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Design and Development of a Smart Digital Tachometer Using At89c52 Microcontroller

M. Ehikhamenle*, B.O. Omijeh

Department of Electronic and Computer Engineering, University of Port Harcourt, Choba, Rivers State, Nigeria
*Corresponding author: mattinite4u@yahoo.com

Abstract A microcontroller based tachometer is a device that measures the rotation speed of a shaft or disk in motor or other machines [1]. This device is an embedded system; it is built using a microcontroller, an alpha-numeric LCD module and an infrared system to detect the rotation of the fan whose speed is being measured. The infrared system generates the pulses from the fan which will be sent to the microcontroller and the pulses will be counted; the reading is displayed on the liquid crystal display (LCD module) in revolution per minute (RPM). It is A low cost digital tachometer that can display exact speed reading based on how fast an object is rotating.it adopts the Use infrared transmitter and receiver as the technology behind the speed detection. It can be used in various applications. It can measure the speed of rotating objects (examples of rotating objects include: a bike tyre, a car tyre, a ceiling fan, or any other motor) in the most accurate form possible. In automotives, it is used as a gauge showing the speed (RPM) of the engine shaft that is driving the transmission, usually in thousands of rotations per minute.

Keywords: *tachometer, revolution per minute, shaft, alpha-numeric*

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1. Introduction

In many phases of industrial and commercial operations, it is frequently necessary to measure the rotational speed of machineries. Such measurements may be accomplished in a number of ways, depending on the nature of the object to be measured. One of such methods to achieve this is by the use of a tachometer.

A tachometer is an instrument that measures the rotational speed of a shaft or disk, as in a motor or machine. The word is derived from two Greek words *tachos* (“speed") and *metron* ("measure") [2]. It works by the same principle as a tachogenerator, which is to say, when a motor is operated as a generator without connecting it to a load or resistance, it produces the voltage according to the velocity of the shaft. By measuring the voltage produced by a tachogenerator, you can easily determine the rotational speed of whatever it is mechanically attached to. Its operation can be electromagnetic, electronic or optical-based.

The speed of the electric motor is determined by the number of revolutions made by the motor in one minute. Thus a tachometer is also known as revolution-counter, and has the same unit as speed--revolution per minute (RPM).

Some tachometers, especially those used in automobiles, are similar in construction and operation to automotive speedometers. However, the major difference between a tachometer and a speedometer is in the fact that, while speedometer measures continuous speed (i.e how fast the car is travelling in miles per hour), tachometer is a gauge that measures instantaneous speed (i.e how fast the engine is spinning especially in manual transmissions).

Other physical quantities considered while choosing a tachometer include: power, accuracy, RPM range, measurements and display. Tachometers can have analog or digital indicating meters; the analog tachometer has a dial, with a needle indicating the current reading and safe/dangerous operating limits. However, our project focuses only on the digital tachometer which gives a direct numeric output and has become more widely used.

2. Literature Review

The first mechanical tachometer was similar in operation to a centrifugal governor. The inventor of the first mechanical tachometer is assumed to be a German engineer Dietrich Uhlhorn; he used it for measuring the speed of machines in 1817. Since after then, it has been used to measure the speed of locomotives in automobiles, trucks, tractors and aircrafts. Early tachometer designs were based on the principle of monostable multivibrator [13], which has one stable state and one quasistable state. The circuit remained in a stable state, producing no output. However, when it receives triggering current pulse from the ignition system, the circuit transitions to the quasistable state for a given time before returning again to the stable state. This way, each ignition pulse produced a clean pulse of fixed duration that was fed to the gauge mechanism. The more of such fixed duration pulses the gauge received per second, the higher it read.

The monostable multivibrator is still used in tachometers today, although the tendency is to use voltage pulses rather than current pulses, the latter requiring that the ignition coil current passes through the tachometer on its way to the coils.

Later designs of tachometer were in no way to do any improvement on the early type; indeed the change seemed to have been made to be more economical.

Integrated Circuit (IC) where in their infancy in the late 1960's and was both expensive and not proven to be robust in automobile applications.

2.1. Classification of Digital Tachometers

Digital tachometers are classified into four types based on the data acquisition and measurement techniques. Based on the data acquisition technique, the tachometers are of the following types: Contact type and Non Contact type digital tachometer. Based on the measurement technique, the tachometers are of the following types: Time measurement and Frequency measurement digital tachometer.

2.1.1. Contact Type Digital Tachometer

A tachometer which is in contact with the rotating shaft is known as contact-type tachometer [8]. This kind of tachometer is generally fixed to the machine or electric motor. An optical encoder or magnetic sensor can also be attached to this so that it measures its RPM.

