Mechatronics II ME511

Experiment 11 Report

DC Motor Speed Control Using PWM

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1. Summary

In this experiment we learnt about DC motor, working principles of DC motor, building the drive for it i.e. H Bridge amplifier circuit, controlling the speed of the motor using the PWM signal output from the Arduino. We also learnt about the optoisolators and its uses.

2. List of Components

- DC motor
- Optoisolator
- Potentiometer
- Didoes
- Arduino
- Jumper wires
- Breadboard
- Transistors

3. Purpose and Objective

To control the speed of a DC motor using a PWM signal from Arduino Microcontroller in conjunction with an H-bridge amplifier circuit and learning the principle behind the H Bridge, DC motor, using the software to control the direction and speed of a DC motor.

4. Theory

PWM - Pulse Width Modulation a PWM signal has two variables that must be decided by the control software PWM signal carrier (or base) frequency, PWM signal duty cycle. The PWM frequency is generally a constant frequency in the kHz range. The duty cycle is the value decided in real-time to indicate the equivalent analog value of the signal. This is accomplished by generating an ON-OFF signal of a high frequency, and then varying the percentage of time that the signal is in the ON state versus the OFF state. This is called varying the duty cycle. The average value of the signal is equivalent to an analog signal, provided that the PWM switching frequency is much higher than the bandwidth frequency of the electromechanical system. Care must be taken to ensure that PWM frequencies are kept reasonably high compared to the bandwidth of the control system, since a low frequency PWM signal may actually be seen as varying, and not continuous, voltages, especially for loads with a smaller electrical time constant. Typical PWM frequencies are of the order of a few kHz.

The PWM signal format is used in two different contexts:

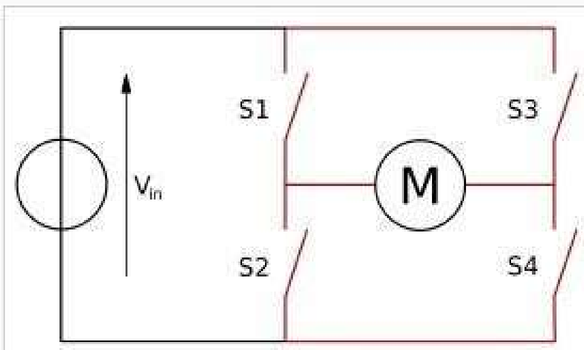
- Power transistor circuits, where the transistors are operated in all ON and all OFF alternating states, which is called the PWM mode. In this mode of operation, as opposed to the linear mode of operation where the transistor is partially turned ON/OFF, the efficiency of the power transistors is significantly improved. In high power transistor applications, the PWM mode of operating the transistors is invariably more efficient than the linear (proportional) mode of operating them. However, due to the high switching frequency of the PWM circuit, there could be a small high frequency noise (in some cases, also audible) induced on the power output lines.

- Low power sensor or signal processor signals: when a signal is transmitted as an analog voltage level, it is susceptible to noise. If it is transmitted as a PWM signal, small changes in the voltage due to noise do not affect the information coded in the signal magnitude unless the noise is so large that it changes the ON/OFF state of the signal, and the resulting duty cycle. Hence, the PWM mode of transmitting an analog signal is more immune to noise than the analog voltage mode of transmission.

Pulse duration modulation (PDM), is a modulation technique used to encode a message into a pulsing signal. Although this modulation technique can be used to encode information for transmission, its main use is to allow the control of the power supplied to electrical devices, especially to inertial loads such as motors. The average value of voltage (and current) fed to the load is controlled by turning the switch between supply and load on and off at a fast rate. The longer the switch is on compared to the off periods, the higher the total power supplied to the load. The PWM switching frequency has to be much higher than what would affect the load (the device that uses the power), which is to say that the resultant waveform perceived by the load must be as smooth as possible. The term duty cycle describes the proportion of 'on' time to the regular interval or 'period' of time; a low duty cycle corresponds to low power, because the power is off for most of the time. Duty cycle is expressed in percent, 100% being fully on. The main advantage of PWM is that power loss in the switching devices is very low. When a switch is off there is practically no current, and when it is on and power is being transferred to the load, there is almost no voltage drop across the switch. Power loss, being the product of voltage and current, is thus in both cases close to zero. PWM also works well with digital controls, which, because of their on/off nature, can easily set the needed duty cycle. PWM has also been used in certain communication systems where its duty cycle has been used to convey information over a communications channel.

