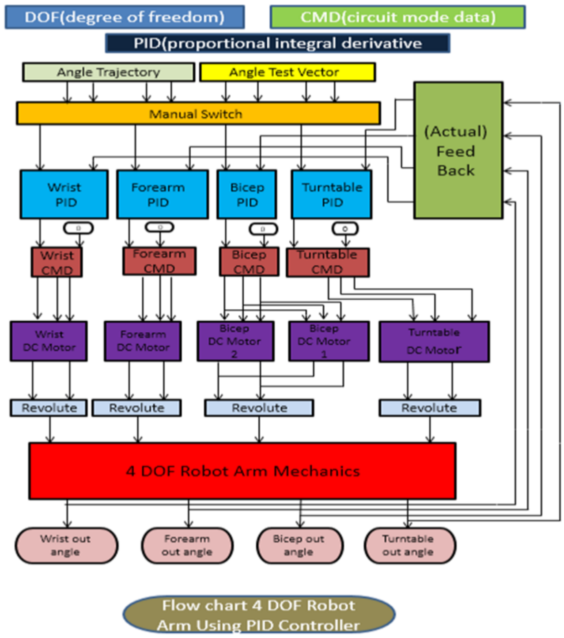


Fig.4: Flow chart of Simulation.

3. Results And Discussion

The response of the feedback control system can be evaluated by a simple measuring method. The main concept was to apply a manipulated signal to the robotic arm and measure how the feedback system responds to the given input.

The simulation result of the turntable angle combined with 20 Hz low pass filter can be shown in Fig.5.

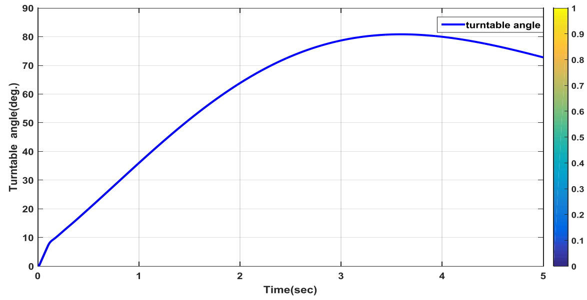


Fig.5: The output turntable angle

The simulation result of the bicep angle shown in Fig.6.

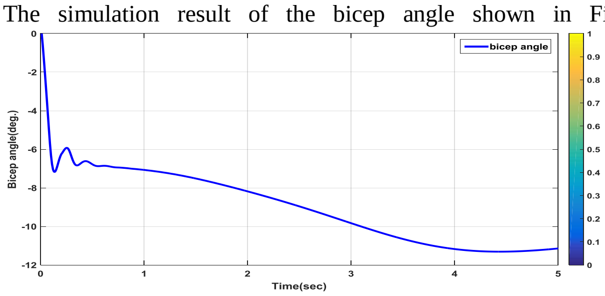


Fig.6: The output bicep angle

The simulation result of the forearm angle shown in Fig.7.

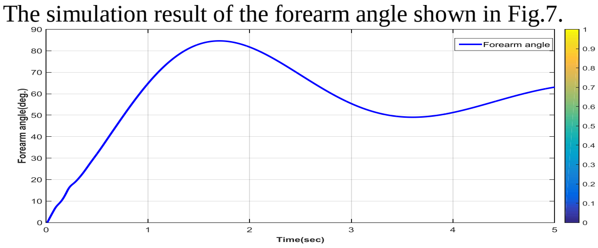


Fig.7: The output forearm angle

The simulation result of the wrist angle shown in Fig.8.

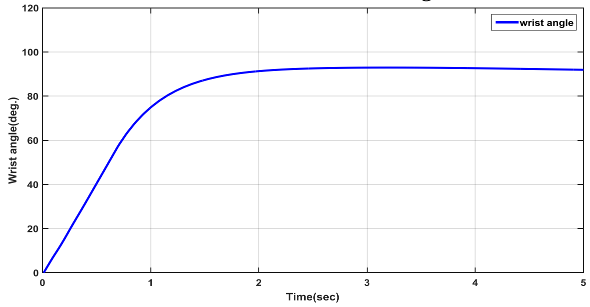


Fig.8: The output wrist angle

Fig.9 represent the step response of the robot arm1 with fine-tuning of PID controller.