2.1.2. Non-Contact Type Digital Tachometer

A tachometer that does not need any physical contact with the rotating shaft is called as noncontact digital tachometer [9]. In this type, a laser or an optical disk is attached to the rotating shaft, and it can be read by an IR beam or laser, which is directed by the tachometer. These types of tachometers are efficient, durable, accurate, compact, and visible from long distance [12].

2.1.3. Time Measurement Digital Tachometer

A tachometer that calculates the speed by measuring the time interval between incoming pulses is known as a time-based digital tachometer. The resolution of this tachometer is independent of the speed of the measurement, and it is more accurate for measuring low speed.

2.1.4. Frequency Measurement Digital Tachometer

A tachometer that calculates the speed by measuring the frequency of the pulses is called a frequency-based digital tachometer [8]. This type of tachometer is designed by using a red LED, and the revolution of this tachometer depends on the rotating shaft, and it is more accurate for measuring high speed. These tachometers are of low-cost and high-efficiency, which is in between 1Hz-12 KHz.

3. Design Methodology

Though there are several ways by which a digital tachometer could be designed, we choose this method which makes use of a microcontroller as the main control unit of the device [11], infrared transmission technique as the detection mechanism, an alphanumeric LCD module for display and a proximity sensor[8] for detection of the rotation of the shaft whose speed is being measured. In these case of these the counted pulses will come from the proximity sensor, which will detect any reflective element passing in front of it, and thus will give an output pulse for each and every rotation of the shaft. Those pulses will be fed to the microcontroller and counted. The result will then be displayed on the LCD module.

The Methodology Employed In This Work Is Shown In The Figure 1 Below.

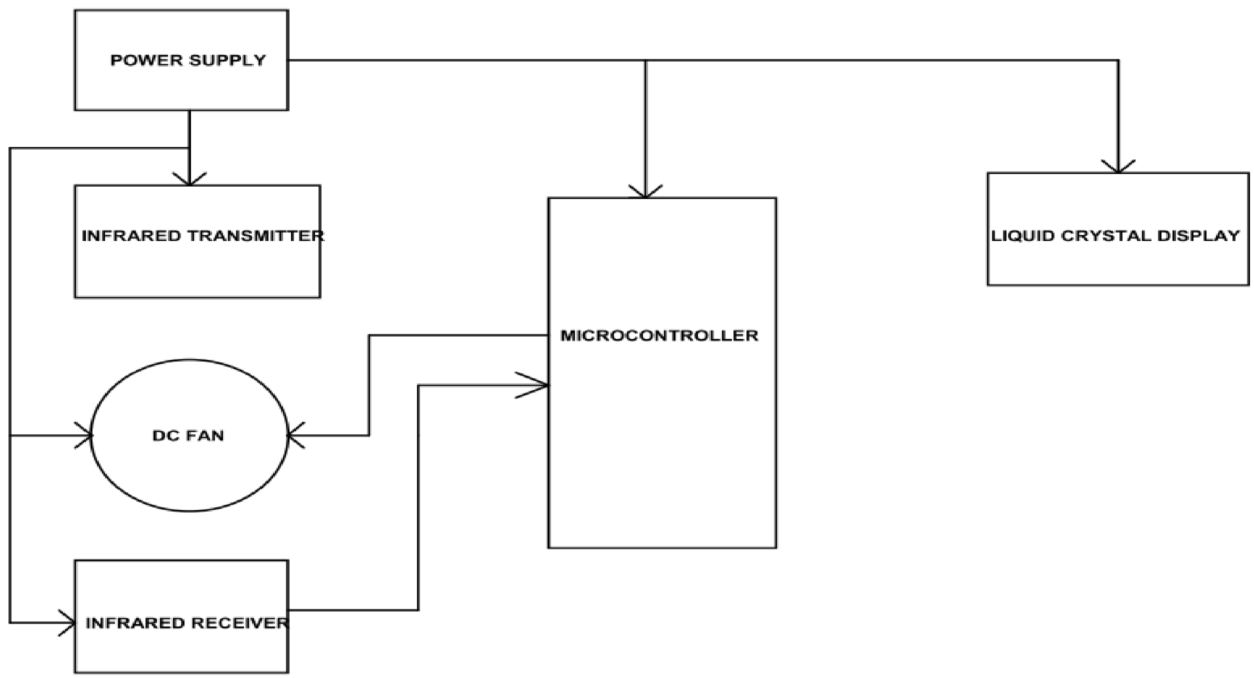

Figure 1. Block diagram of a digital tachometer

3.1. Design Analysis

The digital tachometer detector system is made up of the following stages;

i. Power Supply
ii. Input stage: the input stage comprises of;
  - Infrared transmitter and receiver section
iii. Control stage
  - Microcontroller
iv. Output stage
  - LCD Screen
  - Dc fan

