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Design and Implementation of PID Controller for Motor Position Control

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Abstract— This research describes the design, simulation and implementation of PID controller for a DC motor position control on FPGA. Recently "Field Programmable Gate Array" has become an alternative solution for the realization of Digital PID controllers. DC motor is controlled by the PID controller. The main duty of PID controller is to obtain a desired response using the characteristics of Proportional (P), Integral (I) and Derivative (D) control. Each control has its own specifications. So, the motor position could vary depending on a different control effects. Mostly, the motor position can be controlled by changing rotation signal that contains Pulse Width Modulation (PWM). This paper presents the comparative study of P, PI and PID controllers for the position control of the DC motor. PID controllers require exact system modeling if the system has parameter verification. In this paper, the changes of output of DC motor will be described with MATLAB using PID controller. And then, according to the MATLAB result, the DC motor is implemented in FPGA board with PID controller by hardware programming method.

Index Terms— PID controller, DC motor position control, FPGA board, Pulse Width Modulation (PWM), System modelling, Parameter verification, MATLAB.

1 Introduction

Today, there are many factories in the world in this era of technology and high technologies are developing to produce the best quality products. Therefore, good performance machines are also necessary. To get good performance, modern control systems are needed. The idea of the position control system is to maintain the position of the DC motor at the desired value under various conditions. A number of control scheme such as proportional (P), proportional integral (PI), proportional integral derivative (PID), adaptive and fuzzy logic controller (FLCs) are used for control of position of DC motors. The proposed controller system uses the PID control for position control of DC motor due to its simplicity, clear functionality, applicability and PID controllers are used in more than 95% of the industrial process control applications.

With technological advancement in the field of microelectronics, new digital solutions such as FPGAs (Field Programmable Gate Array) are available and can be used as targets for the implementation of digital control algorithms. FPGA-based controllers offer advantages like high speed, complex functionality, low power consumption and reducing the design cost of the system. Another advantage of FPGA based platforms is their capability to execute concurrent operations, allowing parallel architectural design of digital controllers. Therefore, the FPGA based PID controller is more flexible than general MCU such as PIC, ARDUINO etc.

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2 Overview of the System

The main object of this paper is to control the position of the DC motor to get the desired angle. The angle of motor is variable when input voltage is applied. To get only the desired set-point angle of motor when input voltage is applied, the PID controller will really need for that. PID attempts to correct the error between a measured process variable and a desired response. In this system, the PID algorithm that is added to the system becomes a closed loop system. A simulation using MATLAB software is implemented to tune PID algorithm by changing the value of Proportional gain (K_P), Integral gain (K_I) and Derivative gain (K_D) to get desired response for DC motor which is less overshoot and increase settling time.

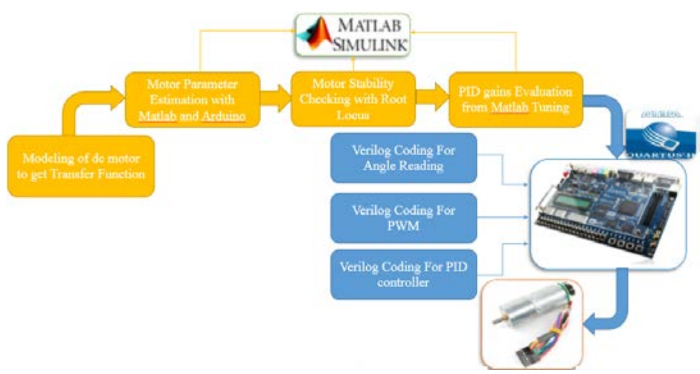

Fig. 1. Block Diagram of Overall System

To verify the PID controller on FPGA, the value of PID gains will also need. The motor parameters cannot get easily even from its manufacturing factory. Therefore, the motor's parameters have to estimate to evaluate the PID gains from MATLAB Tuning. At the end of the thesis, the position of the DC motor should be maintained at the desire angle even the supply voltage is varied.

In this proposed system, the degrees that the user selects will run to the DC motor with the help of PID controller and the block diagram for overall system can be seen in Fig. 1. This research provides a detailed hardware design and procedure to build the system. DC motor position is controlled by using FPGA Board with modern control system (PID). In this system, the quadrature encoder provides the output signal of the DC motor.