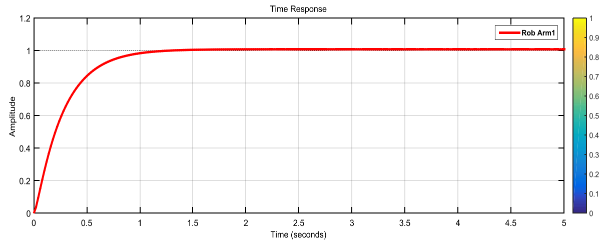


Fig.9: step response rob arm1

Fig.10 represent the step response of the robot arm2 with fine-tuning of PID controller.

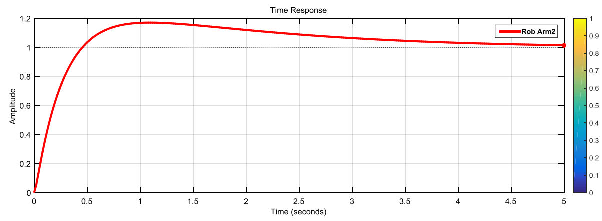


Fig.10: step response rob arm 2

Fig.11 represent the step response of the robot arm3 with fine-tuning of PID controller.

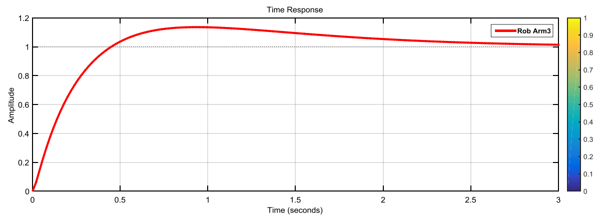


Fig.11: step response rob arm 3

Fig.12 represent the step response of the robot arm4 with fine-tuning of PID controller.

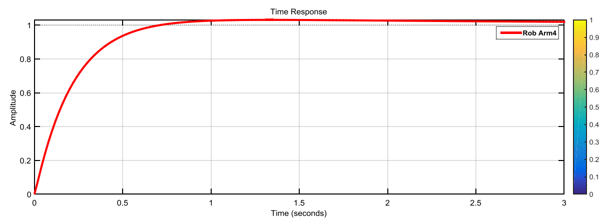


Fig.12: step response rob arm 4

The performance specification of the robotic arms obtained can be shown in table2.

Table2: performance specification of the four arms

	Time(sec)			
Performance	Rob arm1	Rob arm2	Rob arm3	Rob arm4
Rise Time	0.6	0.4	0.35	0.45
Peak time	2.6	1.1	0.9	1.37
Settling time	0.9	4.6	2.75	2.93
Steady state	5	5	5	5
Overshoot	0.1%	17%	14%	3%

The values of (k_p,k_i,k_d) after tuning can be shown in table3.

Table3: Tuning results (K_p,K_i,K_d) of the four arms

parameter	K_p	K_i	K_d
Rob arm1	22.61	4.26	5.21
Rob arm2	8.5 2	3.14	6.72
Rob arm3	20.23	27.34	10.12
Rob arm4	12.17	17.32	1.65

DC motor PWM speed control, using microcomputers as controller, and the details of the realization of the approach based on AT89S51 single-chip microcomputer introduced in (Liu Z., 2011). The PWM involves the modulation of its duty cycle (D), either:
1. Convey information over a communications channel or, 2.Control the amount of power sent to a load (Khalaf S. Gaeid et al., 2013) PWM uses a square or triangle waveform whose pulse width is modulated resulting in the variation of the average value of the waveform. The duty cycle is defined as the percentage of digital ‘high’ to digital ‘low’ plus digital ‘high’ pulse-width during a PWM period (Efy Lab,2006). If we consider a modulated signal as a square waveform f (t) with a low value (y_{min}), a high value (y_{max}) and a duty cycle, the average waveform value is given in(9):

$$y = \frac{1}{T}\int_0^T f(t)dt \tag{9}$$

As stated earlier f(t) is a square wave, its value is (max) for high duty cycle and (min) for the lowest value of the duty cycle. Eq.9 will be as in(10):

$$y = D * y_{max} + (1 - D) y_{min} \tag{10}$$

The duty cycle of the four arms in transient and steady state regions can be shown as in the following figures. The robotics arm main concept is to return back to the initial position using a feedback control system(Naser A.& J. Shrivastava,2015).The following results should support this concept.
The PWM of turntable motor with 400 Hz can be shown in Fig.13.

