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Research Article

Arduino and Labview Based Control for Efficient Drive of Cooling Fan System

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Abstract: This study is concerned with the development of PID/PWM control algorithm for use with Arduino Uno and Labviewe for efficient control of a cooling fan drive system. It relies on the development and testing of a regulatory temperature control system, where forced ventilation is required via cooling fans driven by DC motors. A prototype that emulates the case of PC was developed in which a heater element was introduced in the case. An electric fan is placed in the vicinity of the heated element so that cooled air is forced over it. The amount of heat transfer from the element is directly proportional to the rate of air flow over it. In order to achieve higher efficiency and steady-state stability, the fan speed is regulated by a software-based PID/PWM controller using Arduino Uno controller. More over, Matlab/Simulink model for the PWM motor control is also developed to predict the speed of the motor at various duty cycle to emulate the change in the temperature. In addition, PWM is realized with a high switching frequency (33 KHz) in order to minimize the associated acoustic noise using Labview. Experimental tests show acceptable results.

Keywords: Acoustic noise, Arduino control, cooling fan drive, Labview control, PID, PWM

INTRODUCTION

During the past few years, the world has witnessed a phenomenal growth in microcontroller technology and computer based control packages. In particular, the development of embedded systems has created numerous possibilities to use a variety of new technology tools for many applications. The growth of these tools, their power, their variety and ease of use, allow users to access to new techniques of control beyond the traditional techniques.

Electronic equipment has penetrated every aspect of our modern life. The reliability of the electronic components is a key factor in the overall reliability of any electronic system. Inevitably, the current passing through electronic components raise their surface temperature and they become potential sites for excessive heating. Unless properly designed and controlled, high amounts of heat generation result in high operating temperatures for electronic equipment, which threatens its safety and reliability. The malfunction rate of electronic equipment increases drastically with temperature. Therefore, thermal control has become increasingly important in the design and operation of electronic equipment.

Cooling fans are vital to systems that generate a considerable amount of heat such as computers and other electronic components. Historically, cooling fans run at 100% speed, even when less airflow is needed, constantly turning ON and OFF as the temperature changes. This reaction-based temperature control system causes constant amperage spikes, excessive noise and premature wear. Using soft-start technology, fans ramp up slowly, which eliminates harmful current spikes. Thus the fan operates at the optimum fan rate as needed from 1 to 100% of its speed. This may be done using software-based controllers that offer an incredible degree of controllability. With properly tuned controller it is possible to maintain systems well within 0.1°C of set point. Unfortunately many off-the-shelf solutions for temperature control may not be suitable because they were designed for heating or cooling hardware that is very different. This leave the way opened for seeking alternative solutions.

Review on how to control cooling fan speed was published by Burke (2003, 2004). Traditional on-off temperature control strategy was tackled by Watlow Corp. (1995). More advanced P, PI and PID control modes are discussed in a practical manner by Axiomatic Technologies Corporation (2003). The trend nowadays is to implement closed-loop control using software-based PWM techniques as published by Austriamicrosystem Co. (2010) and Texas Instruments (2009). In general, there are three common types for temperature control: ON-OFF control, linear (steady-state) control and Pulse-Width Modulation (PWM) fan control. When implementing two-position control, the cooling fan rotates at maximum speed or stops rotating, depending on the temperature set point. Main disadvantages of this mode of operation, is that the controlled variable oscillates in a continuous cyclic mode around the set point with an acceptable error

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value determined by the hysteresis width of the controller static characteristic. Another important drawback is that the cooling fan runs at maximum speed which generates high level of acoustic noise. Another more accurate method is the linear fan motor drive. In this case the fan motor supply voltage is varied between its minimum and maximum values. For small power fans this may be accomplished using an adjustable voltage regulator or by using linear power amplifiers. For high power fans, power operational amplifiers such as OPA 512 may be used. However this method of control is always associated with high power losses in the form of heat (Jacob, 1989). Also, the fan is designed to operate at a given voltage, whereas the operation of the fan below this can shorten the life of the motor (Leigh, 1988).

A better method is to use the PWM technique to control the amount of power going to the fan through a switch mode D-type amplifier (Grahame Holmes and Lipo, 2003) which includes the power static switches in its output stage. Such amplifiers feed the motor with the rated voltage value where the average voltage is proportional to motor speed. Using switch mode type amplifiers excellent features are gained such as increasing system efficiency and lowering fan excessive noise. Running the fan speed as a function of temperature means that the consumed power by the motor will be less than the consumed power at full speed. Moreover, as the amplifiers operate in a switch mode, losses in the cutoff mode or in the saturation mode will be minimized. This in turn unlocks the potential for using switch mode power converters in controlling the fan speed.

