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Modeling Feedback Control System with Servomotor for Robotic Arm

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Abstract: ***Control systems provide a leading role in all domains of our day-to-day life. This paper presents the design and development of a servomotor-controlled hardware and software performing various functionalities. This is an automatic closed loop system. Here instead of controlling a device by applying a variable input signal, the device is controlled by a feedback signal generated by comparing output signal and reference input signal. Position, torque and velocity controls are very important in robotics. The controller drives the motor in required position, torque and velocity control. The controller accepts motion commands to adjust the motor. The PID controller produces an error signal as a difference between measured value and desired set point. The entire system performs the essential functionalities for the robotic control.***
Keywords: Teensy3.1, MC33926 Motor Carrier Driver, Quadrature Encoder, AS5048 Magnetic Rotary Encoder

I. INTRODUCTION

Closed loop control systems find a variety of applications in robotics for appropriate control and careful operation as specified by a given command. A system which incorporates almost all of the control system is very expensive. To meet with all the given requirements and to meet with the cost effectiveness we have to design a system which satisfies all this requirement.

The way in which actuators perform is determined by the combination of several factors. The robot's control system sends the actuator some sort of control signal, and various factors of the environment affect what happens for any given control signal. Feedback sensors are used to detect the actuator's output so that the control system can correct for external factors.

A control system which uses a feedback is known as closed loop control system. This feedback is used to compute servo error by finding the difference in desired and actual position, desired and actual velocity and that in desired and actual torque. The central problem is in designing a closed loop system that meet all the performance specifications.

First of all, the system has to remain stable. We define a system to be stable if errors remain small by executing various trajectories even in the presence of some disturbances. An improperly designed control system can sometimes result in unstable in which servo errors may get enlarged instead of being reduced. A PID controller is used in this project as a part of control system. PID stands for Proportional-Integral-Derivative control. Proportional control allows for a much smoother response than simple on/off control. Proportional control calculates an output value that is proportional to the magnitude of the error. Small errors yield a small response. Larger errors result in a more aggressive response.

Proportional control can be used alone, or augmented with Integral or Derivative control as needed. Integral control integrates the error over time. If the measurement is not converging on the set point, the integral output keeps increasing to drive the system toward the set point. Derivative control looks at the rate of change in the error. If the error is rapidly approaching zero, the output of the derivative calculation attempts to slow things down to avoid overshooting the set point.

The motion commands are accepted and the motor is adjusted to reach the required set point at the earliest.

II. SYSTEM DESCRIPTION

A system which incorporates almost all control system is very expensive. To meet with all the requirements and cost effectiveness we have to design a system which satisfies all the requirements. The following control mechanisms comes under controller functionality.

1) Velocity Control.
2) Torque Control.
3) Position Control.

A. Velocity Control

The speed of the motor must be independent of the load. Any external factors affecting the speed of the motor should not affect the overall speed of the system. The measured set point and the desired process variable have to be constantly measured. The entire process is maintained properly by the feedback mechanism which is incorporated in the system.

A PID Control Mechanism is used in the system to constantly monitor the entire system and calculate the error value. The error value is obtained as the difference between the desired set point and the measured value. The error is minimized by adjusting the process through the use of a manipulated variable. The count value of motor and the number of counts during a given time is used in calculating the revolutions during a given period.

The rpm with which the shaft of the motor rotates could hence be calculated. The motor is expected to rotate in an rpm as given in the command. This value is compared with the rpm of the shaft. The difference is calculated and PID mechanism adjusts the error value by minimizing it and maintains the speed of the motor irrespective of the variations in the load. The values are taken from the quadrature encoder.

The PWM values are maintained at constant ranges. Based on the commands given the motor can either be rotated in forward direction or in reverse direction. The proportional and derivative control law with position and velocity feedbacks could be used for the implementation of electronic controllers typically used in ac servomotors [1].

B. Torque Control

In robotic applications, maintaining constant torque is a very essential criterion. Torque refers to the tendency of a force to rotate an object about an axis. In short torque is the measure of force that makes an object rotate. The robotic torque control utilizes the direct relationship of torque and current. If magnetic field is kept constant, then the torque acting on a body will be directly proportional to the armature current. Hence for effective torque control, it is advisable to control the current. This paper presents an effective way of torque control by this method.