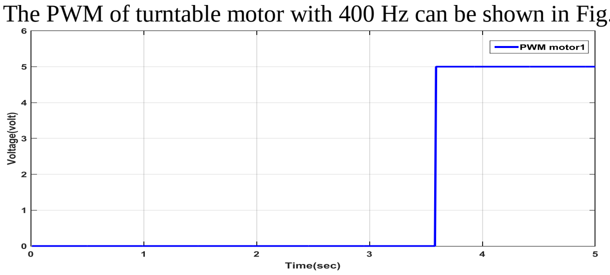


Fig.13: The PWM for turntable motor

The PWM of bicep of the motor can be shown in Fig.14.

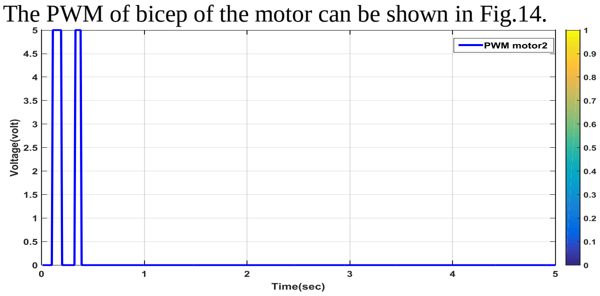


Fig.14: The PWM for bicep motor

The PWM of the forearm motor can be shown in Fig.15.

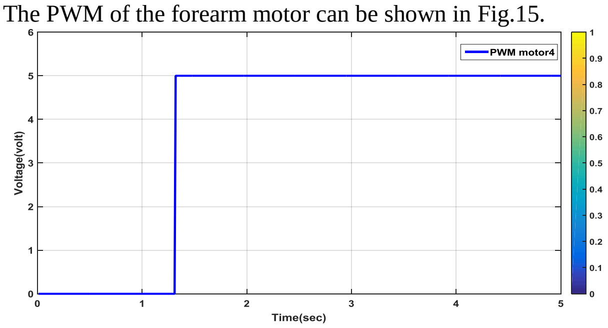


Fig.15: The PWM for forearm motor

The PWM of wrist motor can be shown in Fig.16.

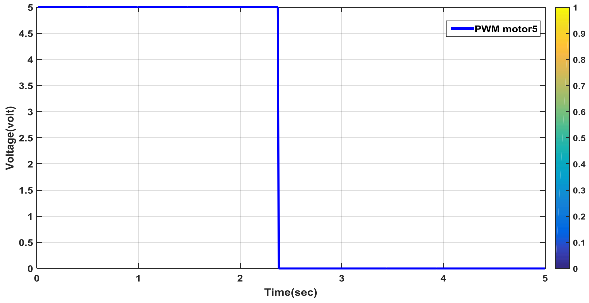


Fig.16: The PWM for wrist motor

Arduino complete setup can be connected to develop the environment for uploading programmers and communication can be established between them(Svergja T.,2016).

The library function is to provide more functions for sophisticated use in programmers while working on hardware. Serial communication data is sent from the Arduino to control the received and transmitted signals and the baud rate which is a measure of the number of bits transmitted per second. The 9,600 baud rate is approximately 1,000 characters per second(Michael M.,2011).

The test signal is introduced to check the effectiveness of the proposed algorithm as can be shown in Fig.17.

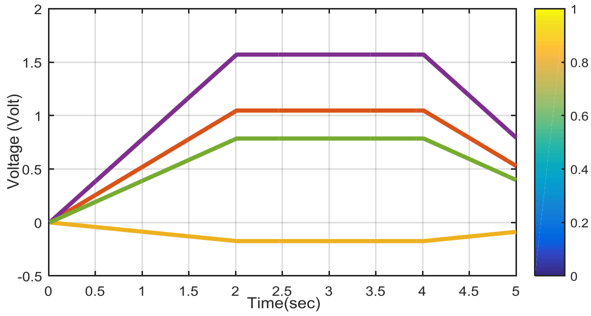


Fig.17: Testing Signal

The duty cycle of the four DC motors can be shown in Fig.18.