H Bridge Circuit - The DC motor is driven using the H-bridge amplifier circuit comprising of four MOSFET power transistors (two of them are p-channel (IRF9520) and the other two are n-channel (IRF511/IRF510) MOSFET transistors), four diodes (1N4003) and the motor itself. Each MOSFET pair on each side of H-bridge consist of a p-channel on the top and a n-channel on the bottom as shown in the figure. The motor connects in between the two legs. The p-channel source terminals are connected to 9 V and the drain terminals are connected to motor leads, whereas the source terminals of n-channel are connected to ground and the drain terminals are connected to motor leads. When PWM channel 1 is turned ON, the transistor pair on the top-left and bottom right will be conducting, hence the current will flow from left to right direction. When the PWM channel 2 is turned ON, the opposite pair will be conducting (bottom-left and top-right), hence the current will flow through the motor winding in the opposite direction (from right to left). When all four transistors are OFF, the motor is in uncontrolled “coast” state. When only the bottom two transistors are turned ON, then both leads of the motor are grounded and the motor is in “dynamic braking” state. It is important that the two transistors on any one side of the H-bridge should not be turned ON at the same time since it would create a short circuit between the DC bus supply voltage and ground, resulting in a very large current and possibly destroying the transistors. Keeping in mind that power transistors have longer turn OFF time than turn ON time, there should be some “dead-time” between turn OFF and turn ON time of the two transistors on any one side. This can be accomplished either in software or by H-bridge integrated circuits (IC) which have dead-time insertion and short-circuit protection capabilities. PWM output peripherals in microcontrollers have dead-time insertion capability as a programmable feature.

An H bridge is an electronic circuit that enables a voltage to be applied across a load in opposite direction. These circuits are often used in robotics and other applications to allow DC motors to run forwards or backwards. Most DC-to-AC converters (power inverters), most AC/AC converters, the DC-to-DC push–pull converter, most motor controllers, and many other kinds of power electronics use H bridges. In particular, a bipolar stepper motor is almost invariably driven by a motor controller containing Two H Bridges. H bridges are available as integrated circuits, or can be built from discrete components. The term H bridge is derived from the typical graphical representation of such a circuit. An H bridge is built with four switches (solid-state or mechanical). When the switches S1 and S4 are closed (and S2 and S3 are open) a positive voltage will be applied across the motor. By opening S1 and S4 switches and closing S2 and S3 switches, this voltage is reversed, allowing reverse operation of the motor. Using the nomenclature above, the switches S1 and S2 should never be closed at the same time, as this would cause a short circuit on the input voltage source. The same applies to the switches S3 and S4. This condition is known as shoot-through. The H-bridge arrangement is generally used to reverse the polarity/direction of the motor, but can also be used to 'brake' the motor, where the motor comes to a sudden stop, as the motor's terminals are shorted, or to let the motor 'free run' to a stop, as the motor is effectively disconnected from the circuit.



Structure of an H bridge (highlighted in red)

PWM channel 1 controls the current in one direction, while PWM channel 2 controls the current in the opposite direction in the H-bridge. By choosing which one of the PWM outputs to turn on, we control the direction of current, and hence the direction of the torque generated by the motor. By controlling the magnitude of the current in the PWM pin, we control the magnitude of the current, and hence the magnitude of the torque. Commercial H-bridge amplifiers accept two different types of PWM command signals and there is a “H-bridge driver/controller” section of the circuit which translates the input command signals to corresponding H-bridge drive signals to operate the transistor pairs:

- PWM command signal (0–100% duty cycle, corresponding to 0–100% of maximum current command) and direction signal. The direction signal (ON for clockwise or positive, OFF for counter clockwise or negative) decides on the direction of the current, the PWM signal’s duty cycle determines the magnitude of the commanded current. Using these two signals, the H-bridge driver circuit generates two command signals that drive one of the pair (two transistors) at a predefined PWM frequency.
- PWM command signal only in (0–100% duty cycle), where 50% duty cycle is considered as zero current command. A PWM duty cycle less than 50% is interpreted as counter

clockwise direction, and a PWM duty cycle above 50% is interpreted as clockwise direction. Then, the H-bridge controller activates the two PWM channels to control one of the two pair of power transistors.

