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Simulation and Implementation of Multiple Unipolar Stepper Motor Position Control in the Three Stepping Modes using Microcontroller

Ayman Y. Yousef*[1], M. H. Mostafa[2]
[1]Electrical Engineering Dept., Faculty of Engineering at Shoubra, Benha University, Cairo, Egypt
[2]Distribution Sectors, South Cairo Electrical Distribution Co., Cairo, Egypt
*Corresponding author, e-mail: Ayman.youssef@feng.bu.edu.eg

Abstract

This paper presents a multiple unipolar stepper motor position control system using microcontroller (MCU) in anticlockwise and clockwise directions. The open loop controller of the implemented position control system for the three stepping modes of operation has been designed and developed with three stepper motors and without position feedback. The MCU is programmed using flowcode software package to generate the pulse signals with the desired stepping sequences and step angles. These pulse signals are necessary to drive the three stepper motors in the three drive modes (wave-step, full-step, and Half-step) according to the control algorithm. Three devices of 8 Channel Darlington Driver (chip ULN2803) are used to drive the three stepper motors and provide them with the sufficient current. The position control system has been simulated using proteus design suite software package and the controller has been implemented using low cost PIC16F877A (MCU). A reliable and accurate position control of the stepper motor is achieved by this position control system.

Keywords: *Stepping modes, MCU, Step angle, ULN2803, Stepper motor*

1. Introduction

The stepper motor is a brushless DC motor that rotates in steps this is very useful because it can be precisely position without any feedback sensor which represents an open loop controller. Some of the stepper motor applications are computer accessories (hard disk drives, CD drive, printers, scanners, etc.), tool machines, automobile industry, and the actuators of industrial robots [1, 2]. The advantage of the stepping motor over the other motors kinds is it works efficiently in open loop where it performs the movement step by step when applying the voltages on its phases [3]. By construction there are three different types of stepper motors; permanent magnet stepper (PMSM), variable reluctance stepper (VRSM), and hybrids synchronize stepper motor (HSM). The permanent magnet stepper is a permanent magnet rotor which is driven by a stator windings. They create opposite polarity poles compared to the poles of the rotor which propels the rotor. The next type is the variable reluctance stepper motor uses known magnetized soft iron rotor. The rotor has teeth that are offset from the stator and when the windings are activated in a particular order, the rotor moves respectively, so that it has a minimum gap between the stator and the teeth of the rotor. The third type is the hybrid synchronous motor which is a combination of the previous those steppers. It has a permanent magnet tooth rotor housed within a machined iron core and also a tooth stator.

The PMSM is small size, economical and very simple in design. The VRSM and HSM give more torque with higher accuracy, but come with the higher cost and larger size [4]. Basically, the stepper motor consists of a permanent magnet rotor surrounded by the windings or coils of the stator. If the stator coils are activated step by step in a particular order and let the currents flowed through them, they will magnetize the stator coils and make electromagnetic poles respectively that will cause repulsion to the rotor. There are two basic winding arrangements for the electromagnetic coils of the stepper motor which are bipolar and unipolar. Also, there are several ways of driving the stepper motor such as wave drive, full drive, and half step drive. These main three modes of stepper motor drive are determined by the applied step sequence of the pulse signals from the motor driver. The driver receives the pulse signals from

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the MCU at TTL logic level at 5v and 25mA and provides the stepper motor by the sufficient current [5]. In this paper a drive system of Multiple Unipolar Stepper Motor Position Control in the three Modes of Operation is designed, simulated, and implemented using PIC16F877A *(MCU)*.

2. Unipolar Stepper Motor

A two phase unipolar stepper motor has one center-tapped winding (two coils) per each main phase, each coil switched on to change the direction of the magnetic field [6]. This winding arrangement of unipolar stepper motor results in six wires, two of them considered as common wires. These two common wires are often connected together internally to make the motor has only five wires (A, A', B, B', common) as shown in Figure 1. Each coil is energized and switched on to change the direction of the magnetic field without needing to switch the current direction in order to reverse the magnetic pole, this means that the current passes in one direction (unipolar). The permutation of the four coils (or phases) can be done easily using a single transistor, which works as a switch for each coil and are controlled by the driving pulse signals as shown in Figure 2.

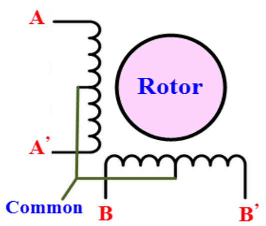


Figure 1. Five-wire unipolar stepper motor

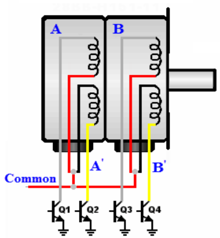


Figure 2. unipolar winding arrangement

These pulse signals required to switch the motor coils are generated digitally using the *MCU*. A driver circuit or device is interfaced with the *MCU* to provide the sufficient current to drive the stepper motor. The stepper motor speed is directly proportional to the frequency ($f=1/T_{delay}$) of the applied pulse signals given to the driver and its position is related to the number of rotation [7].

3. Step Angle, Position, and Speed of Stepper Motor

The important property of the stepper motor is to convert a train of input pulses which is usually square wave into a precisely defined increment in the rotor (shaft) position [8]. Each input pulse moves the rotor shaft by a certain and fixed angle which is called step angle. The step angle is defined as the angle which the rotor moves when one input pulse is applied to the stator and is given by:

$$\delta = \frac{360^o}{S_r} \tag{1}$$

The position and the angular velocity are given by:

$$\theta = N\delta \tag{2}$$

$$\omega = \frac{\delta}{dt} \tag{3}$$

The motor speed is given by:

$$n = \frac{60\delta}{360} f \tag{4}$$

Where *δ* is the motor step angle in degree/step, S_r is the number of steps per revolution, *θ* is the position, *N* is the number of steps, ω is the angular velocity in rad/sec, n is the speed of the motor r.p.m, and f is the pulse signal frequency in Hz (number of input pulse/sec).

4. Stepping Modes of Stepper Motor Drive

There are three stepping modes of driving the stepper motor. The stepping mode refers to the sequence pattern in which stator coils are energized. The first mode is a wave stepping drive [single coil (phase) excitation], In this step mode, just only one coil is activated at a time, which means that of the motor with four coils the rotor will make a full cycle in four steps as in the phasor diagram shown in Figure 3 and the stepping sequence pattern as shown in Table 1. This mode has less torque and minimum stability at higher speeds.