3.1.1. P.S.U (Power Supply Unit)

The power supply serves as the main supply of electrical power to the system. The supply voltage is 220Vac that is step down by a 220Vac/24Vac, 500mA transformer. The $24V_{AC}$ voltage is then rectified by a bridge rectifier to have a DC output. After the rectification process the remaining AC ripples are filtered off by a bypass capacitor. The output from the bypass capacitor is unregulated thereby causing a drastic voltage drop when a load is connected. To solve this problem an integrated IC chip voltage regulator is used to obtain a fixed output.

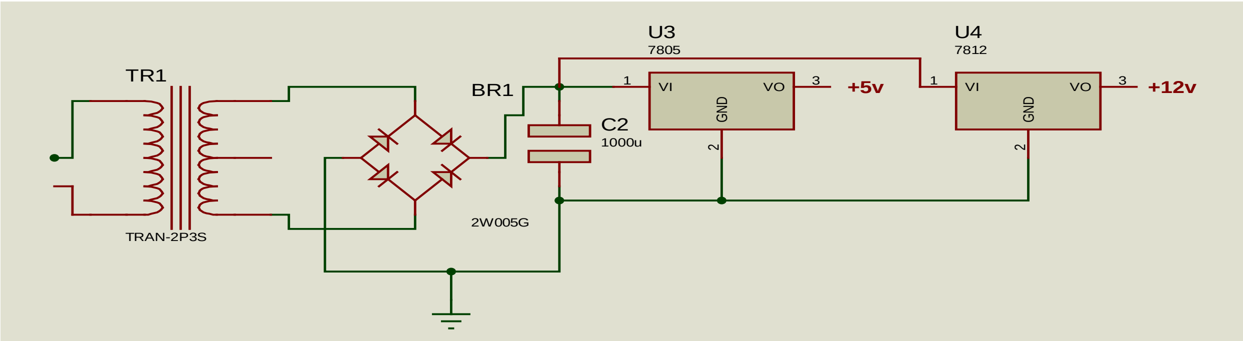

Figure 2. Diagram of Power Supply Unit

Analysis of Power Supply

A center-tapped power transformer with the rating $220/240V_{AC}$ primary voltage, 12V-0V-12V secondary voltage and 500mA current was used to feed the circuit. When connected 12V-12V, it produces 24V which is the supply voltage for the system.

From the transformer equation,

$$K = \frac{V_P}{V_S} = \frac{I_S}{I_P} = \frac{N_P}{N_S}. \quad (1)$$

To find K from equation (1), given that V_P= 220V and V_S=24V becomes

$$K = \frac{V_P}{V_S} = \frac{220}{24} = 9.17.$$

Assuming the lowest voltage supplied by PHEDC is 185V, from equation (1), the lowest voltage supplied to the circuit, given that K is 9.17 and V_P=185V becomes,

$$V_S = \frac{V_P}{K} = \frac{185}{9.17} = 20.17\text{V}.$$

Assuming the highest voltage supplied by PHEDC is 240V, from equation (1), the highest voltage supplied to the circuit given that K is 9.18 and V_P=240V becomes,

$$V_S = \frac{V_P}{K} = \frac{240}{9.17} = 26.17\text{V}.$$

$$\text{Assuming the secondary voltage of transformer}$$
$$= 24V\,(Vrms)$$

$$\textit{the peak secondary voltage;}$$
$$V_m = \sqrt{2} \times Vrms \quad (2)$$
$$= \sqrt{2} \times 24 = 33.9V.$$

The bridge circuit will rectify the 24V from the secondary of the step down transformer. The full-wave bridge rectifier which converts a.c voltage to d.c voltage was used since it has a peak inverse voltage (PIV) of 100V and can pass peak current of up to 2A.

$$V_{L(peak)} = V_{m(\max)} - 2V_{d(on)} \quad (3)$$

$$V_d = \textit{forward voltage drop of a silicon diode} = 0.7$$
$$= [33.9 - 2(0.7)]V = 32.5V.$$

The PIV rating of the diode to be used should be at least equal to the peak voltage. The bridge rectifier has a PIV rating of 100V. Therefore the 100V PIV is far greater than this value 32.5, thus making it suitable for this design.

