3-Axis Robot Arm Using Micro-Stepping with Closed-Loop Control

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3 axis robot arm using micro-stepping with closed loop control

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Abstract— Robot arm is one off the most buzzing word in industrial automation. The challenge of designing a robot arm is anticipating and controlling its system dynamics. This paper focuses on developing and testing of robot arm with 3 degrees of freedom (DoF) with high speed and precision. The position of the robotic arm is determined from the accelerometer using closed loop feedback system. The stepper motor in the arm of the robot which decides the direction and the movements will be controlled by PWM pulses through the controller as per the requirement. A4988 Stepper motor driver is used instead of rotary encoder to control the movements of arm by stepper motor. The step angle of the arm is controlled by micro-stepping using 200 steps to 3200 steps resolution which provides a smooth movement and precision degree of accuracy. A graphical user interface is designed using Labview to display and control the position of each arms. Finally, the electronic circuitry and mechanical parts are assembled, and the robot is tested for accuracy

Keywords — Stepper motor, Micro-stepping, PWM, Labview, accelerometer

1.0 INTRODUCTION

The use of robots in industries is proliferating due to the necessity of automation, reducing worker fatigue and faster productivity. Robots applications are primarily in material handling, operations, assembly and inspection. Apart from industries, robots are also deployed in home sector, health care, service sector, agriculture and farms, research and exploration. Robotic arms play an important role in all these applications. The three axes robotic arms are normally designed with either servo or dc motors to achieve more accurate positioning and smooth movement. Though servo and dc motors are trying to achieve the more accurate positioning and smooth movement they are lagging to achieve a high torque Hence this paper proposes to design a 3 axes robot using stepper motor with micro-stepping and closed loop control to achieve precise positioning, smooth movement and high torque. Micro-stepping is an approach of directing stepper motors, typically used to get good resolution or even motion at minimal speed. The angle of degree of the arm is read from the accelerometer and is compared with the lookup table. The arm angle is controlled by giving the required input through the LabVIEW front panel. The required position of the arm is achieved by calculating the position, forward and backward movement of the arm using LabVIEW block diagram. Accordingly, the PWM is adjusted to control the stepper motor in the required direction. Literature survey is discussed in section 2, Design of the proposed work in section 3, implementation and conclusion will be discussed in section 4 and 5.

2.0 Review of Literature

Biswas Palok, S. Anandan Shanmugam(2016) developed a 3 axes pneumatic robot arm using double acting pneumatic actuators controlled by 5/3 proportional valves. OMRON PLC and Arduino microcontrollers are used for control purpose. Open loop control system is derived through PLC to achieve sequential tasks in material handling whereas closed loop control system is derived through Arduino to improve control system using feedback from MPU-6050 (MEMS accelerometer and MEMS gyroscope) sensor [1].

Niranjan and et.al (2018) designed a robotic arm which is controlled using flex sensor, Arduino Uno, RF module (Wi-Fi Module), & servo motor. Flex sensor will send the values to the controller to run the system. The acquired values are analyzed to control the arm and the fingers how much they have to move and grab materials. This task is carried out with the help of five servo motors and the controller [2].

Abhishek Bhambere (2018) designed a 6-axis robotic arm consisting of manipulators to do perform pitching, rolling and yawing. V-Rep software is used to develop robotic arm using simulation and calculating the Torque [3].

Zhi-Ying Chen (2018) proposed remote controlled 6-axis Robotic Arm to read barcodes and handle Products. The control is achieved using Raspberry Pi with onboard WiFi. Robotic arm is monitored through WiFi by the designed mobile app.[4].

From the literature it is observed that the control of robot arm is achieved using PLC, Arduino Raspberry pi etc. But none of the paper is considering the control of precise positioning, smooth movement and high torque of the robotic arm. Some literature uses servo or dc motor for precise positioning and smooth movement without considering high torque. Similarly, some of the literature suggested to design the arm for high torque using stepper motor with rotary encoder without micro-stepping. Hence precise positioning, smooth movement could not be achieved through earlier designs. In this paper it is proposed to design 3 axis robot arm using micro-stepping with closed loop control to achieve precise positioning, smooth movement and high torque. The novelty of the paper is to achieve high precision by reading the angle of the arm from the accelerometer by comparing the lookup table values and smooth movement and high torque are achieved by stepper motor with stepper motor driver using micro-stepping through PWM control. LabVIEW and Arduino are used to generate the PWM to achieve the objective. The following section will elaborate the design of the proposed work.