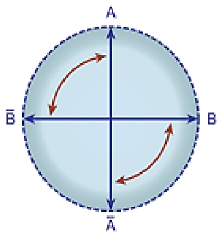


Figure 3. Phase diagram for wave stepping mode

Table 1. Stepping Sequence of Wave Drive

Coils	Step 1	Step 2	Step 3	Step 4
A	High	Low	Low	Low
B	Low	High	Low	Low
A'	Low	Low	High	Low
B'	Low	Low	Low	High
Deg.	0^o	90^o	180^o	270^o

The second mode is a full stepping drive [two coils (phases) excitation]: In this step mode, two coils are activated at a time and also the rotor will make a full cycle in four steps as shown in the phasor diagram shown in Figure 4 and the stepping sequence pattern as shown in Table 2. This drive mode is usually used because it provides much higher torque (full rated torque) due to the activity of two coils at any time but doesn't improve the resolution of the stepper.

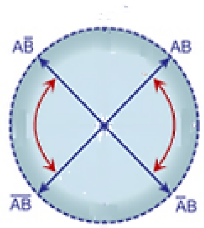


Figure 4. Phase diagram for full stepping mode

Table 2. Stepping Sequence of Full Drive

Coils	Step 1	Step 2	Step 3	Step 4
A	High	Low	Low	High
B	High	High	Low	Low
A'	Low	High	High	Low
B'	Low	Low	High	High
Deg.	45^o	135^o	225^o	315^o

The third mode is a Half stepping drive [one and two coils (phases) excitation]: The half step mode is a combination of the wave and full modes this means that one active coil followed by two active coils and then again one active coil followed by two active coils and so on. The rotor with this mode will make a full cycle in eight steps as in the phasor diagram shown in Figure 5 and the stepping sequence pattern as shown in Table 3. In this case the resolution of the stepper motor is increased, but with less torque than in full-step (about 70% of full-rated torque) [9].

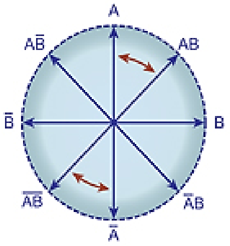
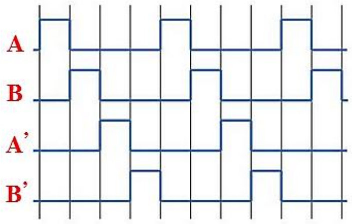


Figure 5. Phase diagram for half stepping mode

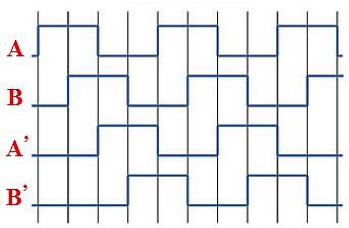
Table 3. Stepping Sequence of Half Drive

Coils	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8
A	High	High	Low	Low	Low	Low	Low	High
B	Low	High	High	High	Low	Low	Low	Low
A'	Low	Low	Low	High	High	High	Low	Low
B'	Low	Low	Low	Low	Low	High	High	High
Deg.	0^o	45^o	90^o	135^o	180^o	225^o	270^o	315^o

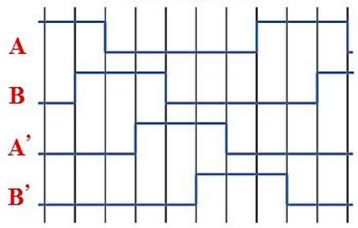
The switching sequence waveforms of a typical stepper motor Input pulse signal in the wave-step, full-step, and half-step drive modes in anticlockwise and clockwise directions are shown in Figure 6 and Figure 7 respectively. The duty cycle of the pulse train for each coil in wave drive, full drive, and half drive modes are 25%, 50%, and 37.5% respectively.



a) Wave Drive or single-coil Excitation

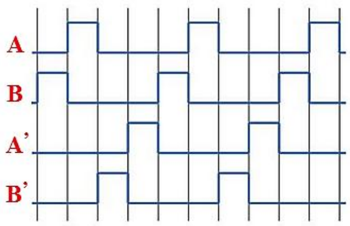


b) Full drive or double-coil excitation

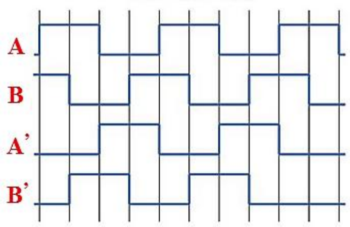


c) Half drive or single and double-coil excitation

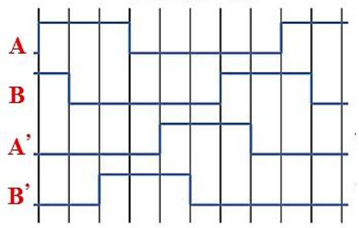
Figure 6. Input pulse series and excitation sequence in anticlockwise direction



a) Wave Drive or single-coil Excitation



b) Full drive or double-coil excitation



c) Half drive or single and double-coil excitation

Figure 7. Input pulse series and excitation sequence in clockwise direction

5. Stepper Motors Drivers

The coils (phases) of each stepper motor must be driven by a specific pulse signals which generated by the PIC16F877A *(MCU)* in order to control the position of the stepper motor. The source currents of the *MCU* input/output pins are not sufficient to drive the stepper motor currents [6]. The integrated ULN2803 chip is a device of high-voltage, high-current Darlington transistor array is used for this purpose. The device consists of eight NPN Darlington arrays that feature high-voltage outputs with common-cathode clamp diodes switching inductive loads as shown in Figure 8 [10]. The rated current of each channel is 500mA and the voltage output is 50V and the channels must be connected in parallel for higher current capability. In this work three ULN2803 devices are used to drive the three stepper motors, each two input/output channels of each device are connected in parallel as shown in Figure 9 to provide a current of 1A instead of 500mA per channel which is sufficient to drive the stepper motor safely.