3 SYSTEM DESIGN FOR MOTOR PARAMETER ESTIMATION

The DC motor's parameters are really needed to evaluate the PID gains to implement the PID controller for that motor. And then the motor parameters cannot get easily from online datasheet pdf. Therefore, the DC motor's parameters must be estimated using MATLAB Identification Tool and Arduino Software.

3.1 Square Wave Production with Arduino Controller

The DC motor is made with coil so it has armature resistance (R), armature inductance (L) and back Electromotive Voltage (V_b). And then the DC motor has moment of inertia of the rotor (J) and viscous friction (b) because DC motor is also movable device. These motor's parameters cannot get easily from online and even manufacturing factory, Therefore, the Motor parameters will have to estimate using MATLAB Simulink and ARDUINO Board since that parameters are needed when the PID gains are evaluated. In this design, Pololu Gear Motor is mainly used.

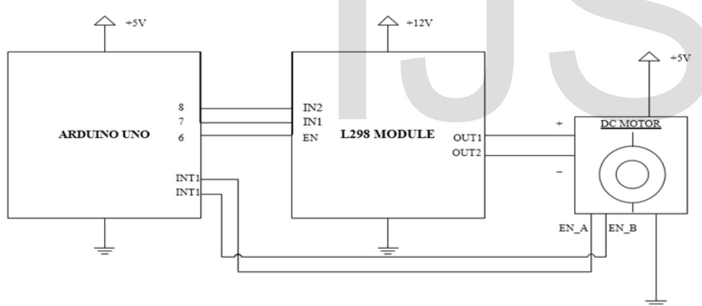

Fig. 2. Circuit Diagram for Square Wave Production in ARDUINO

The Pololu Gear Motor has hall-effect sensor called quadrature encoder and the typical voltage for encoder is 3.3V. The black and red wires of motors are the power supply pins of motor. The blue pin of motor is encoder supply pin and has power rating from 3.3 to 20V. The green pin is encoder ground pin and the other two pins are quadrature encoder channel A and channel B. The channel A and channel B of encoder is connected directly with interrupt pins (2 and 3) of ARDUINO Uno. The positive supply of the DC encoder is connected to 5V supply from ARDUINO Board. The motor driver L293 IC is used to control the motor. Therefore, the two inputs of driver are connected with pin7 and pin 8 of ARDUINO and the two outputs of driver are connected with motor power pins.

Firstly, the square input are produced using ARDUINO UNO and the results are shown in ARDUINO Serial Monitor. The flow chart for square wave production with ARDUINO is shown in Fig. 3.

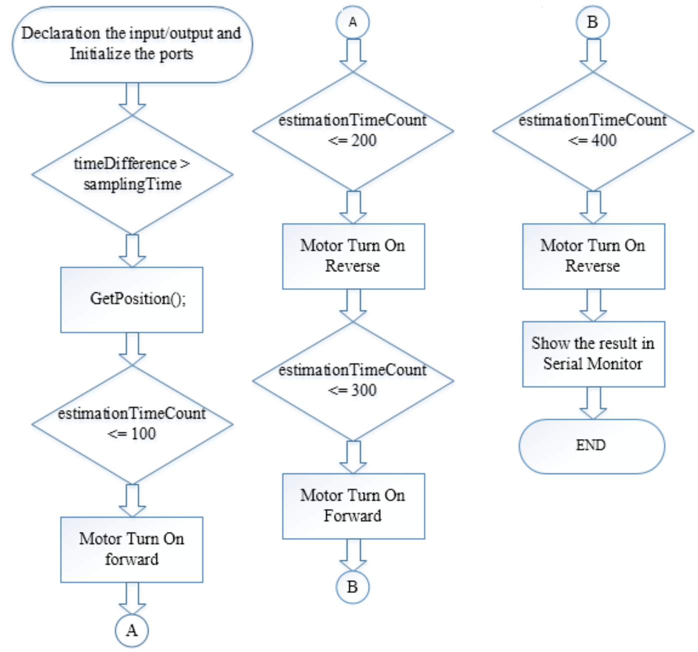

Fig. 3. Flowchart for Square Wave Production in ARDUINO

3.2 Testing for Motor Parameter Estimation with Arduino and MATLAB

Arduino UNO is used to drive the DC motor and to read the encoder outputs. Any microcontroller with 2 interrupt pins and 2 digital outputs can be used instead.

