



Remote Speed Control of Brushless DC Motor with Display

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Abstract: Modern electrical devices all strive for improved efficiency, reduced maintenance and reduced carbon emissions. Brushless DC (BLDC) motors represent the most recent development in a long evolution of motor technology. BLDCs provide enhanced reliability, decreased noise and extended lifetime while also providing efficiency superior to that available from AC induction motors. A speed control scheme of a BLDC motor using a Hall effect sensor is proposed. The Pulse Width Modulation (PWM) technique is used for control through a pre-programmed microcontroller, and the motor speed is handled by a remote and displayed in an LCD by the Hall effect sensor. The Hall effect sensor included in the speed control is a good alternative which can improve drive robustness due to reduced cleaning and maintenance. This development is expected to improve remote monitoring and operation of BLDC motors in a single package well-suited for dusty/ limited access environments.

Keywords: BLDC Motor; Pulse Width Modulation; Remote-Control; Infrared Sensor; Hall Effect sensor

Introduction

Electric motors are the backbone of industrial drives. DC motors are highly controllable but incur higher operations costs than AC motors, partially due to component maintenance for the commutator and brush. Brushless DC (BLDC) motors [1] require no such maintenance, making them popular in the home appliance, automotive, and aerospace industries. BLDCs provide a lifespan exceeding ten thousand hours, and are also highly efficient due to the lack of copper loss in the rotor, and offer reduced noise, better speed range and a higher torque to weight ratio [2]. Precise control is achieved through Pulse Width Modulation (PWM) [3].

BLDC motor control can be achieved with and without sensors [3-6]. To control the rotor, the present position is measured by the sensors. The next control action is then determined by the PWM or DC bus voltage control. The stator winding is energized on the alignment of rotor poles. Hall sensors are used for position measurement [4] more frequently than older types such as optical encoders [6] and potentiometer type sensors [4] because they provide more reliable operations in

environments characterized by high vibration, dust and humidity – environments well-suited to BLDC motors. Also such an arrangement renders sensing more temperature resistant as compared to ambiguous phototransistor output due to interruption of light and its inherent turn on and turn off time which may introduce delays. The proximity of rotor poles is signaled by the Hall sensor as high for north and low for south. Speed is derived from the sensed position. Accuracy of position sensing ensures fast and stable control. Position control is achieved by current control and speed by an outer loop in cascade [5]. A variety of sensor-less techniques for BLDC motors have been proposed to achieve speed control of brushless drives with PWM control [3,5]. Fuzzy and Fuzzy PID controllers [6,7] have been found to provide better BLDC speed control than conventional PI and MRAS controllers in Matlab simulations, but with a speed oscillation about the required value. Controls have been experimentally tested in various digital signal processors (DSP) [3], [8-10] and observed the speed waveform in Oscilloscope or computer connected to the controller. Some hardware-based control methods have been implemented in microcontrollers [10-12] using an LCD display to provide a complete product design. Agung et al.



[11] developed an infrared remote and receiver with control on an ATMEGA 16 microcontroller, also using an LCD for speed information, but using a photo diode for position measurement and a low speed drive control. Further improvements for control and display were achieved by radio frequency remote control in [13].

These studies neglect to mention applications of Hall sensors using remote control and LCD displays in a single package to create a complete product best suited for BLDCs in dusty environments such as automobiles or limited access environments such as medical facilities, where continuous, reliable and low-maintenance operations are desired. This paper describes the development of a rugged sensor control method to run and monitor a BLDC motor remotely at an exact and continuous speed through microcontroller programming [14]. The speed is viewed on an LCD display which assists in remote monitoring and speed control. Hall sensors are not affected by dust or limited light, thus enhancing reliability and reducing the need for maintenance.

The remainder of this paper is organized as follows: Section 2 explains the control strategy, illustrated with a block diagram. Section 3 describes the hardware connection of each component and implementation results. Section 4 presents conclusions and suggestions for future work.

Block Diagram

Fig. 1 provides a schematic illustration of the control.