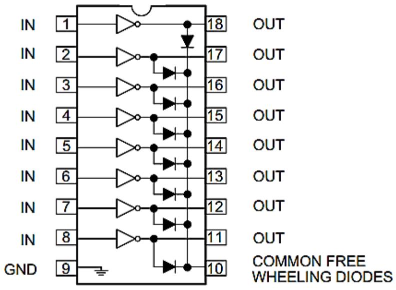


Figure 8. ULN2803 Pin assignments

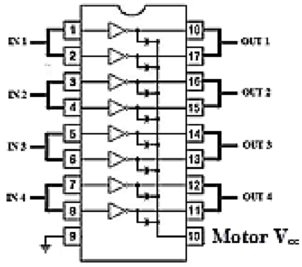


Figure 9. ULN2803 channels connected in parallel

6. Unipolar Stepper Motors Drive System Description

The schematic diagram of the implemented multiple stepper motor position control system is designed and simulated by proteus design suite software package. The Schematic diagram of the PIC16F877A *MUC* is a main element of the implemented position control system with other electric and electronic devices and drivers as shown in Figure 10. This *MUC* have a programmable flash memory of 14 KB, RAM of 368 bytes and EEPROM of 256 bytes and a 40 pin [11].

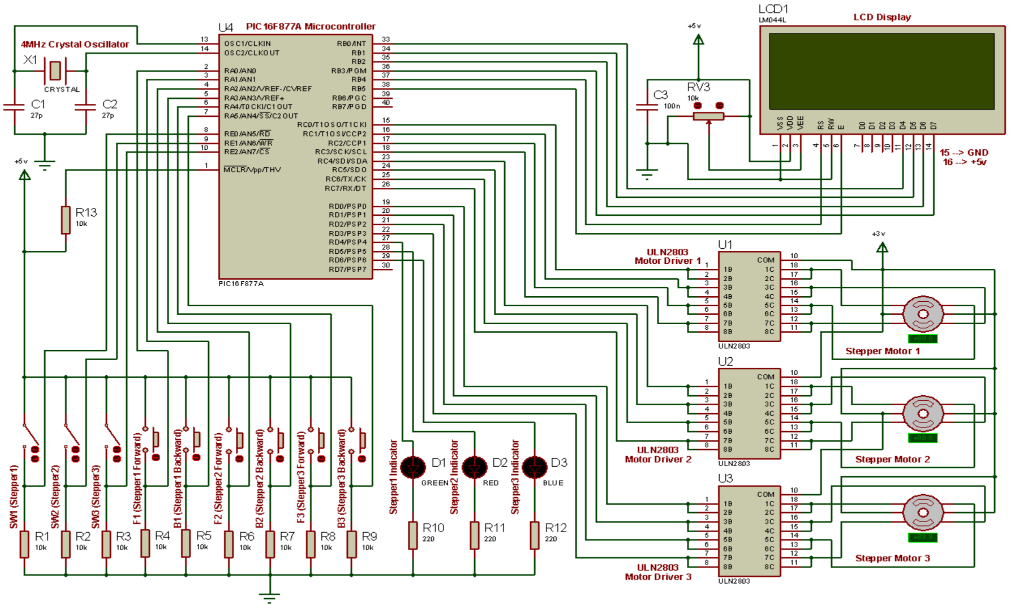


Figure 10. Schematic diagram of the Multiple Unipolar Stepper Motors Position Control System designed by Proteus software

The *MCU* read the signals from any of the three toggle switches (SW1, SW2, and SW3) in order to start drive the three stepper motors in wave step, Full step, and Half stepping mode with three indicator LEDs (D1, D2, and D3) respectively. A six push buttons are used to choose the rotation direction (anticlockwise and clockwise) of the three stepper motors. The Buttons (F1, F2, and F3) are used to anticlockwise direction and the buttons (B1, B2, and B3) are used to clockwise directions of stepper 1, stepper 2, and stepper 3 respectively. The three stepper motors driver chips ULN2803 is interfaced with PIC *MCU* pins (PC0 to RC3), (RC4 to RC7), and (RD1 to RD3) of the output ports C and D respectively. The four parallel outputs of each driver are connected to the four coils (phases) of their corresponding stepper motor according to the desired stepping sequence. A digital LCD (4x20) pins are connected to port B to display the details of stepper motors control modes. The *MCU* is supplied with 5V logic level while the common terminals of the stepper motors and its driver chips are fed by 3V as the rated voltage.

7. Software Implementation

The software control algorithm of the proposed multiple stepper motor position control system was implemented and developed using flowcode software package. The main advantage of using flowcode (graphical tool of *MCU* programming) is its ability to programming the *MCU* to generate the pulse signals with the desired duty cycle simply and easily [12, 13]. The flowchart of the multiple unipolar stepper motor position control system in the two directions is shown in Figure 11.