For a suitable filter capacitor value to be employed the PIV of the capacitor should be larger than the Peak voltage after rectification. From equation (3) the Peak voltage is 32.5.

A capacitor to withstand at least 32.5V must be chosen, the capacitor value should be high to be able to filter off ac ripple voltage from the circuits. A 2200uf, 100V PIV capacitor was used.

3.1.2. Input Stage

The input stage sends signal to the microcontroller. The infrared detector [3] system senses a break in transmission of signal from the transmitter to the receiver and sends logic low to the base of the transistor to switch off the transistor to give logic high to the microcontroller timer pin.

3.1.2.1. Infrared Transmitter and Receiver Section

Infrared transmitter makes use of the 555 timer, and an RC oscillator. The calculation for obtaining the exact components that will generate this frequency is shown below. The carrier frequency is 56 kHz. This is due to the fact that the infrared receiver receives signals at a frequency of 56 kHz.

Calculation for resistance, R_1

$$T = 0.693(R_2 + 2R_1) \quad (4)$$

$$F = \frac{1}{T} = \frac{1.44}{(R_2 + 2R_1)C} \quad (5)$$

Let; $R_2 = 10K\Omega$, $R_1 = ?, F = 56KHz$, R_1 *is unknown, substituting the values into the equation*

$$56KHz = \frac{1.44}{(10K + 2R_1)0.001 \times 10^{-6} F}$$

$$(10K + 2R_1) = \frac{1.44}{56 \times 10^3 \times 0.001 \times 10^{-6} F}$$

$$2R_1 = \frac{1.44}{0.000056} - 10 \times 10^3$$

$$2R_1 = 25715 - 10000 = 15715$$

$$R_1 = \frac{15715}{2} = 7858\Omega$$

Therefore; $R_1 = 8K\Omega$.

Therefore, specifications of the components used to obtain a circuit with a carrier frequency of 56 kHz include: An electrolytic polarized capacitor (102 tantalum), a 10 kilo ohms resistor which is the closest value 8 kilo ohms between pin 6 and pin 7 and a 10 kilo ohms resistor between pin 7 and pin 8. The output of the 555 timer is connected to a transistor that has its emitter connected to the ground. The collector is connected to an infrared diode, which is used to emit light (signal) that the infrared receiver can receive. The receiver circuit is made of a transistor logic inverter which is connected to pin 1 of the microcontroller. The infrared transmitter is made of 555 timer circuit and an infrared diode. The 555 timer is used in the astable mode. The carrier frequency is 56 kHz, so an RC oscillator was connected to the 555 timer to derive the output.

The receiver used in the circuit is TSOP1356; the receiver frequency is 56 kHz. When a signal is sent to the receiver it records a high at its output terminal, but when the signal is removed, its sends a low from its output terminal. The transmitter and receiver will be placed side by side, so that when there is a break of signal transmission, it will send a low to the base of the transistor via a 1kohm resistor (The 1kohm resistor is used to limit the current entering the base of the transistor, R5). This will make the transistor to switch off. Since the transistor is connected as a logic inverter it will give an alternate voltage level at its collector voltage. This voltage is connected to the p1.0 of the microcontroller. This is used to notify the microcontroller of the status of the infrared detector system. When the fan is placed in between the transmitter and receiver, the number of times the object rotates is counted by the microcontroller via its timer terminal.