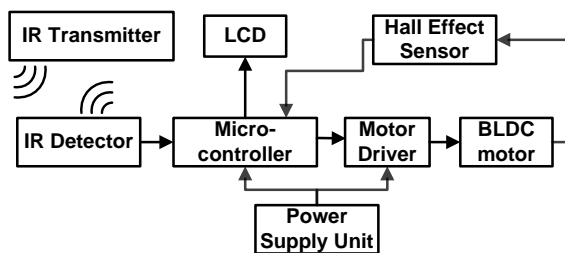


Figure 1. Block diagram of remote controlled BLDC motor.

BLDC Motor

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A BLDC motor is a permanent magnet synchronous motor with a trapezoidal Back EMF waveform. The stator of a BLDC motor consists of stacked steel laminations with windings placed in the axial slots in the inner periphery. A BLDC motor has permanent magnets in the rotor made up of rare earth alloys such as Samarium Cobalt (SmCo), Neodymium (Nd), Ferrite and Boron (NdFeB) [2]. Most BLDC motors have three stator windings formed of multiple coils connected in a star-shaped pattern. The windings are distributed to form an even number of poles. In BLDC motors, the magnetic field produced by the stator and that of the rotor revolve at equal frequencies. Its working principle is that, whenever a current carrying conductor is placed in a magnetic field, it experiences a force, and the equal reaction force causes the magnet on the rotor to move.

The permanent magnet rotor of the BLDC motor imparts low inertia, thus the speed control time reduces with faster acceleration and deceleration. Its linear speed/torque characteristics make speed regulation predictable. Servicing is reduced due to its brushless nature, making it well-suited for applications with limited access, such as medical instruments. The silent operation and reduced Electromagnetic Interference (EMI) in the low-voltage rating are best suited for battery-operated handheld medical instruments. BLDC motors are used for robotics, automotive and small actuating applications at 48 V or lower; whereas industry automation applications operate at 100 V or above. High performance BLDC motors are also used in electric vehicles [3].

Remote

When a button on the remote handset is pressed, an infrared (IR) light signal is transmitted from the light emitting diode (LED) placed at the front end. The 940-nm wavelength IR light is received by the IR sensor on the device.

For a multi-channel remote control, the frequency filter signals are separated following modulation and demodulation.

IR Detector

The IR remote control must be operated in line of sight of the destination device, which has a limited operating angle determined by the optical characteristics of the photo-transistor at the device end. The received signal is then converted to electric signals and used by the microcontroller.

Microcontroller

The microcontroller is a miniature, programmable system-on-chip device designed for specific machine



control. The ATMEGA328 microcontroller used, is the processor for the Arduino Dumilanove board. It features 28 pins [14] as shown in Fig. 2. The device operates between 1.8-5.5 volts.

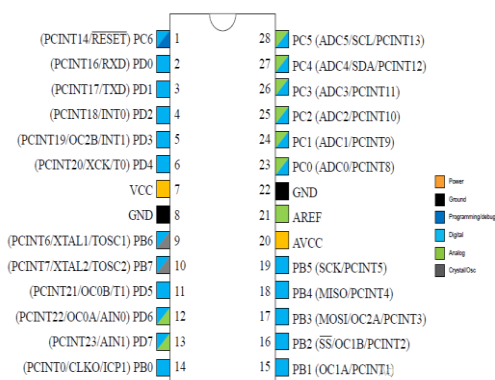


Figure 2. Pin diagram of ATMEGA328 [14].

The device features 6 analog inputs pins PC0 to PC5 and 12 digital input pins PD1 to PD11 which act as discrete digital input ports for PWM. Input power is connected at the VCC and GND pins. Pins PB6 and PB7 connect to a crystal oscillator to generate the clock signal. The PC6 pin resets the chip.

The program is written using Arduino IDE 1.6.9. An onboard USB port is used to upload the program from the PC to the device.

Motor Driver

A motor driver is an H-Bridge current amplifier. It takes a low current control signal and then converts it into a higher-current signal to drive a motor [15]. An H-Bridge can input current of either polarity. It is controlled by Pulse Width Modulation (PWM) [3].

Hall Effect Sensor

When a current carrying conductor is placed in a magnetic field, the field applies a transverse force that tends to push the electrons towards one wall of the conductor [4]. A charge build-up that balances this magnetic field produces a potential difference between the walls of the conductor. This is called the Hall effect. The most commonly used sensors are hall sensors and optical encoders [6].