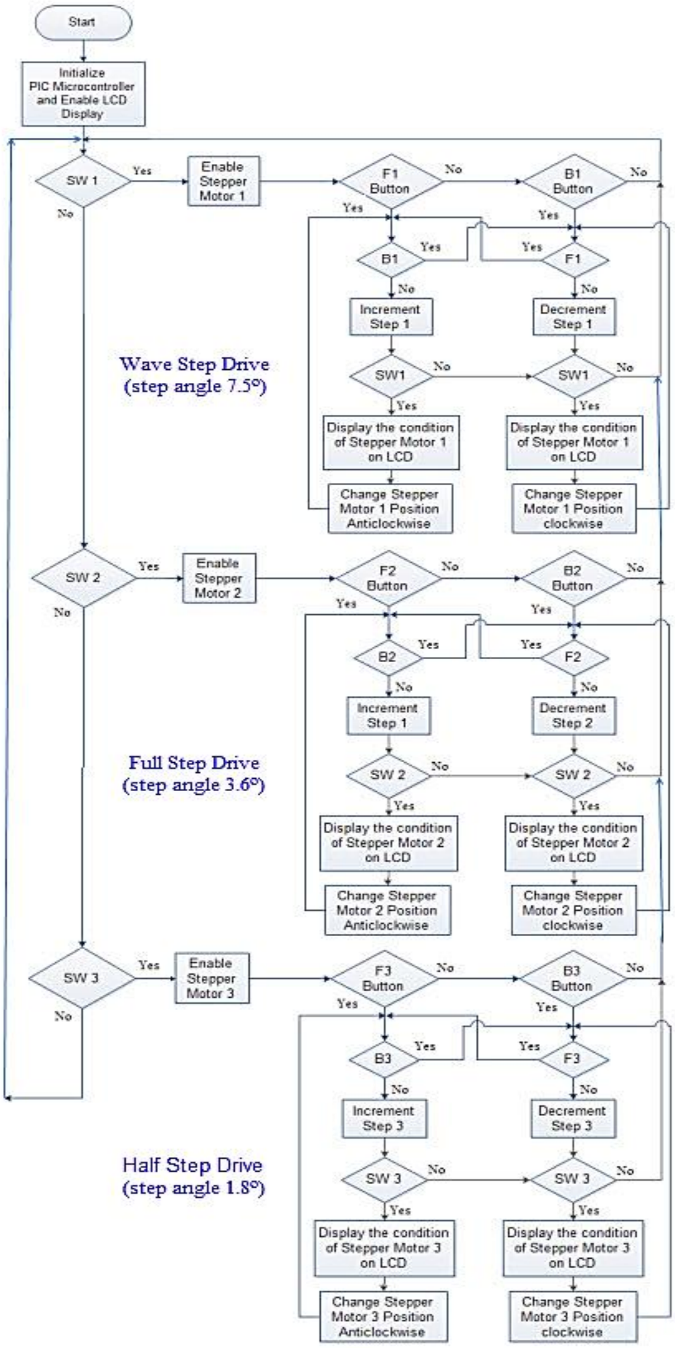
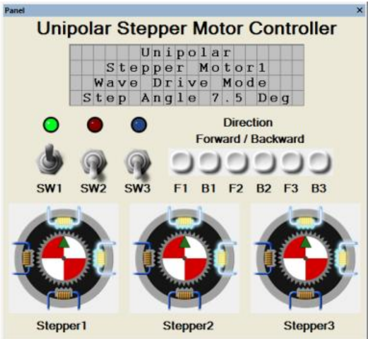


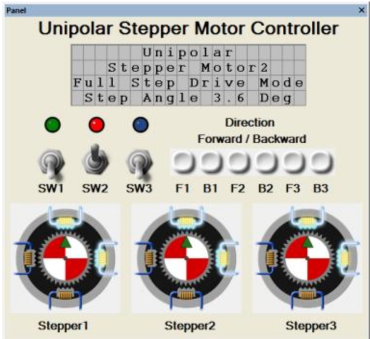
Figure 11. Flowchart of the implemented position control algorithm

8. Simulation Results
8.1. Flowcode Simulation Results

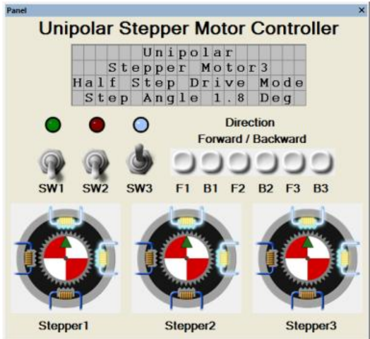
The simulation of the implemented position control system with the three unipolar stepper motors in the three stepping modes of operation (wave-step, full-step, and half-step) using flowcode software at step angles of 7.5^o (48 step/rev), 3.6^o (100 step/rev), and 1.8^o (200 step/rev) are shown in Figure 12, Figure 13, and Figure 14 respectively.



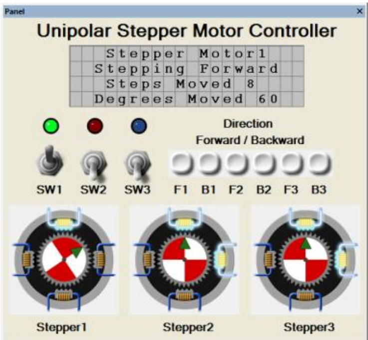
a) Starting panel of stepper 1



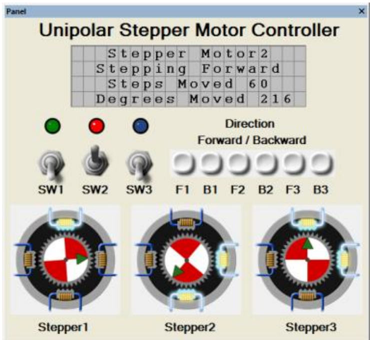
a) Starting panel of stepper 2



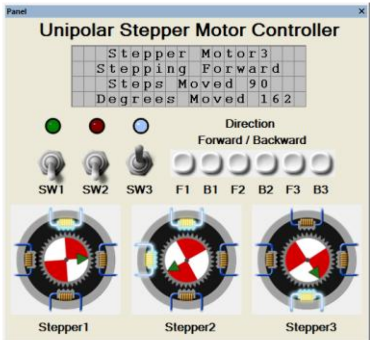
a) Starting panel of stepper 3



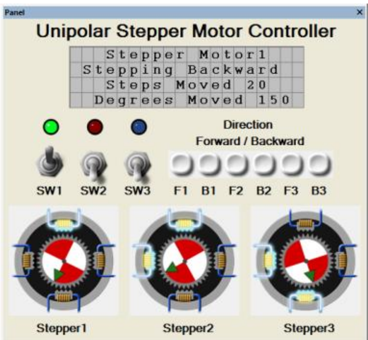
b) Anticlockwise (Forward) direction of stepper 1 with 8 steps and moved degrees of 60^o



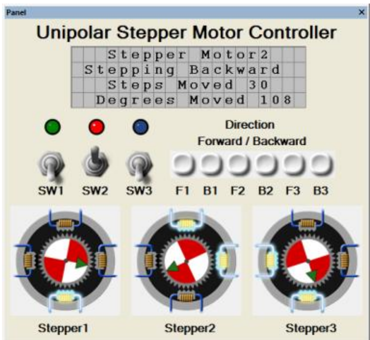
b) Anticlockwise (Forward) direction of stepper 2 with 60 steps and moved degrees of 216^o