When implementing the switch mode power supply with PWM driving signal, one has to consider system stability. If proportional control mode is used alone, a definite value of system offset error will be available. More promising results concerning system stability are achieved by driving the pulse width modulator by the output signal of a PID controller. In such a case, the fan speed can be adjusted to achieve a zero offset at the steady state by the virtue of the integral action. The derivative action is also very helpful, especially in slow processes such as temperature control. The derivative action accelerates the system performance and gives the closed-loop better stability margin. Based on this, in this study, Arduino and Labview are both utilized to develop PID/PWM control algorithm to drive a cooling fan DC motor. In addition, Matlab/Simulink model for PWM motor control is also developed to predict the speed of a DC motor at various duty cycles to emulate the change in the temperature around the motor.

In order to minimize the audible noise, the PWM generated signal will be set to a frequency of 33.3 kHz, which can be realized using the Arduino-Uno controller.

MATERIALS AND METHODS

System description: Normally, the 4 wire PWM controlled fan is used to reduce the overall system acoustics (Intel Corporation U.S.A., 2005). However, in this research, a 3-wire DC brushless fan motor is controlled by adjusting pulse width of a high frequency PWM in order to reduce the overall system acoustic. In such implementation, the tachometer signal is readily available for closed loop speed control. Fan operating range is 12+1.2 V. Peak fan current during start-up operation shall not exceed 2.0 A. The proposed single loop block diagram of the system is shown in Fig. 1. Fan current spike during start up with 13.2 V is in the range of 10 A. Because of that an interface circuit is added to enable delivering of 10 A current. The implemented motor drive circuit block diagram is shown in Fig. 2.

As a temperature transducer, LM35 integrated circuit is already used by Texas Instruments (2016). This transducer gives an output voltage

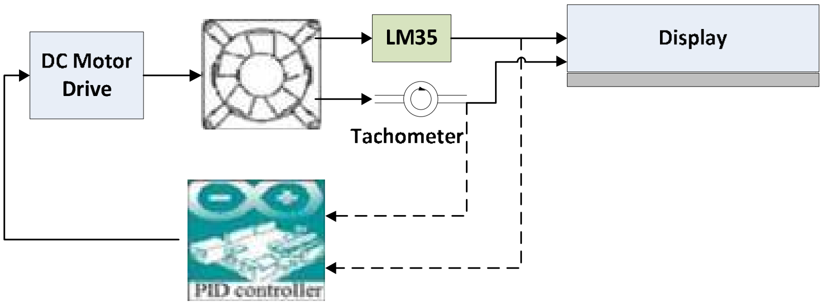


Fig. 1: Single loop Block diagram of temperature controlled system

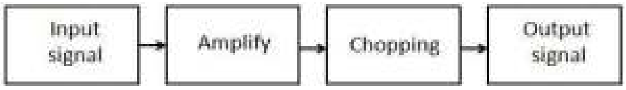


Fig. 2: Implemented motor drive circuit block diagram

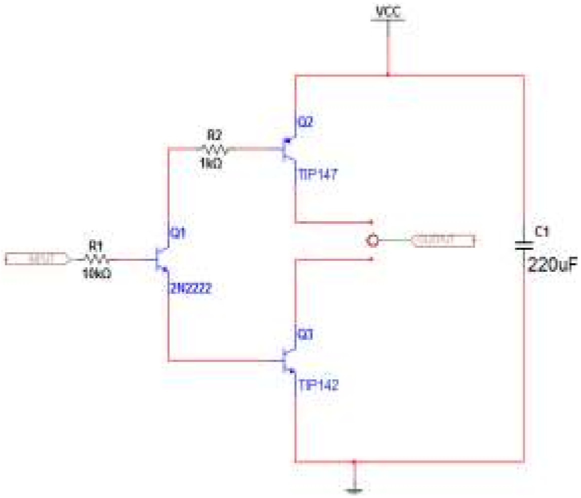


Fig. 3: The schematic diagram for the power interfacing circuit

Table 1: DC motor matlab simulation results vs different duty cycle

Duty cycle %	Speed (rpm)	Motor voltage (V)	Current (A)
28	771	3.6	0.98
44.46	1700	5.33	0.964
80	2420	9.6	0.936

proportional to temperature in Celsius Degrees (10 mV/°C). The schematic diagram for the power interfacing circuit between the Arduino and the fan is shown in Fig. 3.

TIP147 and TIP142 is a Darlington pair of high power transistors (125 W). One is NPN type transistor and the other is PNP transistor. Transistor 2n2222 NPN is used as a buffer between the digital ON/OFF side and the analog motor control side. An electrostatic capacitor- based microphone is used as an acoustic transducer for the evaluation of fan acoustic noise.

Software-based PWM/PID controller: By controlling analog circuits digitally, system costs and power consumption can be drastically reduced. What's more is that many controllers and DSPs, such as Arduino already include on-chip PID control algorithm and PWM configurable modulator. This makes their implementation in any application very easy. The complete code of the PWM signal and PID algorithm are given in Appendix A. The experimental results achieved through the complete control circuit with connection lines between the Arduino and the fan is presented in Appendix B at the end of this study.

Matlab simulation for DC motor PWM control: In order to predict the motor speed at various temperatures, the DC fan motor and its drive were modeled using Matlab/Simulink as shown in Fig. 4. The motor speed was controlled using PWM at three different levels of duty cycle (28, 44.46 and 80%, respectively) to emulate the conditions of various temperatures. PWM output signals for different values of duty cycle (k) are shown in Fig. 5 whereas the simulation results obtained for the motor speed, voltage and current are summarized in Table 1.