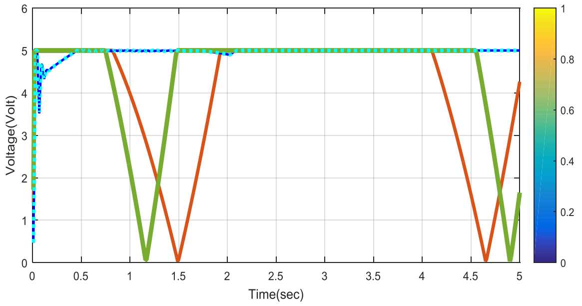


Fig.18: The duty cycles of the DC motors

The reference signal of each arm can be shown in Fig.19.

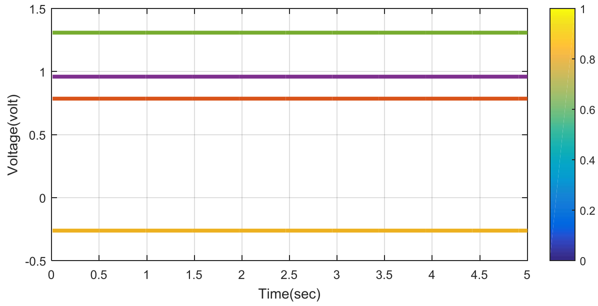


Fig.19: The setting point of each arm

The input of the control signal waveform can be shown in Fig.20. In this Figure small overshoot at the beginning of operation occur and directly compensated with LPF.

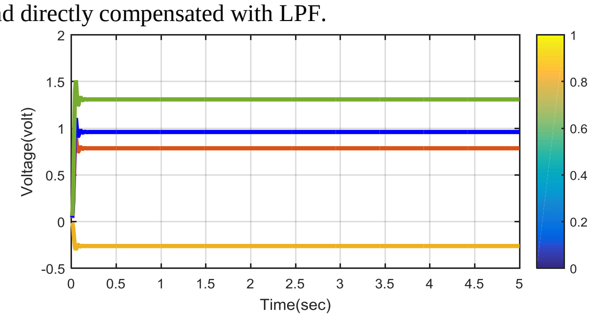


Fig.20: The control input signal

The output signals (angles) are measured to ensure smooth operations in all robotic arms as can be shown in Fig.21.

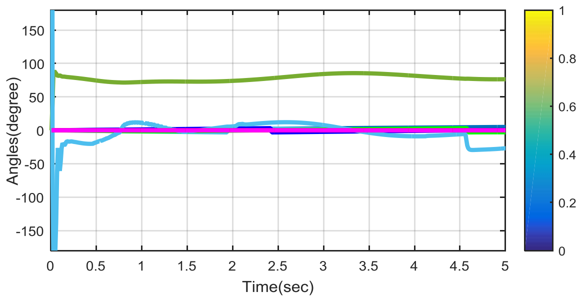


Fig.21: The control input signal

The experimental verification of the proposed algorithm is tested many time and huge data is recorded. The experimental PWM duty cycle of the motor arms is shown as follows.

1. Duty cycle for 3% degree DC motor is shown in Fig.22.

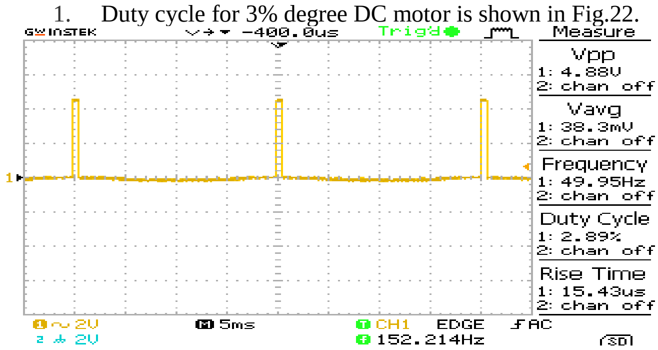


Fig.22: 3% duty cycle DC motor

2. For 12% duty cycle DC motor, the output waveform can be shown in Fig.23.

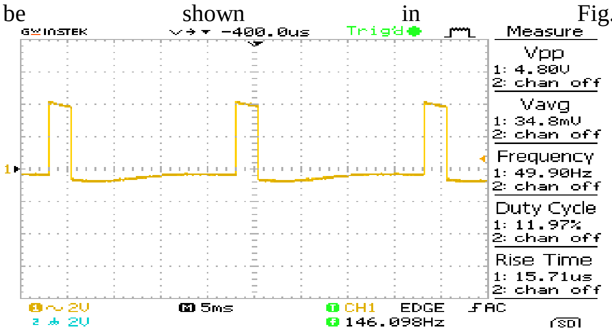


Fig.23: 12% duty cycle DC motor

For 5% duty cycle output waveform can be shown in Fig.24.