The type of PWM command signal an H-bridge expects is a matter of interpreting the command signals in a clear way so that the direction and magnitude of the signal is defined. The direction information determines which one of the two pairs of transistors will be activated. The magnitude information determines what percentage of the time (duty cycle) the active transistor pair is kept ON and OFF. If the H-bridge expects an analog voltage signal for current command, it again needs a way to determine the magnitude and direction. For instance, 0–10 VDC analog input signal defines the magnitude of desired current, and a direction input signal determines the sign (direction) of the desired current. Likewise, an analog voltage command range of −10 V to +10 V alone can be used to define both magnitude and direction of the commanded signal as well. Regardless of the type of command signal used, the H-bridge controller needs to be able to determine the desired current direction and magnitude. Once that is known, then the corresponding transistor pair is activated with a proper duty cycle of a fixed frequency PWM signal.

5. Procedure

- Assemble the circuit as shown in the circuit diagram.
- Calculate the values of the PWM frequency and duty cycle, and implement the code for these values.
- Download and run the program. The motor speed should change based on the duty cycle.
- Vary the duty cycle value in the code gradually to force the motor to correspondingly increase or decrease its speed. Notice that if we simply control the PWM signal based on open loop logic, we are controlling the H-bridge amplifier in voltage mode. The average voltage applied across the motor terminals will be simply proportional to the PWM output signals from the microcontroller. We refer to this type of amplifier as a "voltage amplifier."
- Change the direction and magnitude of the speed under software control.

6. CODE

Here in the Code the constant 's' store the value of the sensor input in our case the input is a constant. 'mapped' variable is used to store the value after the sensor value is mapped. The threshold of 0-500 is set for clockwise direction, achieved by passing the value in to pwn pin 5 and keeping pin 3 in low, 515-1023 is set for clockwise direction, achieved by passing the value in to PWM pin 3 and keeping pin 5 in low and finally no motion state is defined between

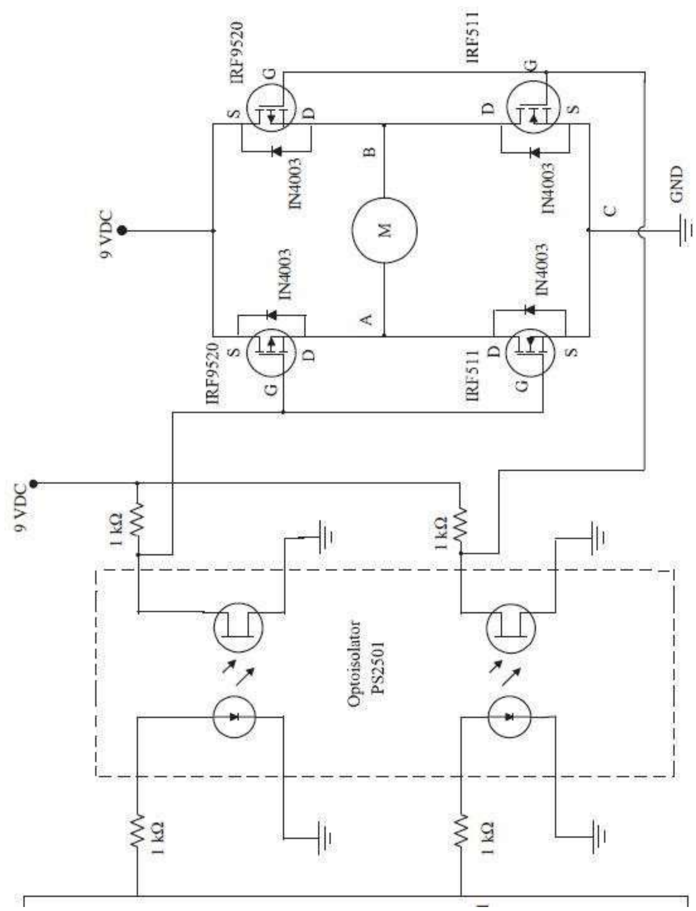
500-514. All these conditions are enforced using if-else condition statement