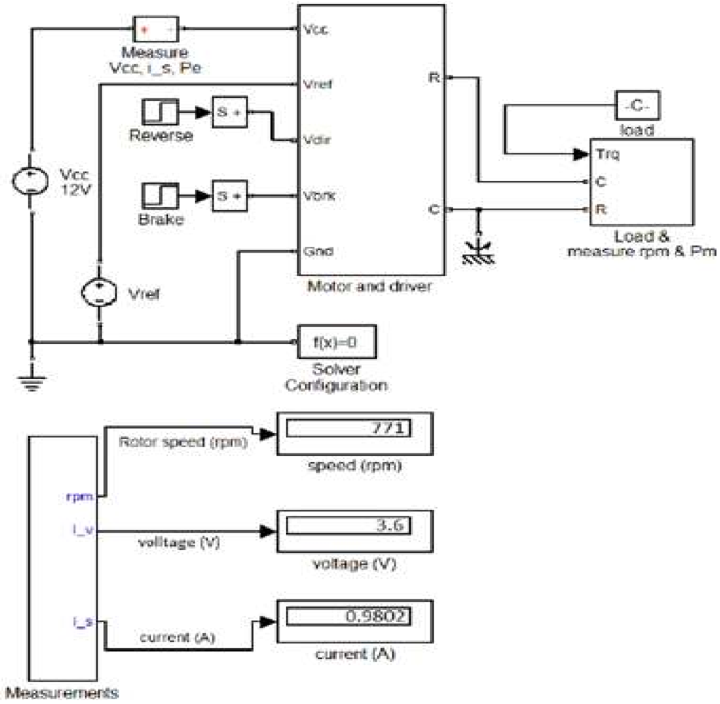


Fig. 4: Matlab/Simulink model for fan motor control using PWM

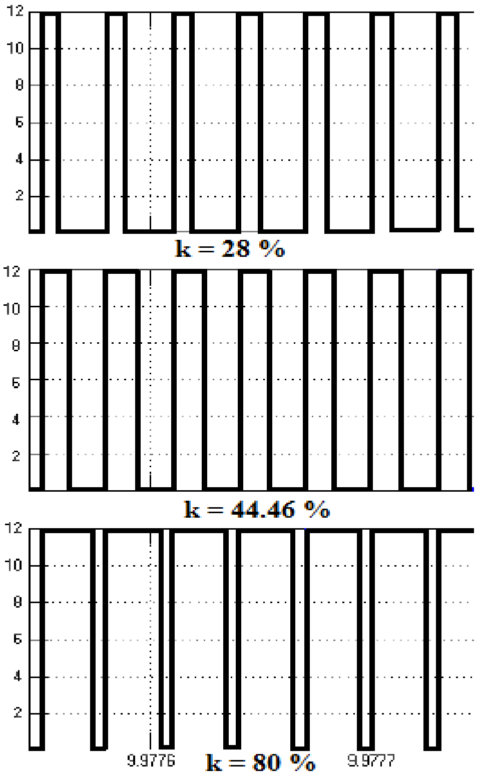


Fig. 5: PWM output from Matlab/Simulink model for duty cycle of 28%, 44.46% and 80%

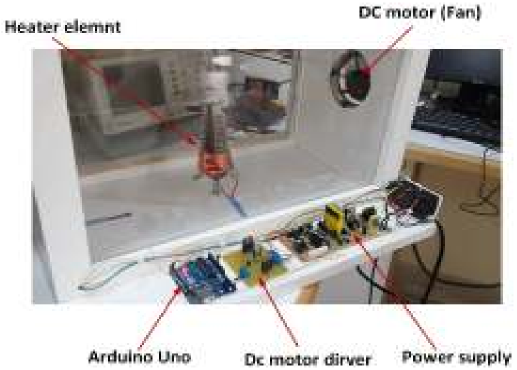


Fig. 6: Prototype for the controlled DC fan motor

RESULTS AND DISCUSSION

Hardware and Experimental setup: In order to implement the proposed control strategy, a simple prototype was built as shown in Fig. 6. The prototype which emulates the case of PC, consists of a box encapsulating a heater element and a DC motor that is driving a fan through a controlled circuitry. A close view for the electronic hardware and the controller is shown in Fig. 7. After connecting the fan motor to the power interface circuit, the switching frequency was adjusted to 33.33 KHz and the duty cycle was set to 28, 44.46 and 80%, respectively.