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3.0 Designing of the proposed 3 axis robot arm with micro-stepping

This work is aimed to design a 3 axis robot using stepper motor with micro-stepping and closed loop control to achieve precise positioning, smooth movement and high torque. The proposed design will use accelerometer to acquire the present position of robot arm; Rotary ball bearing potentiometer, Arduino, and LabVIEW are used to generate the required PWM to control robotic arm and shoulder; stepper motor driver circuit A4988 will produce the required current in the closed loop to control the three stepper motors of the 3 axis robot arm. Stepper motor with Micro stepping in the closed loop control will achieve the objectives such as precise positioning, smooth movement and high torque. The following figure fig1 illustrates the block schematic of the design. The details and description of the blocks will be briefed in the following subsections.

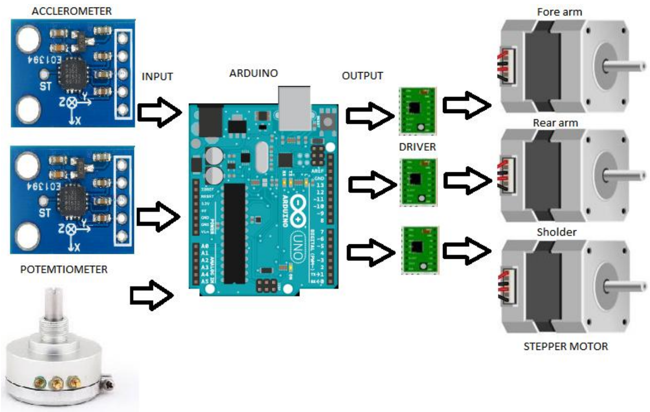

Fig1. Block schematic of the 3 axes robot arm

3.1 Accelerometer

The 3-axis acceleration is estimated using ADXL335. Th acceleration measurement range is within ±3 g in the x, y and z axis. The measured acceleration is converted in to the respective analog voltages as output signals by the module. The angle of inclination is derived from the acquired X, Y, Z's value. Also, the Roll, Pitch and Yaw angles are estimated using X, Y and Z axis. Initially g unit is obtained from the 10-bit ADC. 9.8 m/s^2 is the acceleration equivalent of 1g on the Earth. $1/6^{th}$ of the said value is on the moon and $1/3^{rd}$ is on mars. Tilt-sensing applications, motion, vibration due to dynamic acceleration are obtained from accelerometer.

Maximum voltage level at 0g is 1.65V and sensitivity scale factor of 330mV/g is estimated as per ADXL335 datasheet.

$$\text{Aout} = \frac{\frac{\text{ADC value * Vref}}{1024} - \text{Voltage Level at 0g}}{\text{Sensitivity Scale Factor}}$$

In the above equation, X, Y and Z axis g unit acceleration values are as follows,

A_{xout} = (((ADC value of X axis * V_{ref}) / 1024) – 1.65) / 0.33
A_{yout} = (((ADC value of Y axis * V_{ref}) / 1024) – 1.65) / 0.33
A_{zout} = (((ADC value of Z axis * V_{ref}) / 1024) – 1.65) / 0.33

Based on the X,Y, Z axis values the inclination of the robot arm is estimated. The details of angle of inclination estimation is as follows.

3.1.1 Inclination Angle

Inclination Angle is defined as the tilting level of the device from its surface plane. Inclination angle is illustrated below figure 2.

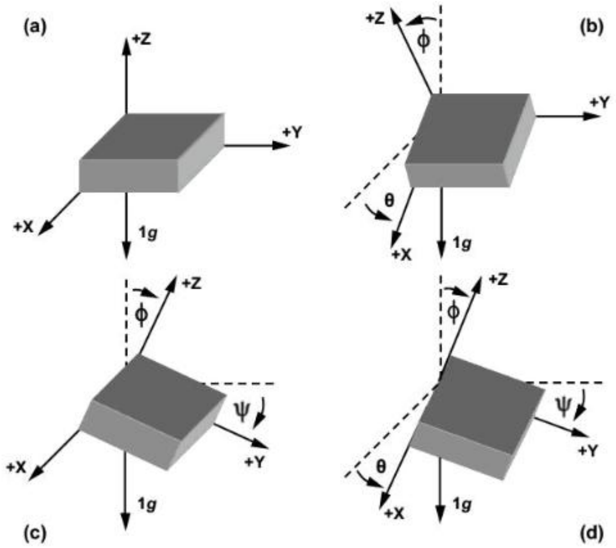

Fig 2. Inclination Angle

The inclination angle of X, Y, Z axis is estimated from its reference. This is calculated using the following equation.