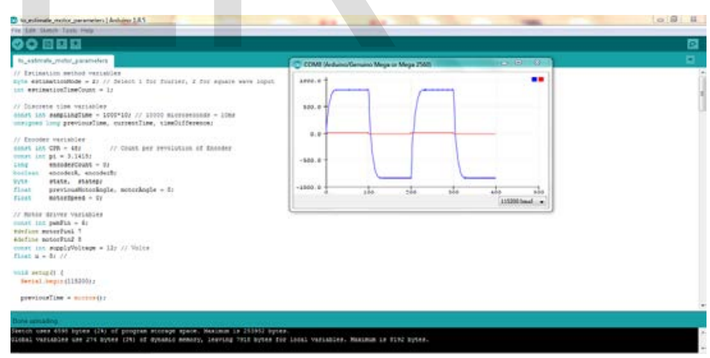

Fig. 4. Results for Square Wave Production with Arduino Plotter

After the square wave has produced with ARDUINO, the data such as motor's speed, motor's angle, estimationTimeCount, and current time are copied and paste Matlab Command Window and enter the following commands.

p2 = tout(:,1);
v2 = tout(:,2);
u2 = tout(:,3);
t2 = tout(:,4);

Five variables J, b, R, L, K with initial guess are created for the parameters. **S**quare input and square output signal are also created in Command Window which represents the experiments.

squareOutput = [t2, v2];
squareInput = [t2, u2];

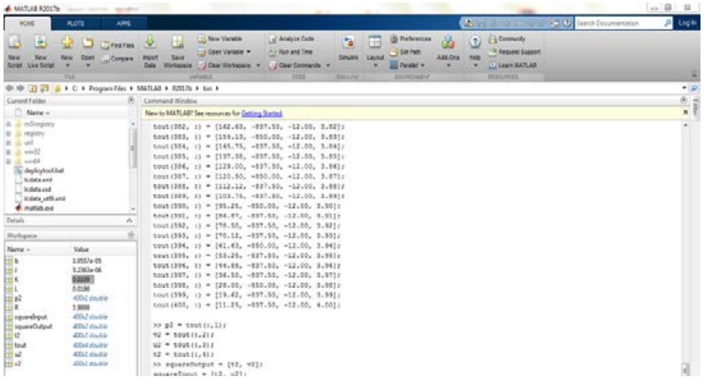

Fig. 5. Creating Motor Parameters and Square Wave Data in Workspace

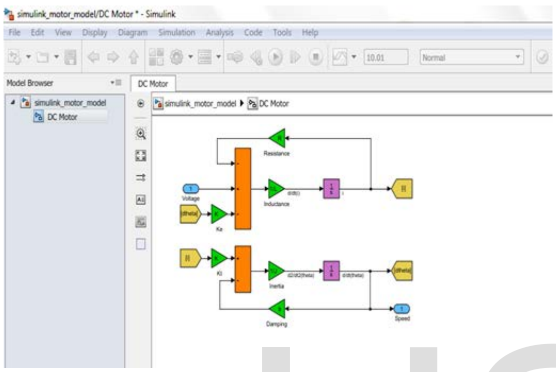

Fig. 6. Simulink Model for Motor Parameter Estimation Process

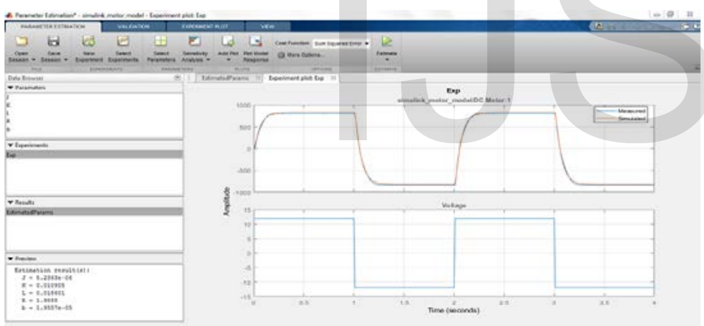

Fig. 7. Identification Results for Measured Data and Simulated Data

For measured data of DC motor, the motor parameters (J, K, b, L, R) are assumed and tuned manually until the simulated data and measured data are identical. When the simulated data and measured data are equal, the actual value of DC motor's parameters are obtained. The estimated motor parameters are shown in Fig. 7.Finally, the internal parameters of Brushed DC motor are obtained from Matlab Estimation Process as follows.