The analog pin of the microcontroller provides the value of current. This value of current is constantly monitored and is compared with the required set point. The difference in the values provides the error value and the system adjusts itself in minimizing the error value. The PID controller adjusts the system to reach the set point with reduced error value.

The commands could be provided to the motor to run either in forward or in reverse direction. The current has to remain constant for a given constant torque. There should not be any variations in the value of the current with respect to the overall load being applied to the system.

C. Position Control

Position control is the important of all control mechanisms. The motor should maintain the correct position in most of the critical applications. Once the commanded position is attained then there should not be any variation from the given set point. The position values are obtained from the magnetic and rotary encoders. If the given set point is farther away from the commanded value, then the motor is adjusted such that it reaches the position with maximum speed. The position control of the system is accomplished with higher precision of the encoders.

The error value is calculated based on the difference in the given value and observed set point. For greater values of the difference the system adjusts itself in reaching the attained position at the earliest.

A new robust composite nonlinear feedback control method to achieve fast and accurate set point tracking for nonlinear systems could be applied to design a control law for dc servomotor positioning system [4]. In an experiment on robotic finger with different PID parameter values for controlling the position it was found that the PID values play a leading role in the performance of a given task at high precision standard [12].

D. Other Controls

The position, torque and velocity control systems employed are briefly described as above. There are other mechanisms which could also be included for the control system. They include adjusting the PID values externally during the cases in which a given system functions improperly with the predefined parameters. In such cases the programmers could adjust the values externally.

In certain cases, the system needs to be stopped abruptly. In such cases by providing a single command the entire system could be stopped from the existing task that is being performed. The system could be enabled back by providing another command.

III. PROPOSED METHODOLOGY

Motion commands are provided by a suitable interface. The controller functionality includes controlling the motor in required position, torque or velocity controls. The control is carried out with the help of feedback mechanism. PID control mechanisms could be done suitably for attaining the required control.

By adjusting the value of kp, kd and ki suitable controls could be attained. Proportional, integral and derivative control forms the key basis of a PID controller. A PID controller calculates an error value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process through use of a manipulated variable. By tuning the three parameters in the PID controller, the controller can provide control action designed for specific process requirements.

The error value is calculated from present value and previous value and this signal is fed back as control signal feedback in appropriate control systems. The value from rotary encoder is used for position control and magnetic encoder provides suitable values. The system could be used in applications where the precise operation of a robotic arm is crucial.

The existing systems are not cost effective and flexible. With the help of proposed system, the proportional integral and derivative constants could be adjusted for required functionality. The user interface also provides the option to change the PID values. The value of current is constantly maintained for torque control irrespective of the variations in load current. No fluctuations of position occur after the required position being attained as given in the position command. The speed of rotation in either direction is also maintained precisely.

Some situations include the case in which we suddenly require to disable a given system. This could be made possible in this given system by providing a command for disable operation. The other control operations and adjustments of the PID constants will remain inactive during this period. The entire system could be enabled by setting the enable pin of the controller HIGH. Other operations function only after enabling the system.

IV. CIRCUIT DESCRIPTION

The IN1 and IN2 pins of the motor carrier driver are connected to the PWM pins of the microcontroller. These pins control the OUT1 and OUT2 pins of the driver. The rotary encoder connections are attached to the microcontroller. The D1 and D2 pins are connected to the Teensy. The feedback pin of the motor driver is connected to the microcontroller to sense the current. The current sensing facilitates in the torque control application of the system. The readings from the rotary encoder are monitored to find the speed at which the motor shaft rotates.

The microcontroller used in this project is Teensy 3.1. The Teensy is a breadboard-friendly development board with loads of features in a, well, teensy package. The Teensy 3.1 brings a 32-bit ARM Cortex microprocessor into the mix so that some serious number crunching could be done. The Teensy 3.1 comes pre-flashed with a boot loader so that programming can be done using the on-board USB connection that is no external programmer is needed. Program for the Teensy can be using C or by installing the Teensyduino add on for the Arduino IDE and write Arduino sketches for Teensy.

The controller has 256K Flash memory, 64K RAM and 2K EEPROM memory. Teensy contains 21 high resolution analog inputs, 34 digital I/O pins, 3 UARTs and 7 timers. The processor on Teensy also has access to the USB and can emulate any kind of USB device.