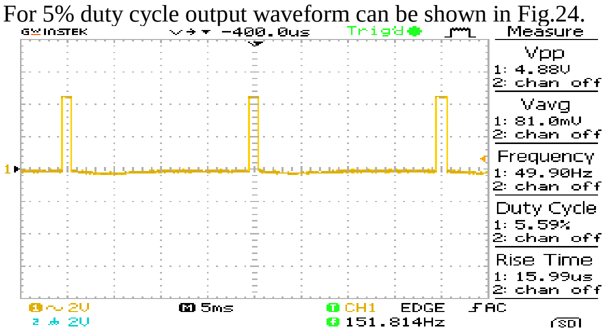


Fig.24: 6% duty cycle DC motor

To test the communication signal which ensures the reliability of environmental Arduino status both transmitted and received signal has been measured.

The smooth transmitter voltage of the Arduino can be shown in Fig.25.

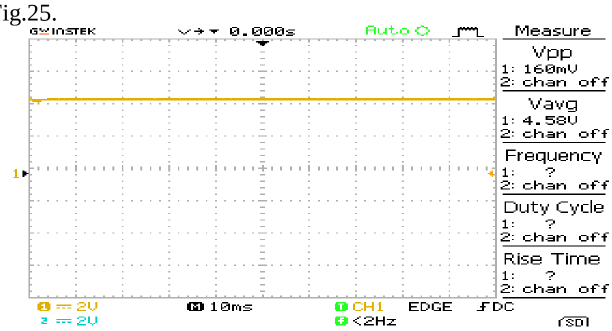


Fig.25: Transmitted signal of the Arduino.

The received voltage of the Arduino can be shown in Fig.26.

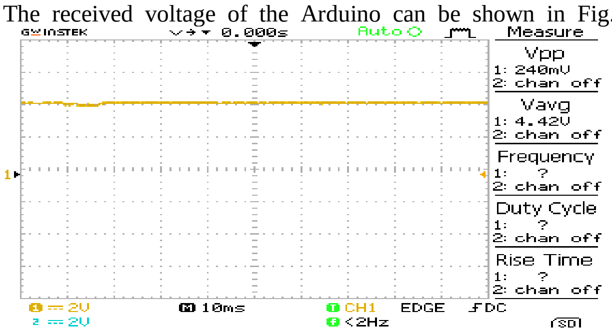


Fig.26: The received voltage of the Arduino

The Arduino programming language to control the arms to implement the complete control system run in all operating system was one of the primary goals to develop and makes it easy to understand for the users that want to improve the system.

4. Conclusions

Complete and powerful design of four degree of freedom automated robotic arm with a 2DoFPID controller is developed. Precise and accurate movement of the robotic arms with the effective control system is implemented.

The feedback control system has been made effectively in a detailed manner so that the movement of the robot can be controlled smoothly and accurately. The robotic arm will be powerful in many fields to make human life easy. Further development of this work can be carried out such as on wireless communication using Wi-Fi model or camera, thus allowing the user to move in easier and an unrestricted manner. The DoF of the robotic arm can be increased by using more servos motors or any other motor type. GUI can be implemented as well to make robotic arm user interactive. First order LPF has been effectively used to compensate the noise signal in the closed-loop control system.

5. Conflict Of Interest

Authors declare that, there is no conflict of interest regarding the publication of this paper.