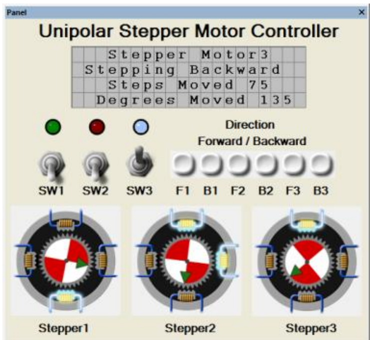
b) Anticlockwise (Forward) direction of stepper 3 with 90 steps and moved degrees of 162^o



c) Clockwise (Backward) direction of stepper 1 with 20 steps and moved degrees of 150^o



c) Clockwise (Backward) direction of stepper 2 with 30 steps and moved degrees of 108^o



c) Clockwise (Backward) direction of stepper 3 with 75 steps and moved degrees of 135^o

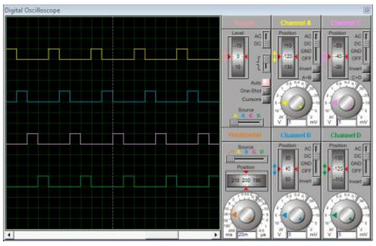
Figure 12. Wave stepping drive mode of stepper motor 3 at 7.5^o step angle

Figure 13. Full stepping drive mode of stepper motor 2 at 3.6^o step angle

Figure 14. Half stepping drive mode of stepper motor 3 at 1.8^o step angle

8.2. Proteus Simulation Results

The simulation of the generated pulse signals from the *MCU* and the driving input signals to the three stepper motors in the three stepping modes based on the implemented position control system using proteus software in anticlockwise direction and at step angles of 7.5^o (48 step/rev), 3.6^o (100 step/rev), and 1.8^o (200 step/rev) are shown in Figure 15, Figure 16, and Figure 17 respectively.


a) *MCU* output signals

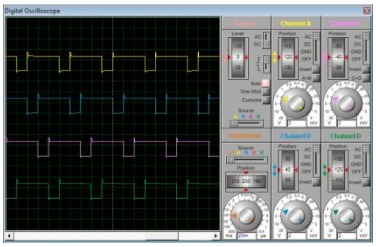
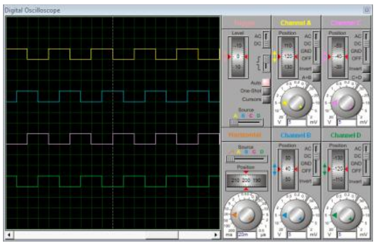

b) Stepper 1 input signals

Figure 15. Wave mode signals in anticlockwise direction of Stepper motor 1 at 7.5^o step angle.


a) *MCU* output signals

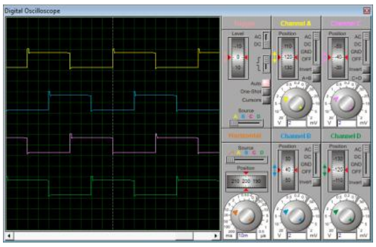
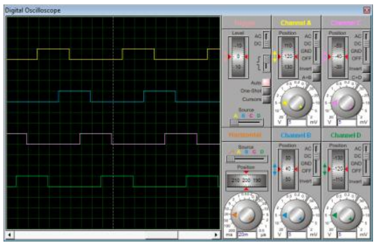

b) Stepper 2 input signals

Figure 16. Full mode signals in anticlockwise direction of Stepper motor 2 at 3.6^o step angle.


a) *MCU* output signals

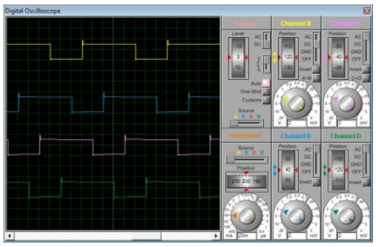
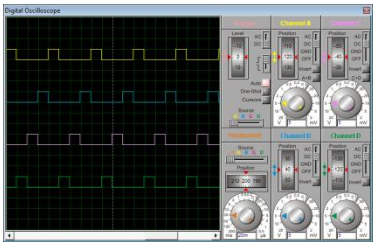

b) Stepper 3 input signals

Figure 17. Half mode signals in anticlockwise direction of Stepper motor 3 at 1.8^o step angle.

Also, the simulation of the same pulse signals of the implemented position control system using proteus software in clockwise direction and at the same step angles is shown in Figure 18, Figure 19, and Figure 20 respectively.


a) *MCU* output signals

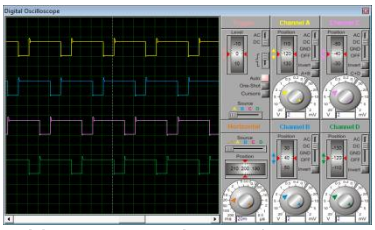
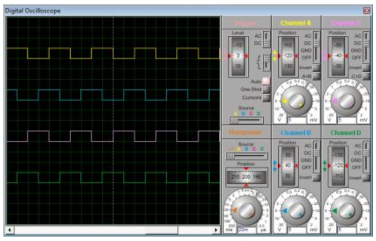

b) Stepper 1 input signals

Figure 18. Wave mode signals in clockwise direction of Stepper motor 1 at 7.5^o step angle


a) *MCU* output signals

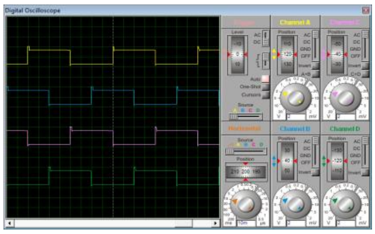
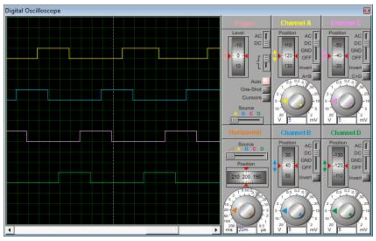

b) Stepper 2 input signals

Figure 19. Full mode signals in clockwise direction of Stepper motor 2 at 3.6^o step angle


a) *MCU* output signals

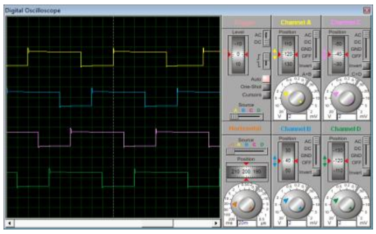

b) Stepper 3 input signals

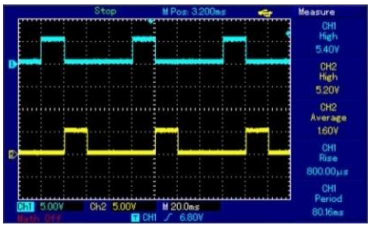
Figure 20. Half mode signals in clockwise direction of Stepper motor 3 at 1.8^o step angle

9. Hardware Implementation

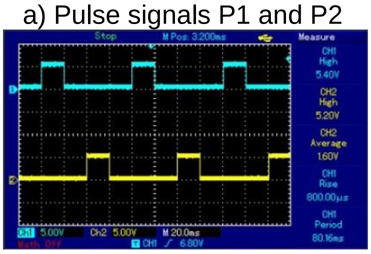
The hardware setup of the implemented position control system with the three unipolar stepper motors (rated voltage V = 2.9V, rated current I = 0.8A, and step angle 1,8^o) using PIC16F877A *(MCU)* is shown in Figure 21.