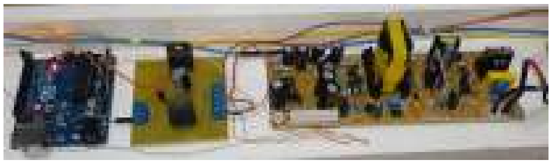
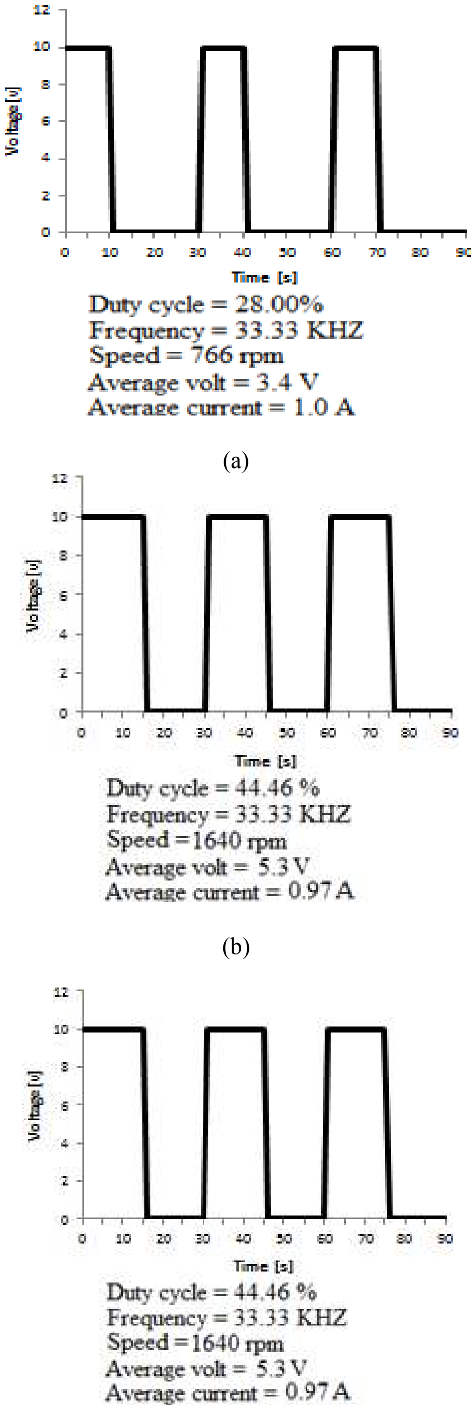


Fig. 7: Close view for the motor drive circuit and controller



(c)