As seen from Fig. 3, the rotor of the BLDC motor has alternate north (N) and south (S) poles. Three Hall sensors are precisely placed in the stator to ensure correct rotor position detection. Hall sensor magnets are placed on the rotor beside the main rotor magnets at a 60 or 120 phase shift displacement, and impart the same effect.

Liquid Crystal Display (LCD)

The LCD display module with a green black light

built-in HD44780 standard with 2X16-characters is powered by 5V DC [12] to display the angular speed.

Power Supply Unit

A DC Power Supply Unit (PSU) uses the AC supply and maintains a constant output voltage in the event of AC supply or load current variation.

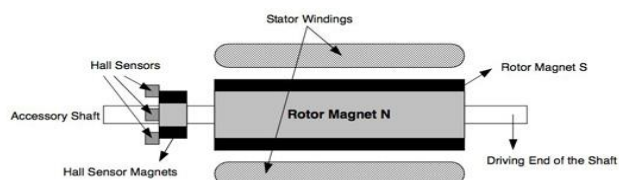


Figure 3. Longitudinal section of BLDC motor.

Hardware Implementation

Material Requirements

Hardware Requirements

- BLDC motor fan: 12V, 0.36 A
- Motor driver circuit L298:25W, +5V to 46 V
- IR receiver/ Detector:2.7V to 5.5V
- Serial LCD display: green, 2X16
- Magnetic Hall sensor
- Arduino Duemilanove
- TV remote
- Power supply
- Bread board
- Connecting wires

Software Requirement

- Arduino IDE 1.6.9

The Arduino Duemilanove is an 8 bit microcontroller board, which serves as the center of the hardware set up. It features 14 digital input/output pins, 6 analog inputs, a 16 MHz oscillator, 32 kb Flash memory, a USB connection, a power jack, an ICSP header, and a reset button. It is powered by a 12V AC-to-DC adapter or battery [14]. Out of 14 I/O pins, 0 and 1 are used for USB programming, debugging, and communication. Pin 13 connected to a resistor and LED is used for testing, diagnostics, and other forms of blinking. When the Hall effect sensor detects a signal, the LED lights up, but stays off otherwise. Six of the digital pins (3, 5, 6, 9, 10, and 11) can output the PWM signal. Six additional Analog pins (A0 to A5) are connected to the microcontroller's analog to digital converter (ADC). Each I/O pin works on a range of 0 to +5 V DC where 0 to +2V is off and above +3V is on.

Implementation Methodology

Motor Driver Circuit Connection to BLDC fan and Arduino

Here an L298N H-bridge Dual Motor Controller is

used. It has 14 pins, as shown in Fig. 4. The L298 can drive inductive loads such as relays, solenoids, and DC motors [9]. The BLDC motor is connected to pin 1 and 2. The positive power supply is given to pin 4 and GND to pin 5. Pin 3 is open as 5V is output from pin 6 on the module. This can feed power to Arduino's 5V pin and Arduino GND is connected to pin 5 on this module.

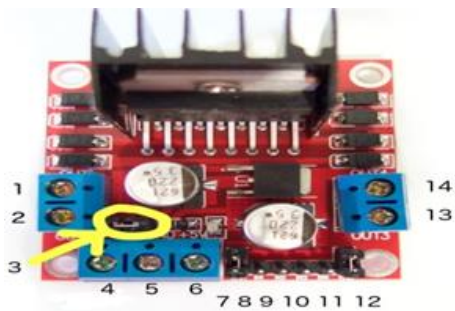


Figure 4. Motor driver (L298N H-bridge).

Out of the six digital output pins on the Arduino Dumilanove board (Fig. 5), two will be used for PWM, denoted by the tilde ("~"). The Arduino digital output pins 3 and 5 are respectively connected to the driver module at IN1 and IN2, which are respectively pin nos. 8 and 9.



Figure 5. Arduino PWM Pins.

Hall sensor connection and operation

Pin 5 seen in Fig. 6 of the magnetic hall sensor is connected to the Arduino analog pin A0. Pin GND is connected to the Arduino GND pin and then the middle pin +5V is connected to the Arduino +5V. When the rotor crosses the magnetic hall sensor it detects the magnet and, when its output is input to the programmed Arduino ATmega 328 microcontroller, the interfaced LCD finally shows the computed speed.