Figure 21. Photograph of the hardware setup connection of the multiple unipolar stepper motors position control system

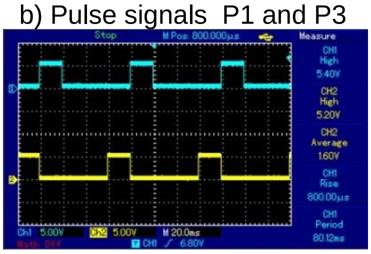
10. Hardware and Experimental Results



a) Pulse signals P1 and P2

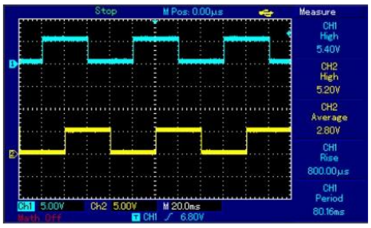


b) Pulse signals P1 and P3

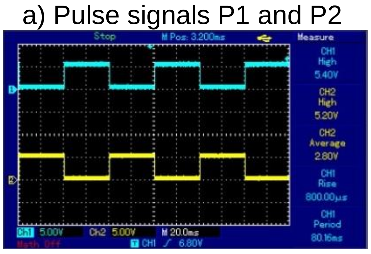


c) Pulse signals P1 and P4

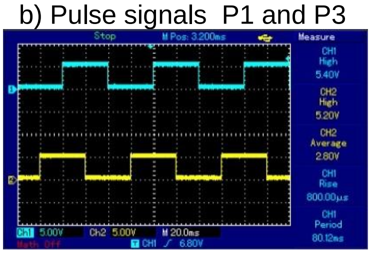
Figure 22. Scope of *MCU* pulse signals for Wave mode in anticlockwise direction of Stepper motor 1 at 7.5^o step angle



a) Pulse signals P1 and P2

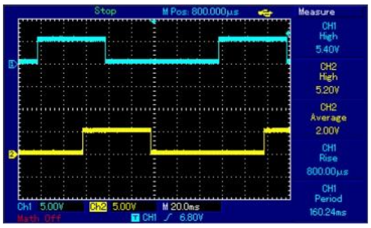


b) Pulse signals P1 and P3

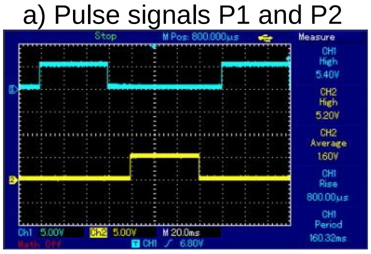


c) Pulse signals P1 and P4

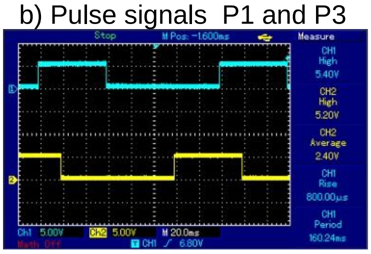
Figure 23. Scope of *MCU* pulse signals for full mode in anticlockwise direction of Stepper motor 2 at 3.6^o step angle



a) Pulse signals P1 and P2



b) Pulse signals P1 and P3

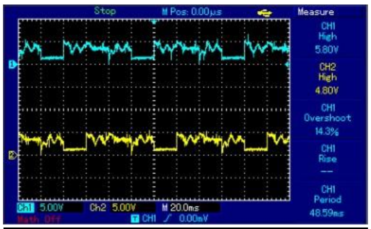


c) Pulse signals P1 and P4

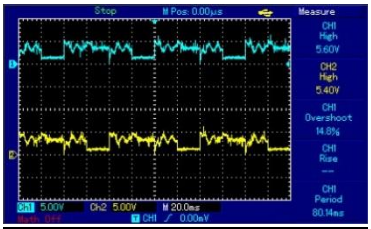
Figure 24. Scope of *MCU* pulse signals for half mode in anticlockwise direction of Stepper motor 3 at 1.8^o step angle

The Hardware results using real oscilloscope of the *MCU* pulse signals of the implemented control system for the three unipolar stepper motors with three stepping modes in anticlockwise direction at step angles of 7.5^o (48 step/rev), 3.6^o (100 step/rev), and 1.8^o (200 step/rev) are shown in Figure 22, Figure 23, and Figure 24 respectively.

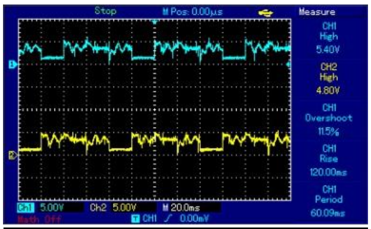
The Hardware results of the phase voltage signals of the three unipolar stepper motors in anticlockwise direction and at step angles of 7.5^o (48 step/rev), 3.6^o (100 step/rev), and 1.8^o (200 step/rev) are shown in Figure 25, Figure 26, and Figure 27 respectively.