Fig. 8: Fan speed (rpm) vs temperature (C) with the corresponding PWM

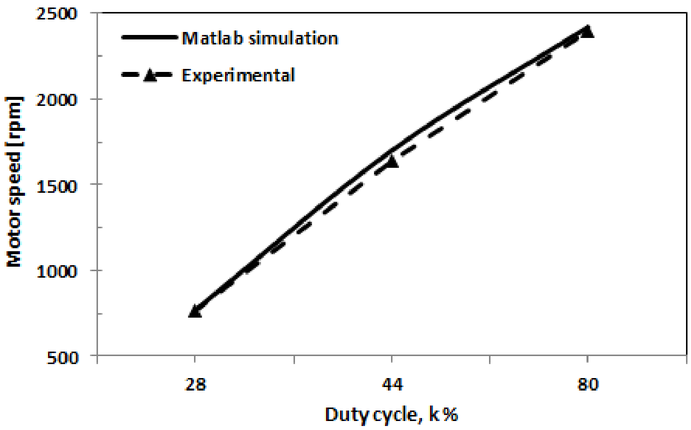


Fig. 9: Motor speed; simulation vs experimental

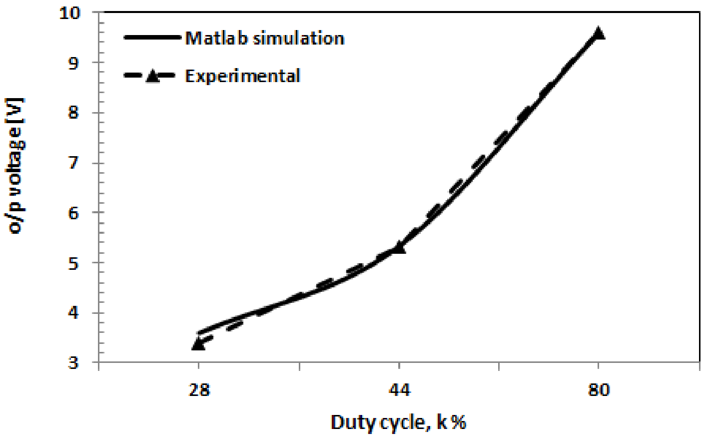


Fig. 10: Motor voltage; simulation vs experimental

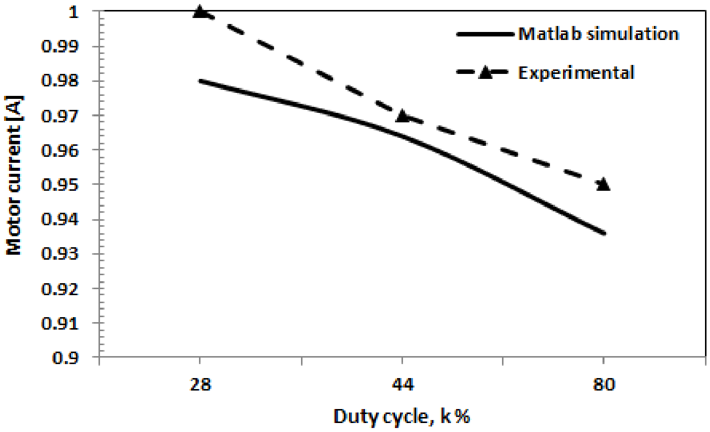
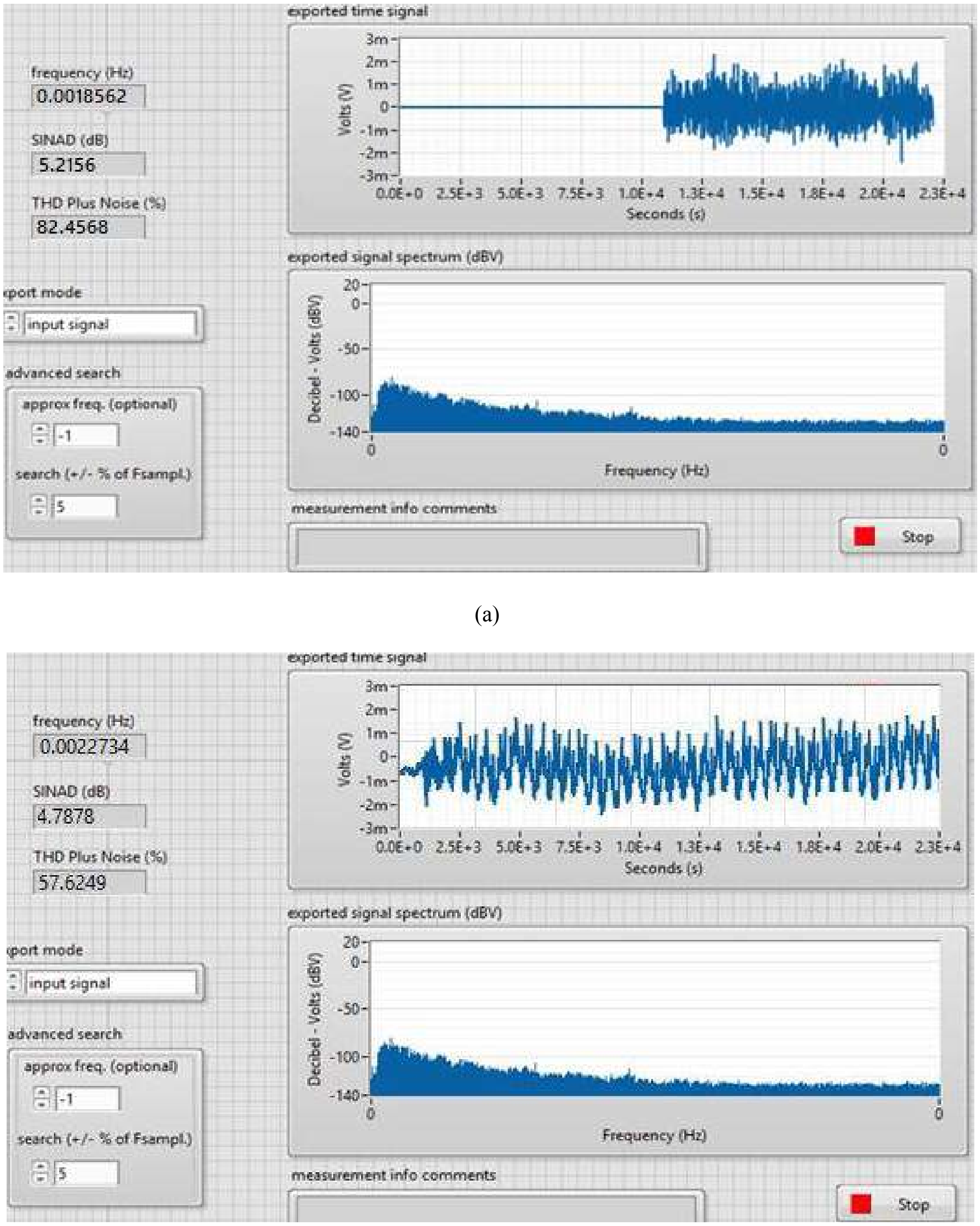


Fig. 11: Motor current; simulation vs experimental

Figure 8 shows the experimental results for PWM signals and the corresponding speed, voltage and current values for different temperatures. Experimental results vs Matlab simulation results for motor speed, voltage and current are graphically represented in Fig. 9 to 11 respectively. It can be seen from the graphs that good match between experimental and simulation results are achieved which allows for using the Matlab model for further investigations and analysis.