References

[1] Adrian I., R. Qiu, Dayou Li, 2017. A Simple, Cost Effective and Practical Implementation of SLAM Using ROS and Arduino. IEEE International Conference on Internet of Things,pp:835-840.
[2] Anish P., Shalini P., P. Gupta,2017. Intelligent navigation and control of a mobile robot in static and dynamic environments using hybrid fuzzy architecture. International Journal of Autonomic Computing, 2(3):255–281.
[3] Baikar P.,2014.Design of PID Controller Based Information Collecting Robot in Agricultural Field. International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, 3(8):11013-11019.
[4] Efy Lab,2017. Speed Control of DC Motor Using Pulse Width Modulation. Available: www.efy mag.com.
[5] Erik W., S. Gunnarsson,2006. Nonlinear Identification of a Physically Parameterized Robot Model. 14th IFAC Symposium on System Identification,pp:143-148.
[6] Fernandez A. J., G. J. Moreno, A. L. Barranco, M. J. Dominguez-Morales, R. P. Vicente, and A. C. Balcells,2012, A Neuro-Inspired Spike-Based PID Motor Controller for Multi-Motor Robots with Low Cost FPGAs. Sensors (Basel), 12(4):3831–3856.
[7] Goldy K., S. Gupta, S. Kakkar,2013. Design and Operation of Synchronised Robotic Arm, International Journal of Research in Engineering and Technology,2(8):297-301.
[8] Haibin Y., Y. Kobayashi, T. Emaru,2011. Modeling and vibration analysis of flexible robotic arm under fast motion in consideration of nonlinearity. J Syst Des Dyn, 5:909–924.
[9] Jaffar S., Ali Raza, A. Nitish. Gupta, N. Chitaliya, G. Sukthankar,2018. Real World Modeling of a Pathfinding Robot Using Robot Operating System (ROS). arXiv:1802.10138.
[10] Khalaf S. Gaeid,2013.Optimal Gain Kalman Filter design with DC motor speed controlled Parameters. journal of asian scientific research, 3(12):1157-1172.
[11] Khalaf S. Gaeid, J.Hameed, M.Ali, M. K. Habeeb,2013. Static DC Motor Speed Controlled Parameters Correction. British Journal of Applied Science & Technology,3(3):586-597.
[12] Liu Z., 2011. PWM speed control system of DC motor based on AT89S51, International Conference on Electronic and Mechanical Engineering and Information Technology (EMEIT),pp:1301-1303.
[13] Makkar C., W. E. Dixon, W. G. Sawyer, G.Hu,2005. A New Continuously Differentiable Friction Model for Control Systems Design, IEEE/ASME
[14] International Conference on Advanced Intelligent Mechatronics, CA, pp:600-605.
[15] Michael M.,2014. Arduino Cookbook. O' Reilly Media, Inc.pp:1-800.
[16] Mohamed N.,2007. Pick And Place Robotic Arm Controlled By Computer. University Technical Malaysia Melaka,pp:1-103.
[17] Naser A., J. Shrivastava,2015. Performance comparison of robotic arm using Arduino and Matlab ANFIS. International Journal of Scientific & Engineering Research, 6(1):1077-1082.
[18] Neola R., A. Virgono, R. Erfa Saputra,2018. Design of Moving Simulator Prototype for Driving Training Subsystem Input System.

International Journal of Applied Engineering Research, 13(4):1945-1950.
[19] Oshana R.,2006. DSP Software Development Techniques for Embedded and Real-Time Systems, A volume in Embedded Technology. Science Direct Elsevier Inc.,pp:1-608.
[20] Russell S., Peter Norvig,2016. Artificial Intelligence. A Modern Approach, 3rd Edn. Cram101, Pearson International.
[21] Sivakumar B. G.,2018. An independent situating &navigation System for stair climbing robotic wheelchair. TAGA journal, 14:2771-2783.
[22] Syukriyadin S., S Syahrizal, G Mansur, H P Ramadhan,2018. Permanent magnet DC motor control by using arduino and motor drive module BTS7960. OP Conf. Series: Materials Science and Engineering,352,pp:1-6.
[23] Svergja T., A. Mats, G. Rodseth,2016. System for Self-Navigating Autonomous Robots. Master thesis in Cybernetics and Robotics, Department of Engineering Cybernetics, Norwegian University of Science and Technology.
[24] Wan M., Hanif Wan Kadir, R. Ezuan Samin, Babul Salam Kader Ibrahim,2012. Internet Controller Robotic Arm. Procedia Engineering 4,pp:1065 – 1071.
[25] www.Mathwork.com., 2018.
[26] Yaw Y., Lim, C. Lih Hooand Yen, Myan Felicia Wong,2018. Stabilizing an Inverted Pendulum with PID Controller. MATEC Web Conference, 152,pp:1-14.