LAB11 §

```
//code for lab11
int s=0;
int mapped=0;
void setup(){
  Serial.begin(9600);
  pinMode(A0,INPUT);
  pinMode(3, OUTPUT); // set PWM output pin on 3
  pinMode(5, OUTPUT); // set PWM output pin on 5
  }
  void loop()
  {
    //s=analogRead(A0)
    s = 10; //constant for testing
    if (s < 501) //clockwise
    {
     mapped = map(s,0,1023,0,255);
     analogWrite(3, mapped);
     analogWrite(5,0);
    }
    else if (s>514)
      {
        mapped=map (s,0,1023,0,255); //anti-clockwise
        analogWrite(5, mapped);
        analogWrite(3, 0);
      }
    else   // zero motion
    {
    analogWrite (3, 0);
    analogWrite (5, 0);
    }
}
```

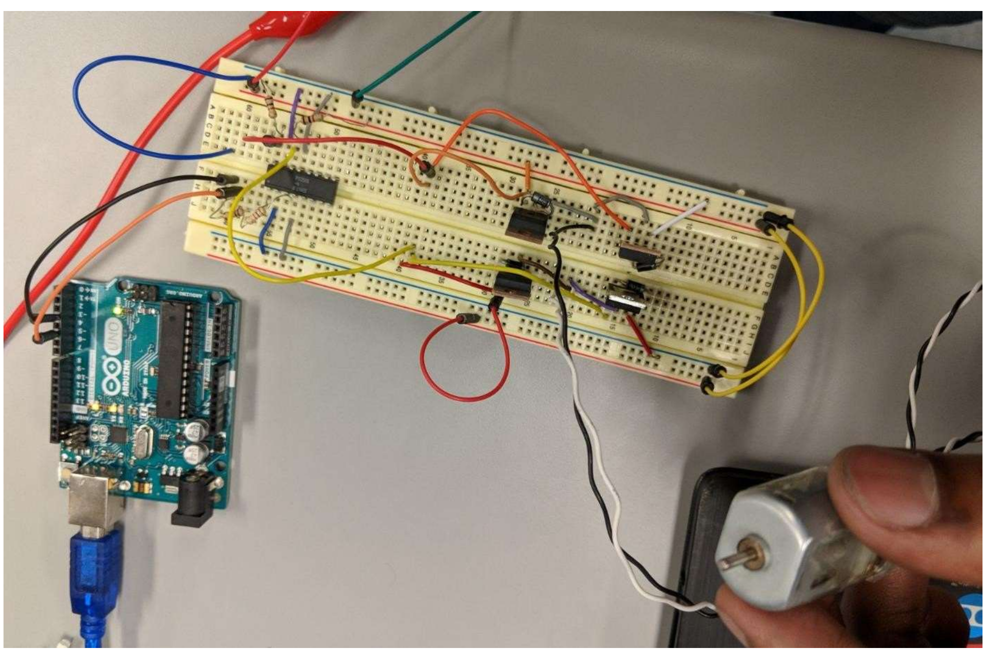
7.IMAGES

Circuit Diagram:



Here we use PWM pins 3 and 5 for input to the H bridge and analog pin A0 for the potentiometer reading

Actual Circuit image:



To test the working of the circuit the sensor input was given in the software. i.e. in the IDE as a constant.

8. Results

In this experiment, we made the H-bridge using two N-type and two P-type transistors and used 9v power supply to control the DC motor. The control of the DC motor is done based on the sensor input given from the sensor (or a constant). We established the threshold of 0-500 for clockwise rotation and 515 - 1023 to anti-clockwise rotation. Also based on the duty cycle of PWM signal the speed of the motor in either direction was altered. To achieve the speed control the map function is used. The 500-514 range was setup for the zero speed by assign low for all both the PWM pins, here we saw the DC motor come to rest.

9. Conclusion

In conclusion, fundamental uses of H-bridge and its use to control the speed of the DC motor's speed and motor direction, was focus of this experiment. We also learnt how the opto-isolator is used to isolate the Microcontroller from the voltage fluctuation from the circuit. We learnt how speed and direction can be varied with constant voltage.

The increase in the use of electric motor is automobile and automation sector, and its control using the H-bridge was understandable in this experiment. Here we understood why electric actuators are controllable and widely used and H-bridge's contribution to that. We also understood that heat dissipation from the transistor and was very high for that reason commercial H-bridges have the heatsink for better heat dissipation.

10. Reference

1. Lab manual