$$\Theta(\text{theta}) = \text{atan}\left(\frac{\text{Axout}}{\sqrt{\text{Ayout}^2 + \text{Azout}^2}}\right)$$

$$\Psi(\text{psi}) = \text{atan}\left(\frac{\text{Ayout}}{\sqrt{\text{Axout}^2 + \text{Azout}^2}}\right)$$

$$\Phi(\text{phi}) = \text{atan}\left(\frac{\sqrt{\text{Axout}^2 + \text{Ayout}^2}}{\text{Azout}}\right)$$

The angular movement of the arms are sensed using two accelerometers whose analog voltage vary along with the arm movement. The respective values are converted to angular degree by mapping with efficient lookup table values. The mapping of the lookup table with angular degree will estimate the precise positioning effectively.

3.2 Precision potentiometer

Rotary movement of the robot are feedback from the rotary ball bearing potentiometer to read the present position of the robot arm. Metal ball bearing are used for rotation of the potentiometer to provide exact analog value. The acquired precise analog value is to be scaled to the angle of degree of the robot arm

3.3 Arduino Controller

Controlling application is achieved with the help of low cost Arduino Controller. The generated PWM outputs of the Arduino Uno controller are taken from the digital I/O pins 3, 5, 6, 9, 10 and 11. The duty cycle of a PWM pulse train is set at 500 Hz using the analog Write function. The forearm arm and rear arm and shoulder are controlled by the stepper motor using the PWM generation from the Arduino. The feedback regarding the current position of the arm is given from the accelerometer and the potentiometer. The forearm and rear arm movement is sensed by the accelerometer and the shoulder movement is sensed by the potentiometer which are given as input to the Arduino and the analog value is converted to bits. Depending upon the bit value the desired angle is determined by lookup table which is stored in the EEPROM of the Arduino and the present value is displayed in the Graphical user interface (Labview) using serial protocol.

3.4 GUI using Labview

The graphical user interface is developed using LabVIEW and data transfer between LabVIEW and Arduino is done using serial communication[5]. The destination angle can also be set using GUI such that the arm moves to the desired position. Figure 3 a and 3b present the 3 axis robot front panel design and control programming using LabVIEW.

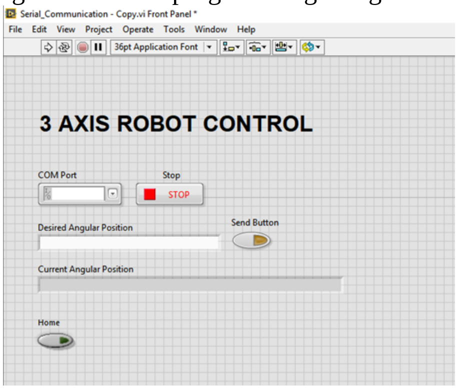

Fig 3a LabVIEW Front panel control design

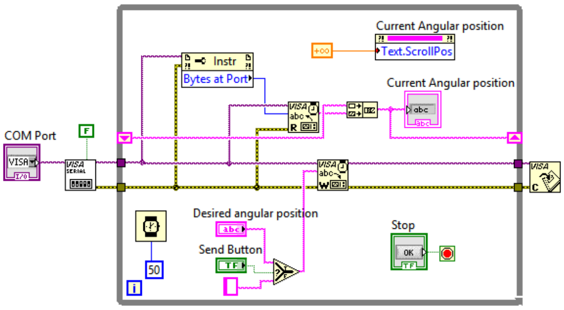

Fig 3 b LabVIEW Block diagram control programming

The commands for all the three arms are send serially and the differentiation between each command are defined using the special character. These are sent along with the commands such that each stepper motor driver gets the command.