a) Ph1 and Ph2

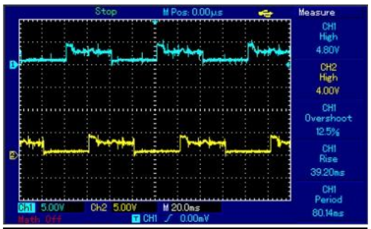


b) Ph1 and Ph3

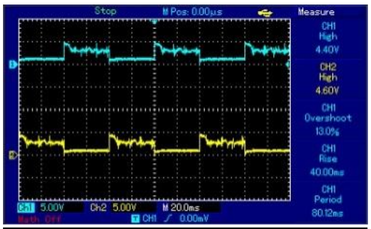


c) Ph1 and Ph4

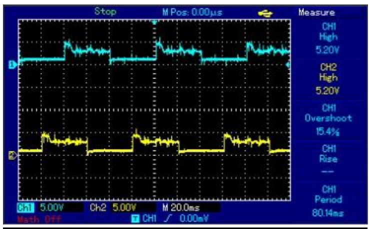
Figure 25. Scope of phase voltage signals of Stepper motor 1 in anticlockwise direction for wave mode and at 7.5^o step angle



a) Ph1 and Ph2

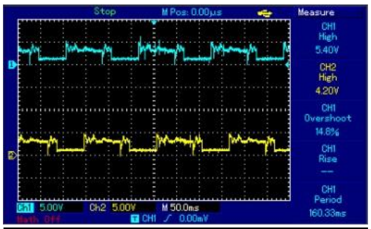


b) Ph1 and Ph3

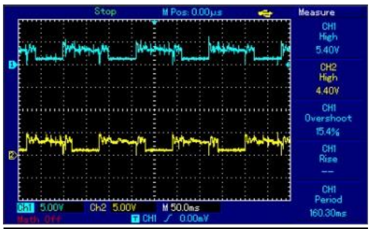


c) Ph1 and Ph4

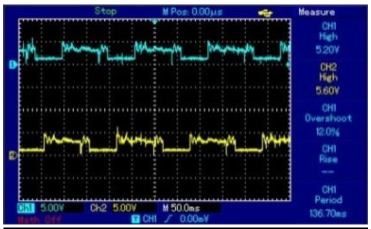
Figure 26. Scope of phase voltage signals of Stepper motor 2 in anticlockwise direction for full mode and at 3.6^o step angle



a) Ph1 and Ph2



b) Ph1 and Ph3

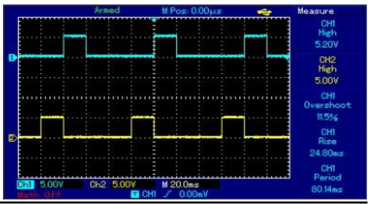


c) Ph1 and Ph4

Figure 27. Scope of phase voltage signals of Stepper motor 3 in anticlockwise direction for half mode and at 1.8^o step angle

Also, the Hardware results of the *MCU* pulse signals of the implemented control system with the three modes of operation at the same step angles, but in clockwise direction are shown in Figure 28, Figure 29, and Figure 30 respectively.

The Hardware results of the phase voltage signals of the three unipolar stepper motors in clockwise direction and at the same step angles of 7.5^o (48 step/rev), 3.6^o (100 step/rev), and 1.8^o (200 step/rev) are shown in Figure 31, Figure 32, and Figure 33 respectively.


a) Pulse signals P1 and P2


b) Pulse signals P1 and P3

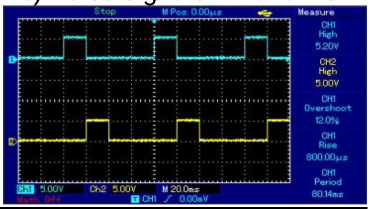
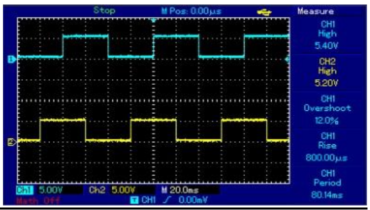
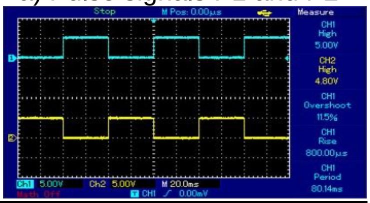

c) Pulse signals P1 and P4

Figure 28. Scope of *MCU* signals for Wave mode in clockwise direction of Stepper motor 1 at 7.5^{o} step angle.


a) Pulse signals P1 and P2


b) Pulse signals P1 and P3

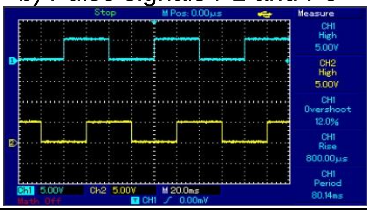
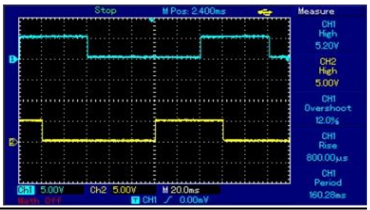
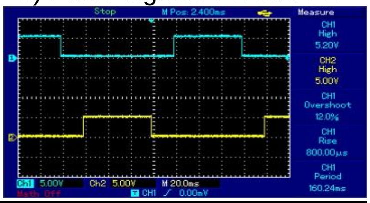

c) Pulse signals P1 and P4

Figure 29. Scope of *MCU* signals for full mode in clockwise direction of Stepper motor 2 at 3.6^{o} step angle.


a) Pulse signals P1 and P2


b) Pulse signals P1 and P3

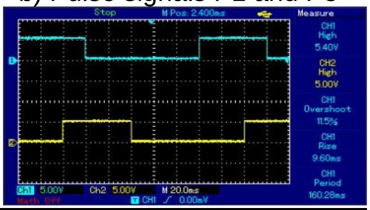
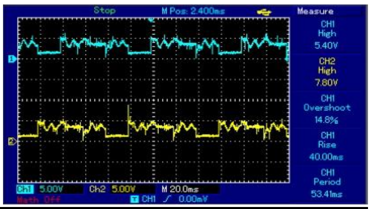
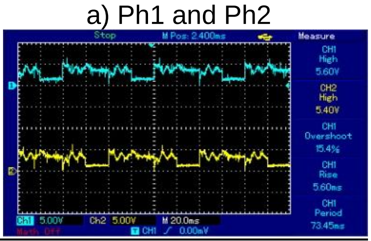

c) Pulse signals P1 and P4

Figure 30. Scope of *MCU* signals for half mode in clockwise direction of Stepper motor 3 at 1.8^{o} step angle.