Labview setup: Virtual instruments have been extensively used in control as well as measurements of



(a)

frequency (Hz): 0.0018562

SINAD (dB): 5.2156

THD Plus Noise (%): 82.4568

xport mode: input signal

advanced search

approx freq. (optional): -1

search (+/- % of Fsampl.): 5

(b)

frequency (Hz): 0.0022734

SINAD (dB): 4.7878

THD Plus Noise (%): 57.6249

xport mode: input signal

advanced search

approx freq. (optional): -1

search (+/- % of Fsampl.): 5

Fig. 12: Noise level and noise density; (a): without using controller; (b): using controller

components and systems (Swain *et al*., 2001; Bachnak and Steidley, 2002). For example, Labview has been used in severalmodern control applications (Bishop, 2012; Larsen, 2011; Resendez and Bachnak, 2003; Naghedolfeizi *et al*., 2002; Sokoloff, 1999). In this study, to control the temperature of the system, LABVIWE is programmed to read serial data from Arduino as shown in Appendix C.

Also, in order to evaluate the effect of the controller on the noise level, a LabVIEW program was designed as shown in Appendix D. The system is first tested to measure the noise level and density without using the fan controller and the results obtained are presented in Fig. 12a, whereas the effect of controller on the noise level and density is presented in Fig. 12b.

As can be seen from the measurement indicators, when using fan controller, the Signal level is reduced from 5.21 dB to 4.78 dB which is equivalent to 8% whereas the THD and noise level was reduced from 82% to 57% which is equivalent to 30% reduction. The figure also shows that the noise amplitude and density are effectively reduced.

CONCLUSION

This study proposes a software-based PID/PWM controller using Arduino Uno; which was developed and utilized to drive a high efficiency low noise cooling fan. A prototype for the proposed system was developed and experimentally tested and results obtained showed that using a high frequency PWM it was possible to effectively reduce the noise level. The PID/PWM controller yields a zero steady state error and improves system stability margin by proper tuning of integral mode and differential mode gains. High switching frequency (33 KHz) is realized in order to minimize the associated acoustic noise and the duty cycle was made 28, 44.46 and 80% respectively. Matlab simulation model for the PWM DC motor control showed a good match of the results as compared to experimental results.

ACKNOWLEDGMENT

The authors would like to thank the deanship of scientific research at Zarqa University for supporting this research.

Appendix A: PWM/PID codes

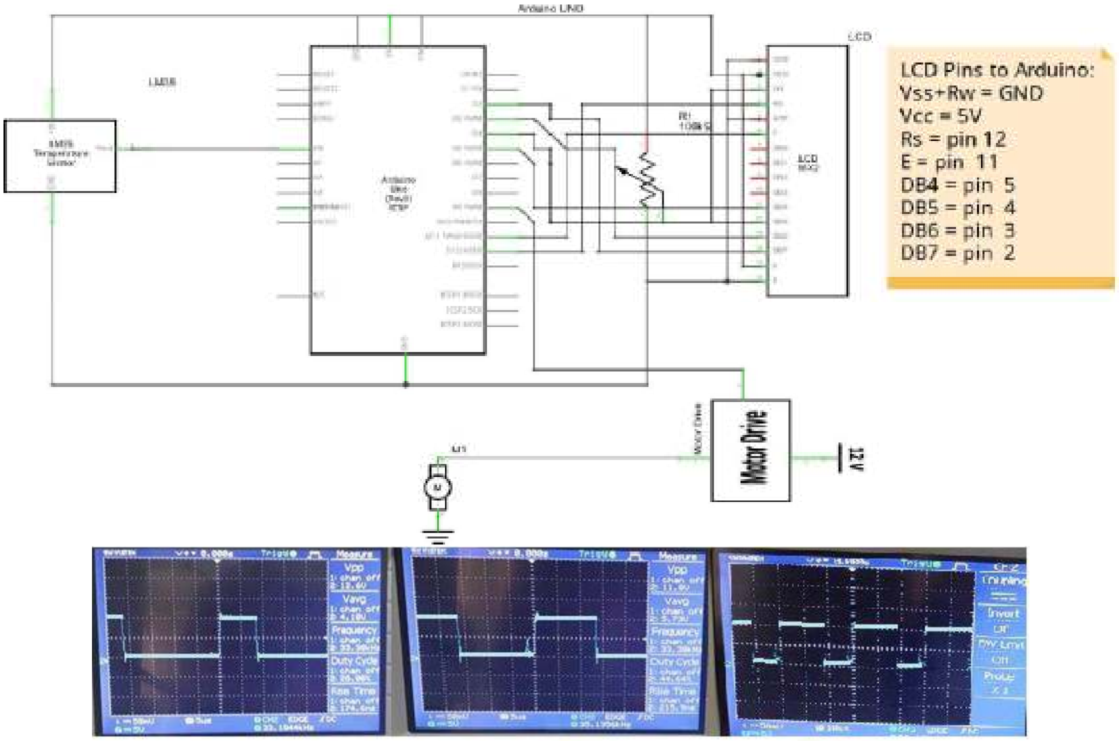
The Code of PWM signal:

```
void setup() {
DDRD |=1<< PD3;
}
void loop() {
PORTD |= 1 << PD3;
delayMicroseconds (15);
```