Serial LCD display unit

The serial LCD connects to the Arduino by a pair of wires. There are four pins on the UART labeled GND, Vcc, SDA and SCL, as shown in Fig. 7. The GND pin is connected to the Arduino GND pin, and the Vcc pin to the Arduino 5V or VCC pin then the SDA and SCL pins respectively to the Arduino analog pin A4 and A5 pin.

IR Receiver and Remote

The IR receiver features 3 pins named Vout, GND, VCC which respectively connect to the Arduino board as:

Vout - pin 11, GND-GND, VCC -VCC. Remote is used to transmit the required signal while the IR receiver receives the signal according to the controlled speed.

The Arduino IDE written sketch is uploaded to the ATMEGA328 microcontroller from computer by USB cable connection on the Arduino Duemilanove board. The coding allows the serial LCD display to show the result 'VSSUT_BURLA', 'FAN SPEED' while also using PWM techniques to control the speed of the BLDC motor.

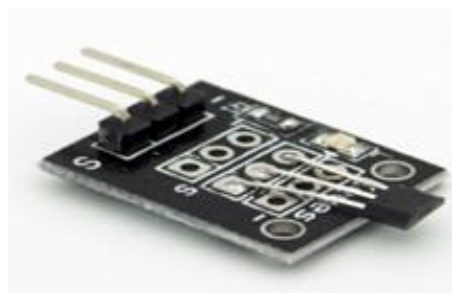


Figure 6. Hall effect sensor.



Figure 7. Serial LCD display unit (back side).

PWM Technique

PWM signal is a constant frequency square wave, where the time the signal is on (the duty cycle) can vary between 0 and 100%. In PWM [4], the voltage output fed to the motor is controlled by adjusting the width of the gating pulse of the electronic switch at a high frequency as per duty cycle. Duty cycle is the fraction of on time to the period. A larger duty cycle corresponds with a larger average output voltage from the driver to the motor, thus increasing the torque and speed. A duty cycle of 100% is on for the whole period, as shown in Fig. 8. When a switch is off there is no conduction, and when it is on, there is nearly zero voltage drop. Power loss is negligible in both states.

Thus the motor is run at the required speed by varying the duty cycle. PWM program in the microcontroller is run to adjust the duty cycle.

Using the Arduino's program, PWM can be achieved by inputting analog write (pin, duty Cycle), where the duty cycle is a value from 0 to 255. Here the pin is one of the PWM pins (3, 5, 6, 9, 10, or 11). The analog write function provides a simple hardware interface. Here two PWM pins 3 and 5 are used, thus any speed can be adjusted by only changing the duty cycle which is the ratio of pulse width to time period [16].

Arduino firmware (Arduino IDE 1.6.9)

The sketch was compiled on the Arduino IDE to

control and display the measured speed of the BLDC motor for different values of the PWM duty cycle. A delay of 1000 ms was given between successive parameter displays on the LCD. The baud rate was initialized at 9600. The inputs to the sketch were from the magnetic Hall sensor, the IR receiver, and the motor driver circuit and after control and processing the output was displayed on the serial LCD.

The project is written in the form of a sketch in the Arduino integrated development environment (IDE) [14] with the file extension.ino. After compiling, the *avrdude* program converts the executable code into a hexadecimal code that is loaded into the Arduino board by a loader program in the board's firmware.

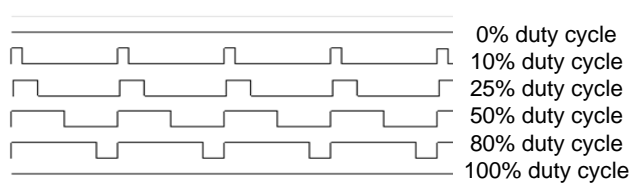


Figure 8. PWM pulse representing duty cycle.

Results

The final operational model after interconnection is shown in Fig. 9. The speed of the BLDC motor was controlled by the IR remote control method which was driven by the motor driver circuit with a supply voltage of 12V through the AC/DC adapter. The model components were interfaced with a bread board.