a) Ph1 and Ph2


b) Ph1 and Ph3

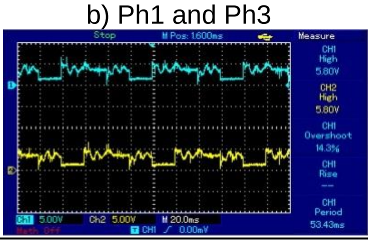
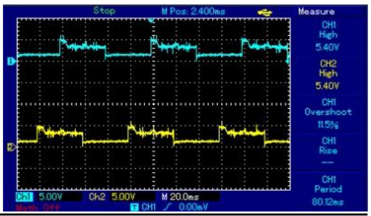
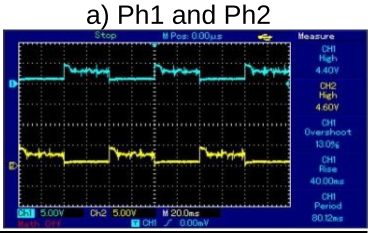

c) Ph1 and Ph4

Figure 31. Scope of phase voltage signals of Stepper motor 1 in clockwise direction for wave mode and at 7.5^{o} step angle


a) Ph1 and Ph2


b) Ph1 and Ph3

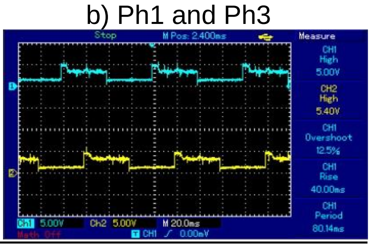
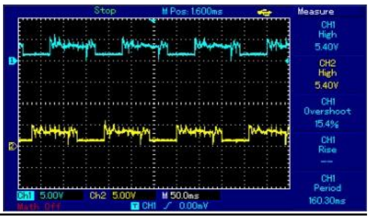
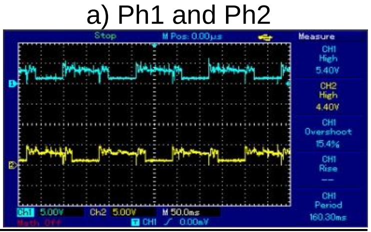

b) Ph1 and Ph4

Figure 32. Scope of phase voltage signals of Stepper motor 2 in clockwise direction for full mode and at 3.6^{o} step angle


a) Ph1 and Ph2


b) Ph1 and Ph3

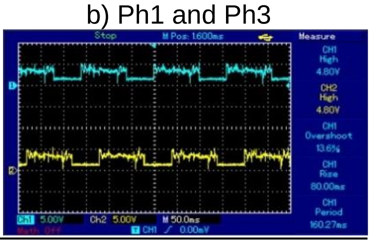

b) Ph1 and Ph4

Figure 33. Scope of phase voltage signals of Stepper motor 3 in clockwise direction for half mode and at 1.8^{o} step angle

11. Conclusion

In this paper, an open loop position control system of multiple unipolar stepper motors using PIC16F877A *(MCU)* in the two directions (anticlockwise and clockwise) has been designed and implemented. A control method was used wave-step, full-step, and Half-step modes of operation for the three stepper motors respectively. The input pluse signals of the three drivers (ULN2803 IC) are provided by the MCU which programmed according to the patterns of the stepping sequence of the three stepping modes. The position control system for the three unipolar stepper motors was simulated and tested with the three stepping modes in the two directions at step angles of 7.5^o (48 step/rev), 3.6^o (100 step/rev), and 1.8^o (200 step/rev) respectively. The stepper motor speed is inversely proportional to the delay time (T_{delay}) of pulse signals given to the stepper motors and the position is related to the number of rotations. The simulation and experimental results are verified accordingly and portray the adequacy of the position controller.

References

[1] Ivan Virgala, Michal Kelemen, Alexander Gmiterko, Tomáš Lipták. Control of Stepper Motor by Microcontroller. *Journal of Automation and Control*. 2015; 3(3): 131-134.
[2] Tanu Shree Roy, Humayun Kabir, Md A Mannan Chowdhury. Simple Discussion on Stepper Motors for the Development of Electronic Device. *International Journal of Scientific & Engineering Research*. 2014; 5(1): 1089-1096.
[3] Aniket B Kabde, A Dominic Savio. Position Control of Stepping Motor. *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*. 2014; 3(4): 8974-8981.
[4] Pratiksha N Balai, Jimit A Talati. Open Loop Motion Control of Stepper Motor for Video Surveillance System. *International Journal of Novel Research in Electrical and Mechanical Engineering*. 2015; 2(1): 41-46.
[5] Kausik Chakraborty, Nisarga Chand, Bappadittya Roy. Design and Development Stepper Motor Position Control System Using Atmel 85c51 Microcontroller. *International Journal of Emerging Research in Management &Technology*. 2013; 2 (12): 44-48.
[6] Chetan R Bhale, Palak G Sharma, Sagar M Lanjewar, Hemant Thakre. Comparative Analysis of Stepper Motor Drivers. *International Journal on Recent and Innovation Trends in Computing and Communication*. 2016; 3(5): 213-218.
[7] Amit Kumar, Ramjee Prasad Gupta. Speed and Position Control of Stepper Motor using 8051 Microcontroller. *International Journal for Scientific Research & Development*. 2015; 3(6): 267-271.
[8] Dharmender Aswal, Karn Singh, Vikas Yadav. The Study of Stepper Motors. *International Journal of Innovative Research in Technology*. 2015; 1(12): 706-708.
[9] Thomas Hopkins. Stepper motor driving. AN235 Application Note. Doc ID 1679 Rev 2. November 2012; 1-23.
[10] Texas Instruments "ULN2803A Darlington Transistor Arrays" SLRS049G –FEBRUARY 1997–REVISED JANUARY 2015.
[11] PIC Microcontroller Instruction Sets. PIC16F877A Enhanced Flash Microcontrollers Datasheet. Microchip Technology Inc. 2003.
[12] Ayman Y Yousef, MH Mostafa. Dual DC Motor Speed Control Based on Two Independent Digital PWM Signals using PIC16F877A Microcontroller. *Indonesian Journal of Electrical Engineering and Computer Science*. 2016; 2(3): 592-606.
[13] Dan S Mihai. *A Multi-Approach Design in Training Motion Control for the Stepping Motors*. 7th International Conference on Electromechanical and Power Systems. Iaşi, Romania. 2009: 127-131.