The Code of PID:

```
PORTD&= ~(1<<PD3);
delayMicroseconds (15);}
#include <PID_v1.h>
#include <LiquidCrystal.h>
#include <TimerOne.h>
//Definitions
#define FAN 9 // Output pin for fan
#define CRITICAL 28.00 //Critical temperature to
ignore PID and turn on fans
int temp,tempvalue;
LiquidCrystal lcd(12, 11, 13, 5,6,7); //set up LCD
//Setup PID
double Setpoint, Input, Output; //I/O for PID
double aggKp = 40, aggKi = 2, aggKd = 10; //original:
aggKp = 4,
aggKi = 0.2, aggKd = 1, Aggressive Turning, 50, 20, 20
double consKp = 20, consKi = 1, consKd = 5; //original
consKp = 1,
consKi = 0.05, consKd = 0.25, Conservative
Turning,20,10,10
PID myPID(&Input, &Output, &Setpoint, consKp,
consKi, consKd, REVERSE); //Initialize
PID
//interface
int timeCounter;
double gap;
int highfreq = 0;
void setup()
{
// start serial port for temperature readings
Serial.begin(9600);
Serial.println("Start");
Setpoint = 28; //Inintialize desired Temperature in Deg
C
//PID Setup
myPID.SetMode(AUTOMATIC);
16 CHAPTER 3 | IMPLEMENTATION
//TCCR2B = TCCR2B & 0b11111000 | 0x01; //adjust
the PWM Frequency, note: this changes
timing like delay()
//Setup Pins
pinMode(FAN, OUTPUT); // Output for fan speed, 0 to
255
//interface
timeCounter=0;
//Setup LCD 16x2 and display startup message
lcd.begin(16, 2);
lcd.print(" Smart Fan");
lcd.setCursor(0,1);
lcd.print ("Starting Up");
delay (1000);
lcd.clear ();
Timer1.initialize(15); // set a timer of length 100000
microseconds (or 0.1 sec - or 10Hz => the
led will blink 5 times, 5 cycles of on-and-off, per
second)
Timer1.attachInterrupt (timerIsr); // attach the service
routine here
}
void loop()
{
temp = analogRead (A0);
tempvalue = temp*.488;
timeCounter++;
//print out info to LCD
lcd.setCursor (1,0);
Serial.print ("Temp:");
Serial.println (tempvalue);
lcd.setCursor (1,1);
Serial.println ("Set:");
Serial.println ((int)Setpoint);
17 CHAPTER 3 | IMPLEMENTATION
//Compute PID value
if(tempvalue>Setpoint){
gap = abs(Setpoint-tempvalue); //distance away from
setpoint
if(gap<1)
{
//Close to Setpoint, be conservative
myPID.SetTunings(consKp, consKi, consKd);}
```

```
else{
//Far from Setpoint, be aggresive
myPID.SetTunings(aggKp, aggKi, aggKd);}
myPID.Compute();
Serial.println(timeCounter);
Serial.println(tempvalue);
analogWrite(FAN,255);
//Write PID output to fan if not critical
if (tempvalue<CRITICAL)
analogWrite(FAN,Output);
else
analogWrite(FAN,255);}
else{ analogWrite(FAN,0);}}
void timerIsr()
{if(highfreq==1)
{digitalWrite(3,HIGH);
highfreq=0;}
else
{digitalWrite(3,LOW);
    highfreq=1;}}
```