$$J=5.2363e\text{-}6\ Kg.m^2$$
$$b=1.9557e\text{-}5$$
$$K=0.010905\ V/rad/s\ (or)\ N.m/A$$
$$R=1.9888\ Ohm$$
$$L=0.018601H$$

4 Simulation Tests and Results

The transfer function of motor position is used to check the stability using P control, I control, PI control and PID controller in Matlab. By checking step by step, only the PID controller based step response can control to get more stability state.

4.1 Propotional Control Result

Running MATLAB m-file in the command window for closed loop P-controller with motor transfer function is shown in Fig. 8 and K_P=4.3. It shows that the rise time becomes 0.0206 and the overshoot is 9.31% and the settling time is 0.0661 by small amount of change. By using final value theorem, the steady state error is reduced to 1-0.986=0.014 since the final value of the output is 0.986.

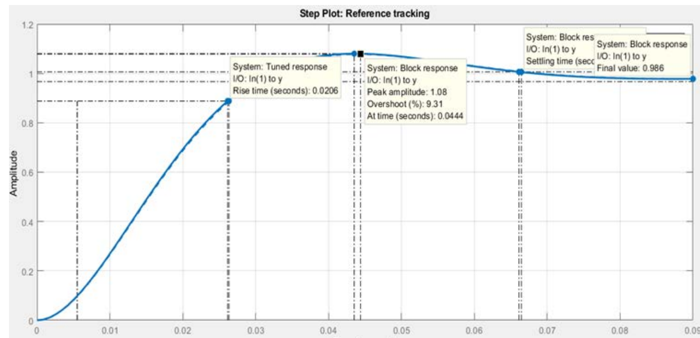

Fig. 8. P-Controller Step Response

4.2 PI-Controller Control Result

Running MATLAB m-file in the command window for closed loop PI-controller with motor transfer function is shown in Fig. 9 and K_P=4.2 and K_I=6.3. It shows that the rise time becomes 0.873 and the overshoot is 3.57% and the settling time is 2.82 by small amount of change. By using final value theorem, the steady state error is reduced to 1-1=0 since the final value of the output is 1. So e_{ss} is eliminated.1.

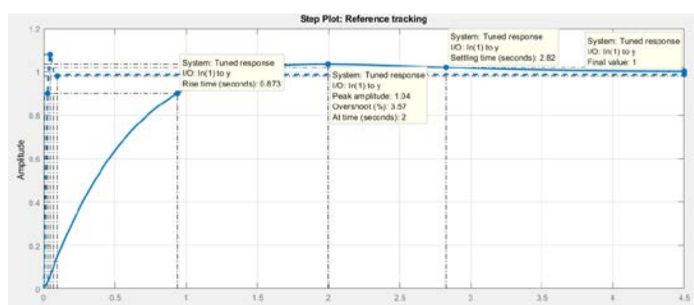

Fig. 9. PI-Controller Step Response

4.3 PID-Controller Control Result

The simulation result for K_P=4.835, K_I=6.318 and K_D=0.37116 with MATLAB simscape library output plot is resulted, as shown in Fig. 10. It shows that the rise time becomes 0.944 and the overshoot is 1.96% and the settling time is 1.43 by small amount of change. By using final value theorem, the steady state error is reduced to 1-1=0 since the final value of the output is 1. So e_{ss} is eliminated.