3.5 Stepper motor and Micro-stepping

The most important quality that a pick and place robot should have is the precise angle of rotation with higher torque which makes stepper motor a best choice for higher torque applications. The movement of Stepper motors will be defined in terms of discrete steps, or revolution fraction [6]. For example, for every full revolution of the stepper motor with 1.8 degree step angle it will make 200 steps (360 ÷ 1.8). This 1.8 degree step will give imperfect smooth in the rotation of the motor which will cause slow rotation. The relatively large step size results in lack of smoothness at slow speeds. A way to improve the smoothness is to reduce the size of the motor step. Hence the need of micro-stepping arises. Micro-stepping controls the stepper motor by producing higher resolution or smoother motion at low speeds. But providing smaller degree of movement such as micro-stepping is quite difficult in normal stepper motor. In this 3 axes robot micro-stepping is achieved by using step stick driver which provides upto 3200 steps making resolution of 0.11 degree per rotation. To get smooth motor's rotation, especially at slow speeds, the step stick driver splits each full step into smaller steps. For example, to achieve a step angle of 0.007 degrees, a 1.8-degree step can be divided up to 256 times, (1.8 ÷ 256), or 51,200 micro-steps per revolution[8]. The current to the motor winding is controlled by pulse-width modulated (PWM) voltage to achieve micro-stepping.

The driver is controlled by PWM generated using Arduino and the direction is also controlled by Arduino. The controls are given through serial protocol by which the present coordinates are read using accelerometer, servo potentiometer. The output analog voltage depending upon each angle of movement of the arms are noted as lookup table and depending upon the difference between the present and the destination coordinates the PWM is incremented or decremented with reference to the lookup table.

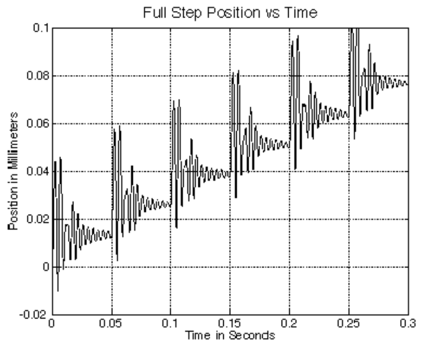

Fig 4. Graph of Full step position vs time

The two voltages sine waves sent to the motor windings are 90 degrees out of phase driver. If current increases in one winding, it will decrease in the other winding. When compared to full- or half-step control due to this gradual transfer of current smoother motion and more consistent torque is produced.

3.6 A4988 Stepper motor driver

The required supply voltage of 3 – 5.5 V for the driver is connected across the VDD and GND pins and a supply voltage of 8 – 35 V for motor is connected across V_{MOT} and GND. The appropriate decoupling capacitors are used to deliver the expected currents (up to 4 amp peak for the motor supply). A4988 will drive four- wire, six- wire, and eight-wire stepper motors, if they are connected properly; A typical step size of 1.8° or 200 steps per revolution stepper motors are used to attain full steps. A4988 micro-stepping driver allows higher resolutions by permitting intermediate step locations. These are attained by stimulating the coils in-between current levels. Four different current levels will support to drive a motor in quarter-step mode of 200-step-per-revolution or 800 micro-steps per revolution.) Selection from the five step resolutions are enabled from the resolution (step size) selector inputs (such as M_{S1}, M_{S2}, and M_{S3} which are given in the following table. 100kΩ pull-down resistors and 50kΩ pull-down resistor are the internal resistance values of M_{S1} & M_{S3} and M_{S2}. Hence leaving these three micro-step selection pins disconnected will cause full-step mode. The current limit should be set low for the micro-step modes to function perfectly. This in turn makes the current limiting gets engaged. Else, the in-between current levels will not be maintained perfectly which will cause skipping of micro-steps.

STEP input of Each pulse will produce one micro-step of the stepper motor in the direction selected by the DIR pin. The STEP and DIR pins are not pulled to any specific voltage internally, so these pins should not be left floating in the application. If the stepper motor is rotating in a single direction, DIR is directly connected to VCC or GND. Three different inputs of the chip are used in controlling its various power states like RST, SLP, and EN. If the RST pin is floating; then the pin is connected to the neighbor SLP pin on the PCB to make it high and activate the board. Active current limiting is supported by the A4988; To set the current limit the trimmer potentiometer is used on the board. Keeping the driver into full-step mode is one of the way to set the current limit. Current passing through a single motor coil is to be measured while adjusting the current limit potentiometer. This should be carried out with the motor holding a fixed position.