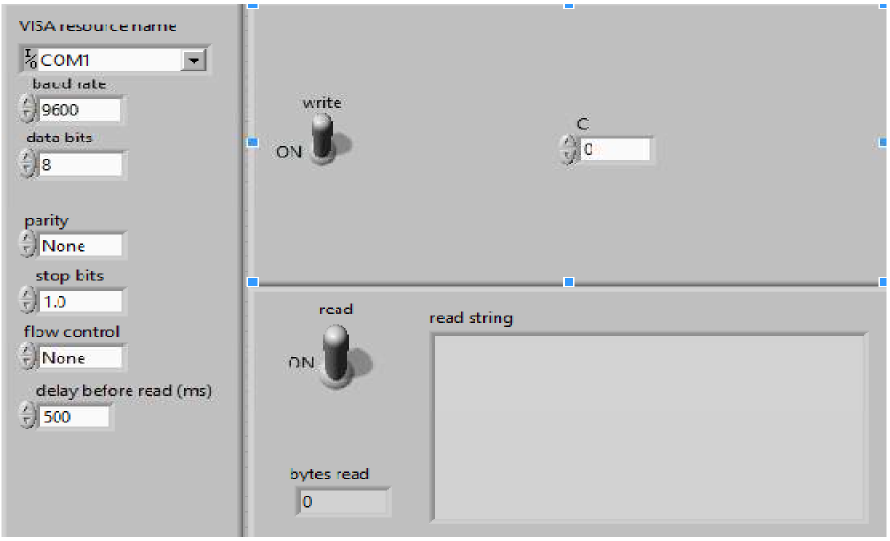


Duty cycle 28 %

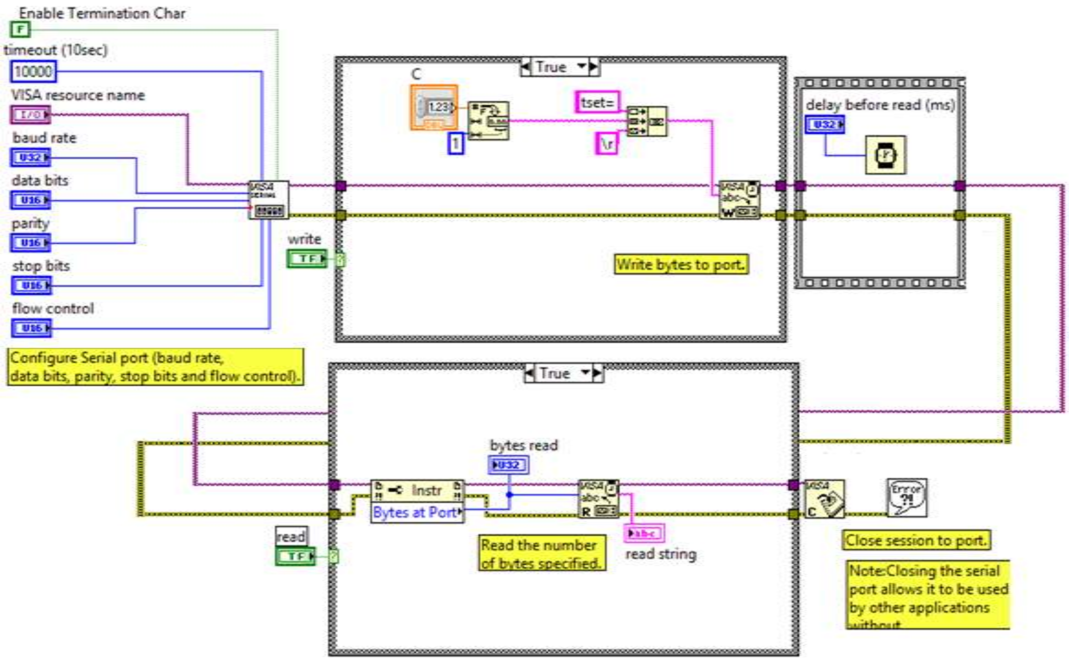
Duty cycle 44.46 %

Duty cycle 80 %

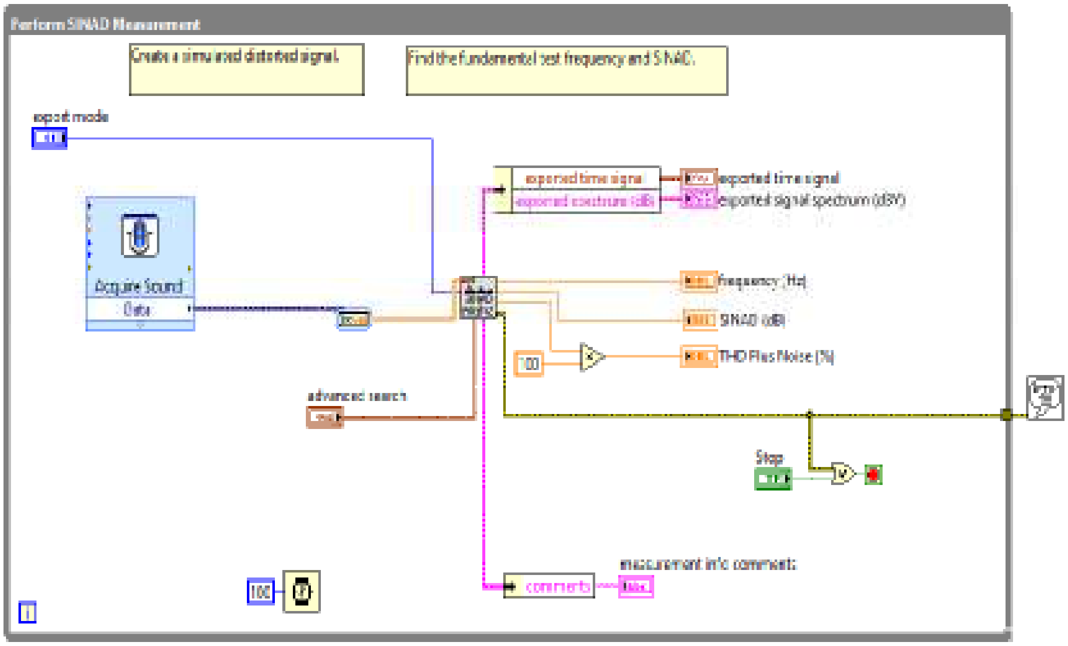
Appendix B: Complete control circuit with PWM experimental results



VISA resource name
COM1
baud rate
9600
data bits
8
parity
None
stop bits
1.0
flow control
None
delay before read (ms)
500
write
ON
C
0
read
ON
read string
bytes read
0



Appendix C: Labview front panel and block diagram for fan temperature control



Appendix D: Labview block diagram for fan noise measurement

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