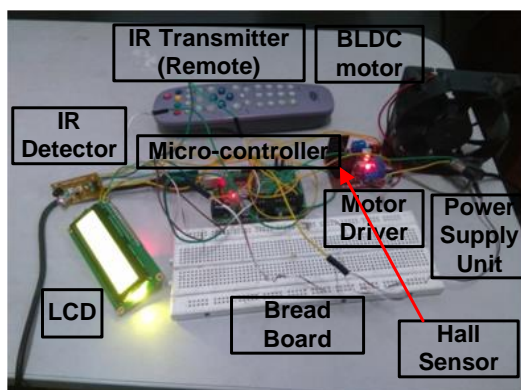


Figure 9. Hardware model in working condition.

Table 1 presents the speeds obtained by varying the PWM duty cycle. The duty cycle is expressed in increments of ten percent. But the motor driver is fed with 8 bit digital inputs which are coded in the microcontroller from 0 to 255 in increments of 50. The slight deviation in speed is due to this setting in the sketch. Six speeds are shown for different button signals from the remote. Input 0 gives off state and input 5 gives the maximum speed of 2100 RPM. Part of the program

sketch is given in the Appendix to check the inputs of the PWM control.

From the above tabulation, it is clear that by varying the duty cycle speed can be modulated. For example, at a duty cycle of 50, the speed was 412 RPM which is 20% (50/255), while duty cycles of 100 and 150 produced speeds of 826 RPM and 1238 RPM, and so on. First, speed control was achieved and the same was displayed on the LCD screen.

Table 1. Speeds according to duty cycle.

Remote button	% Duty cycle	Speed (in RPM)
0	0	0
1	20	412
2	40	826
3	60	1238
4	80	1650
5	100	2100

Conclusion

Remote speed control was achieved and speed data was shown through a serial LCD which is program-interfaced with the Arduino Duemilanove to upload certain code written on the Arduino IDE. The Hall effect sensor is found to best improve the robustness of speed sensing in BLDCs. The whole system was automated, fast, reliable, accurate, cost effective and compact. In this system, the motor speed can be adjusted to multiple intermediate values by varying the PWM duty cycle in between 0-255. The measured speed can also be displayed allowing for instant speed variation in small scale machines. This system, with shielding against Electromagnetic Interference (EMI) can be successfully used in medical, industries and automotive appliances.

The existing system can be used in small scale applications, but use of BLDC speed control in large scale industrial applications can be accomplished by increasing the effective remote control distance, possibly through GSM or ANDROID, which would enhance system efficiency, accuracy and effective range.

Appendix

```
#include <Wire.h> /
#include <LiquidCrystal_I2C.h>
LiquidCrystal_I2C lcd(0x3F, 2, 1, 0, 4, 5, 6, 7, 3, POSITIVE);
// Set the LCD I2C address
#include <IRremote.h>
int RECV_PIN = 11;
IRrecv irrecv(RECV_PIN);
```

```

decode_results results;
const int lowestPin = 3;
const int highestPin = 5;
void setup()
{
// set pins 2 through 13 as outputs
Serial.begin(9600);
irrecv.enableIRIn(); // Used to type in characters
lcd.begin(16,2);
pinMode(lowestPin, OUTPUT);
pinMode(highestPin, OUTPUT);
lcd.backlight();
lcd.setCursor(0,0); //Start at character 0 on line 0
lcd.print("VSSUT BURLA");
delay(1000);
lcd.clear();
}
void loop()
{
if (irrecv.decode(&results)){
Serial.println(results.value);
irrecv.resume(); // Receive the next value
} // iterate over the pins:
if(results.value==0 || results.value==2048)
{analogWrite(highestPin, 0);
analogWrite(lowestPin, 0);
Serial.println("zero");
lcd.clear();
lcd.setCursor(0,0); //Start at character 0 on line 0
lcd.print("VSSUT BURLA");
lcd.setCursor(0,1);
lcd.print("FAN SPEED = 0");
}
if(results.value==1 || results.value==2049)
{analogWrite(highestPin, 50);
Serial.println("one");
analogWrite(lowestPin, 0);
lcd.clear();
lcd.setCursor(0,0); //Start at character 0 on line 0
lcd.print("VSSUT BURLA");
lcd.setCursor(0,1);
lcd.print("FAN SPEED = 1");
}
}

```

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