The motor driver used in this project can supply up to almost 3 A continuous current to a single brushed DC motor at 5-28V , and it can tolerate peak current up to 5 A for a few seconds. The device has under-voltage, over-current and over temperature protection. It supports ultrasonic pulse width modulation of the motor output voltage, which eliminates the audible switching sound caused by PWM speed control, and a current feedback circuit outputs an analog voltage on the FB pin that is proportional to the output current.

The magnetic rotary encoder used in this project is an easy-to-use 360° angle position sensor with a 14-bit high resolution output. The IC measures the absolute position of magnet's rotation angle.

The absolute position information of the magnet is directly accessible over a PWM output and can be read out over a standard SPI or a high speed I²C interface. The zero position can be programmed through an SPI or I²C interface. The mechanical alignment of the zero position of the magnet can hence be avoided and this benefits to an added advantage of using the encoder. No external programmer is required. The other features include 14-bit full scale resolution, daisy chain capability, wide magnetic field input range and immunity to stray magnetic fields.

V. RESULTS AND DISCUSSION

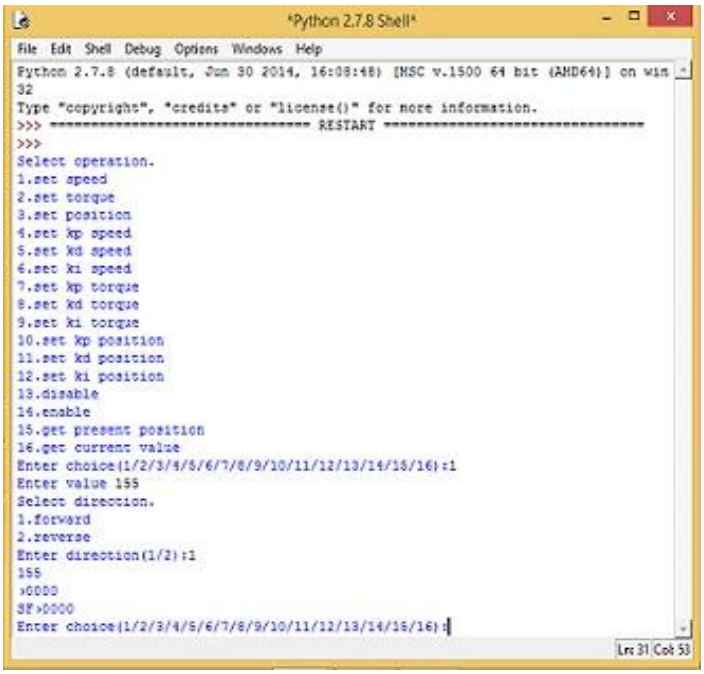

Fig 1. Rotating the motor at specified constant speed in forward direction

Fig 2. Rotating the motor at specified constant speed in reverse direction

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Fig 3. Maintaining specified torque in forward direction