4.0 Implementation of the proposed work

Initially the current position of the arms are noted from the accelerometer and the potentiometer serially and the value are been compared with the lookup table stored in the EEPROM and the angle of each are determined. The desired value is been the sent through labview which is been compared with the current value, if the current value is greater than the desired value the PWM pulse is been decremented such as no of pulse count which is been stored is been decremented till it reaches the desired value. Pulse count is initially been determined as zero from the initial power up of the robot from which it is increment or decremented depending upon the current position similarly if the current value is less than the desired value the PWM pulse is been incremented till it is equal to the desired value. Once the current value reaches the desired value the PWM pulse is been latched. The PWM pulse are been counted using counter initially and depending upon the current value the counter value is been increment or decremented using which the arms are been moved. The PWM is varied depending upon the pattern at which the driver is been set.

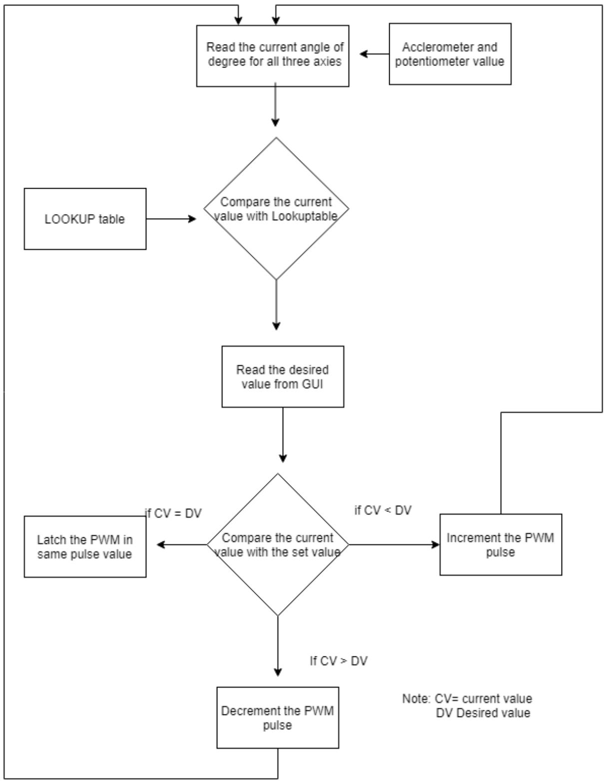

Fig 5 Flow chart of the proposed work

4.1 EXPERIMENTAL SETUP

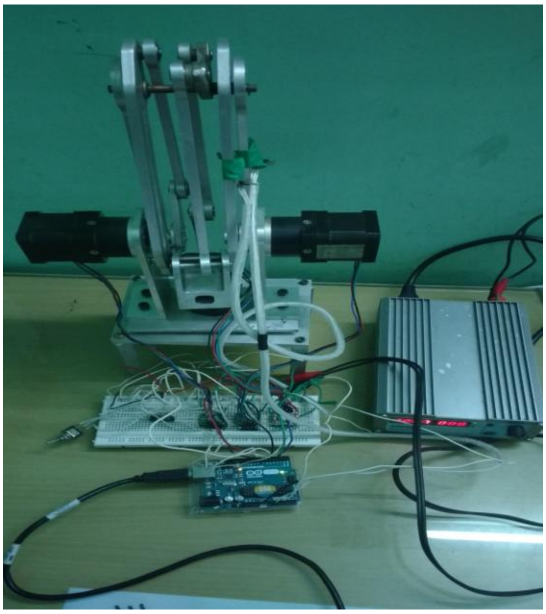

Fig 6 Experimental setup of the proposed work

Experimental setup has been fabricated with aluminum alloy and nema stepper motor with 1:10 ratio gear has been used to reduce the set for smoothness and précised angular movement. The power supply to the motor are provided with external DC source with current limitation of 1A. The payload upto 1kg can be driven by each stepper motor. The current status are sent serially using Arduino and is displayed in the Labivew front panel.

5.0 Conclusion

A 3 axis robot using stepper motor with micro-stepping and closed loop control is designed and implemented to achieve precise positioning, smooth movement and high torque. Control input was given through the LabVIEW software to fix the robot arm at the required position. The current position of the robot arm is acquired through the accelerometer by mapping with the lookup table to achieve precise positioning. Interfacing Arduino with LabVIEW provides PWM pulses according to the controlled input fed through front end. The smooth movement and high torque is achieved with the help of stepper motor using micro-stepping. The usage of stepper motor driver replaces the existing conventional rotary encoder whose cost is more than the stepper motor driver. The adjustment of the arm positioning is carried out through the closed loop control. The work can be extended for higher axis robot arm design.

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