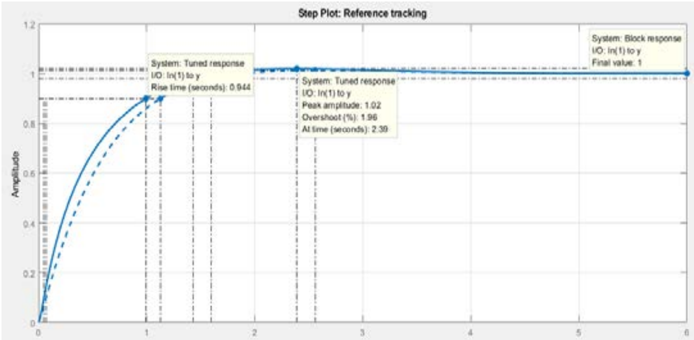

Fig. 10. PID-Controller Step Response

By comparing the results of P, PI and PID controllers in manual tuning result, PID controller is suited to implement this system. Therefore K_P=4, K_I=5 and K_D=0 are used in program for implementation.

5 Hardware Test and Result of Motor and FPGA Board

The hardware program for the implementation of motor control system with PID controller includes five sub modules in one main program. That sub modules are pid fsm module, display module, quadrature decoder, pwm module, frequency divisor module and ROM for LCD display module. The program is testing with Quartus II software and implements the program with FPGA DE2-115 Board and the result is shown in Fig. 11.

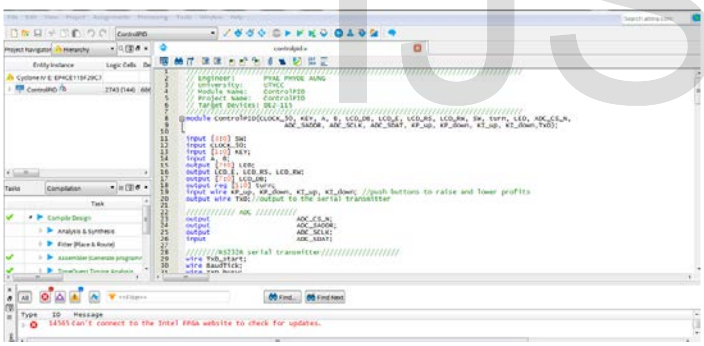

Fig. 11. Testing the Overall Program in Quartus II Software

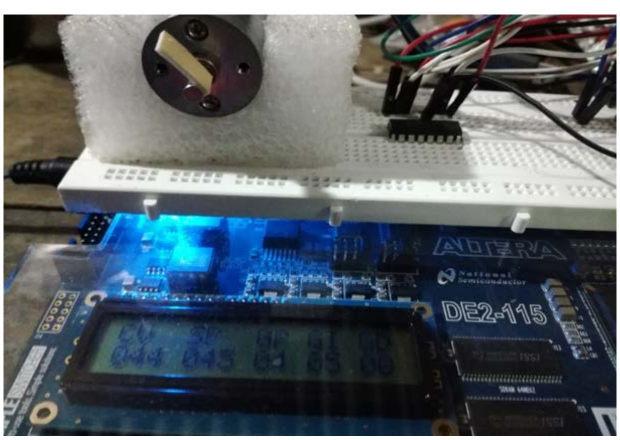

Fig. 12. Result of 45 Degree Setpoint

And the result is added to the controller by using hardware programming with Verilog on FPGA platform. After that, motor power pins, encoder pins and L293D motor driver are connected with FPGA Board. In Fig. 12, setpoint of 45 degree testing can be seen. After that, setpoints of 90 degree, 180 degree and 270 degree are tested and error are shown in Table 1.

TABLE 1

Output Result and Error Analysis for Four Set Points

Set point	Current Value	P-Gain	I-Gain	D-Gain	Error
45	44	4	5	0	2.2%
90	89	4	5	0	1.2%
180	180	4	5	0	0%
270	269	4	5	0	0.4%

6 Conclusion

The proposed system has benefits. Since motor modeling is general type, any type of motor can be modeled by knowing its parameters. The difficulties of the PID gain can be reduced because the detail facts of PID tuning methods are presented. The methods of implementing PID controller with hardware programming method can be known and easily implemented in real world. The FPGA based implementation system is flexible than general MCU and it has rapid prototyping. The usages of MATLAB software and Quartus II software are studied for control systems.

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