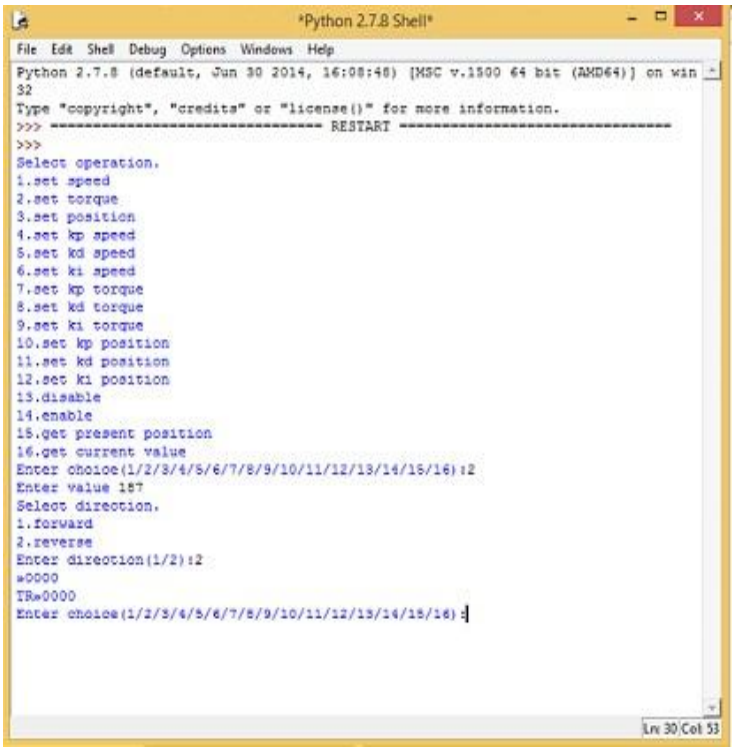

Fig 4. Maintaining specified torque in reverse direction

Fig 5. Position Control of the System

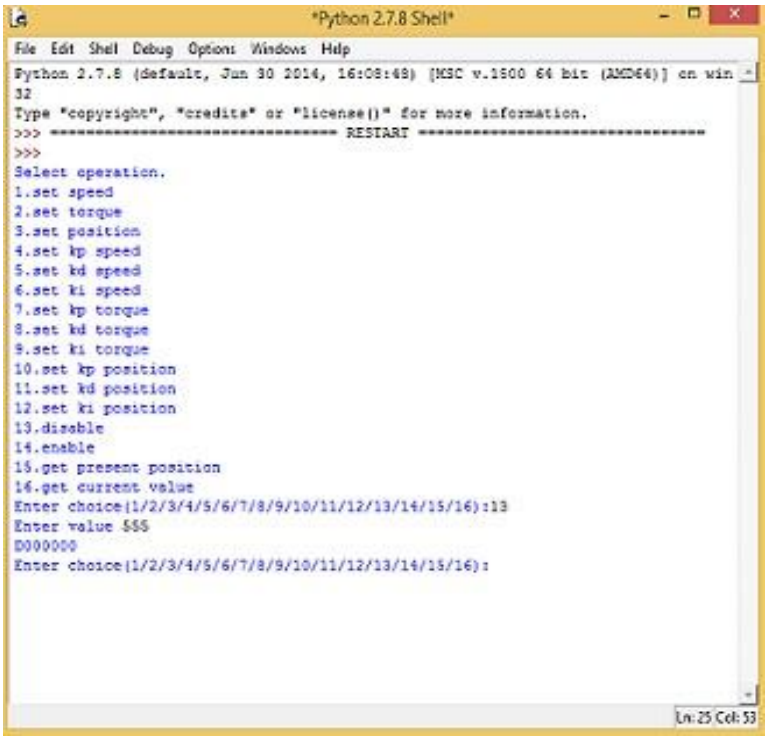

Fig 6. Disabling the System

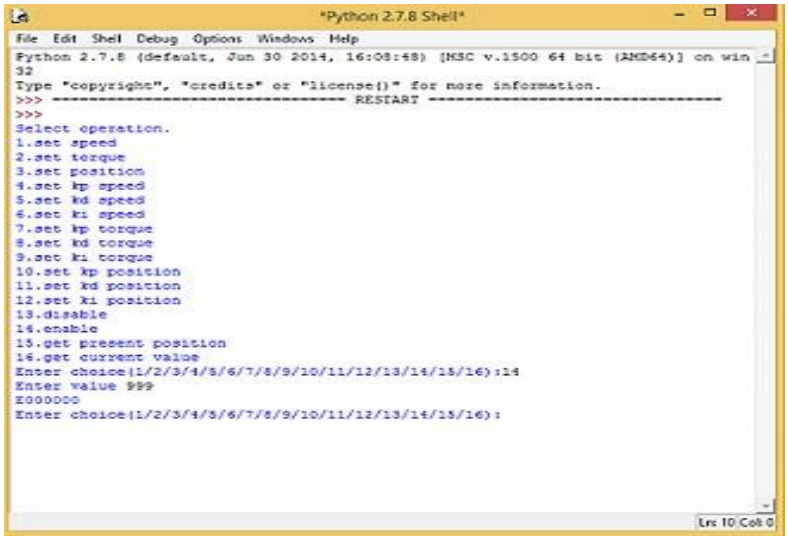

Fig 7. Enabling the System

VI. CONCLUSION AND FUTURE WORK

The motors used in robotic arms are really important and has to be well adjusted such that they work in required form as in the command given to it. Position, torque and velocity controls are employed in this project. The controller drives the motor in the required command. The entire system could even be connected to a bread board and hence consumes less space. The overall cost for the entire system is less. Teensy used in this project is available with a wide range of inbuilt functionalities. The current feedback signal provides for the required current control necessary for the torque control of given system. The position control of the system is precisely calculated with the help of quadrature and magnetic encoders. The commanded position is reached accurately and no further movement is sensed. The PID tuning employed here allows for the further adjustment of the PID values whenever required. The rotation in forward or reverse direction in a specified speed is possible with the help of the velocity control mechanism of the system. The overall system is cost effective and area effective.

VII. ACKNOWLEDGMENT

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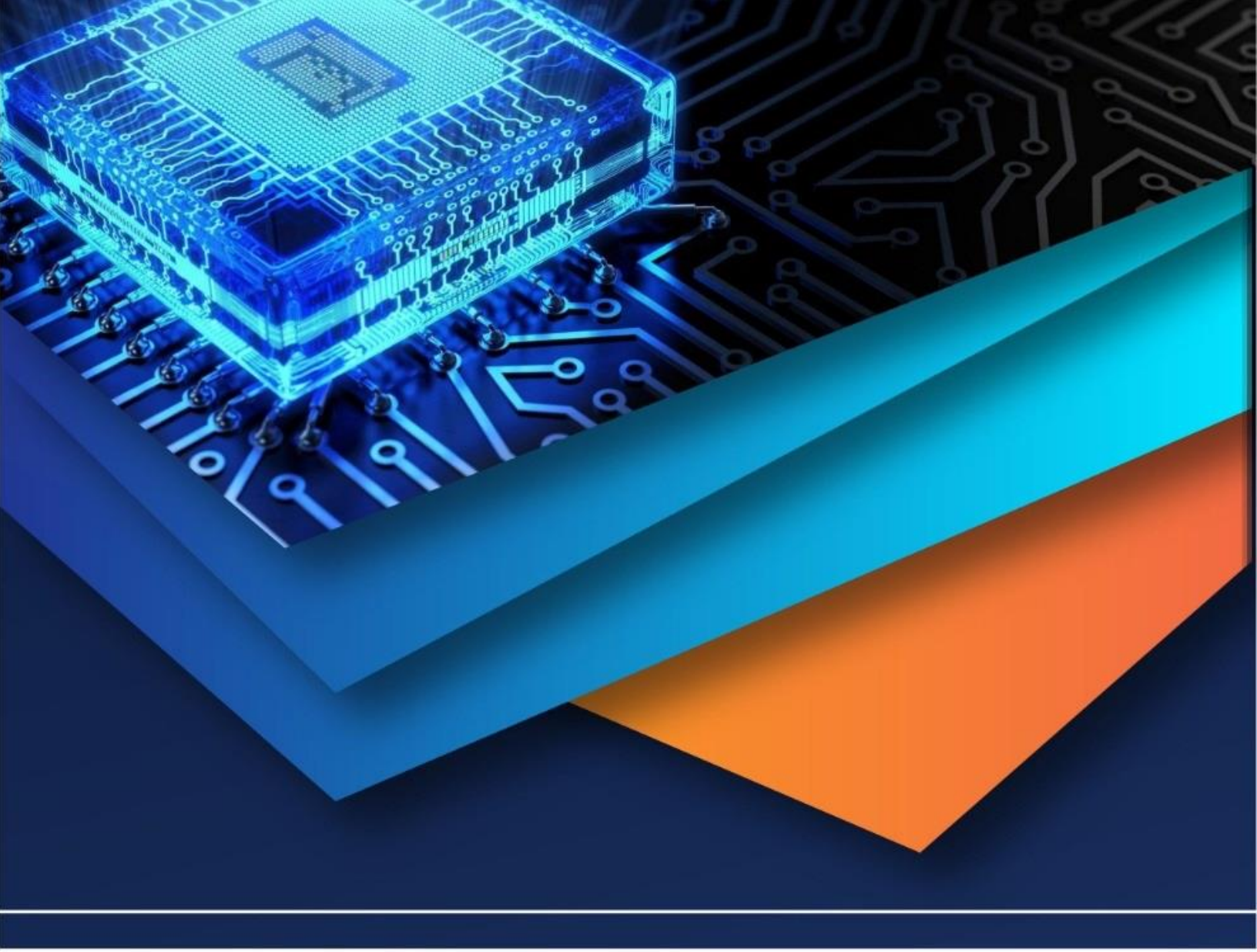

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