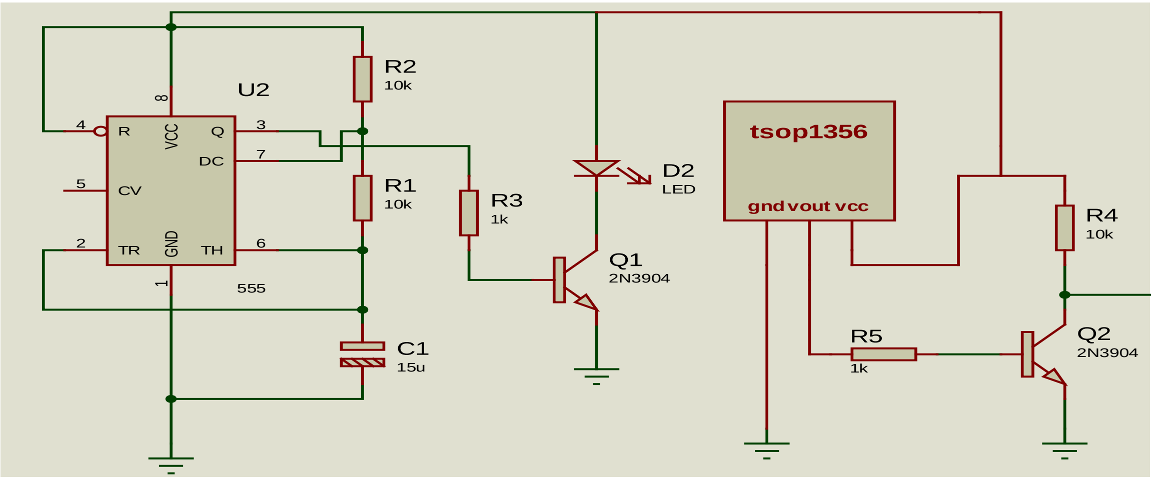

Figure 3. Diagram of Infrared transmitter and receiver section

Table 1. Pin Configuration of 555 timer

PIN		I/O	DESCRIPTION
NO.	NAME		
5	Control voltage	I	Controls the threshold and trigger levels. It determines the pulse width of the output waveform. An external voltage applied to this pin can also be used to modulate the output waveform.
7	Discharge	I	Open collector output which discharges a capacitor between intervals (in phase with output). It toggles the output from high to low when voltage reaches 2/3 of the supply voltage.
1	GND	O	Ground reference voltage
3	Output	O	Output driven waveform
4	Reset	I	Negative pulse applied to this pin to disable or reset the timer. When not used for reset purposes, it should be connected to Vcc to avoid false triggering.
6	Threshold	I	Compares the voltage applied to the terminal with a reference voltage of 2/3 Vcc. The amplitude of voltage applied to this terminal is responsible for the set state of the flip-flop.
2	Trigger	I	Responsible for transition of the flip-flop from set to reset. The output of the timer depends on the amplitude of the external trigger pulse applied to this pin.
8	V^+	I	Supply voltage with respect to GND

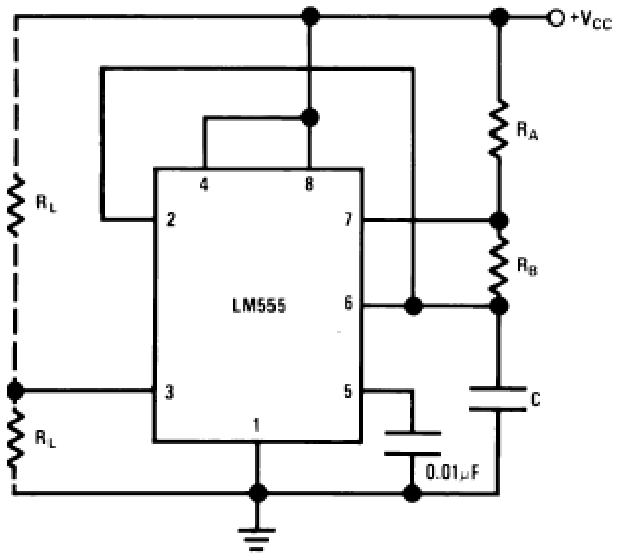

Figure 4. Astable operation of a 555 timer

3.2.3. Control Unit

The control unit makes use of an AT89C52 microcontroller chip whose main function is to read the bit logic of port 1.0, it is used to count the high to low transition of the signals connected to the port. The timer is programmed to count the pulses of the low to high transition in one second. Each pulse represents the angular speed of the object. The speed of the rotating object is calculated by multiplying the value of the final count by 60 to get the speed in revolutions per minute. This is due to the fact that the speed of the fan is measured by the timer of the microcontroller in seconds. Port 2 terminals are used to send data to the LCD screen. Port 2.5 and 2.7 are connected to the command register of the LCD display, register select (RS)) and the enable (EN). These command registers are configured to make the microcontroller to be able to display words on the LCD screen. They are used as support. The data pins are connected to p2.0, p2.1, p2.2, p2.3 which use 4 bit data mode to send data to the liquid crystal display. The data that is displayed is the speed of the rotating object. This process is achieved by using assembly language programming through MIDE-51 compiler. The program is burn into the microcontroller chip by a universal programmer Topwin 2007. The code is written in an integrated environment of the MIDE studio. After the completion of the code the program runs and three file formats are gotten from the compiler's software with extensions of hex, asm and list. The hex file will be burn into the microcontroller using the TOPWIN programmer.

The ASM file is the code file that will be used by the program to edit or improve on the program when necessary. While the list file shows all the addresses of the programming code and the number of cycles needed for the execution of each of the code.

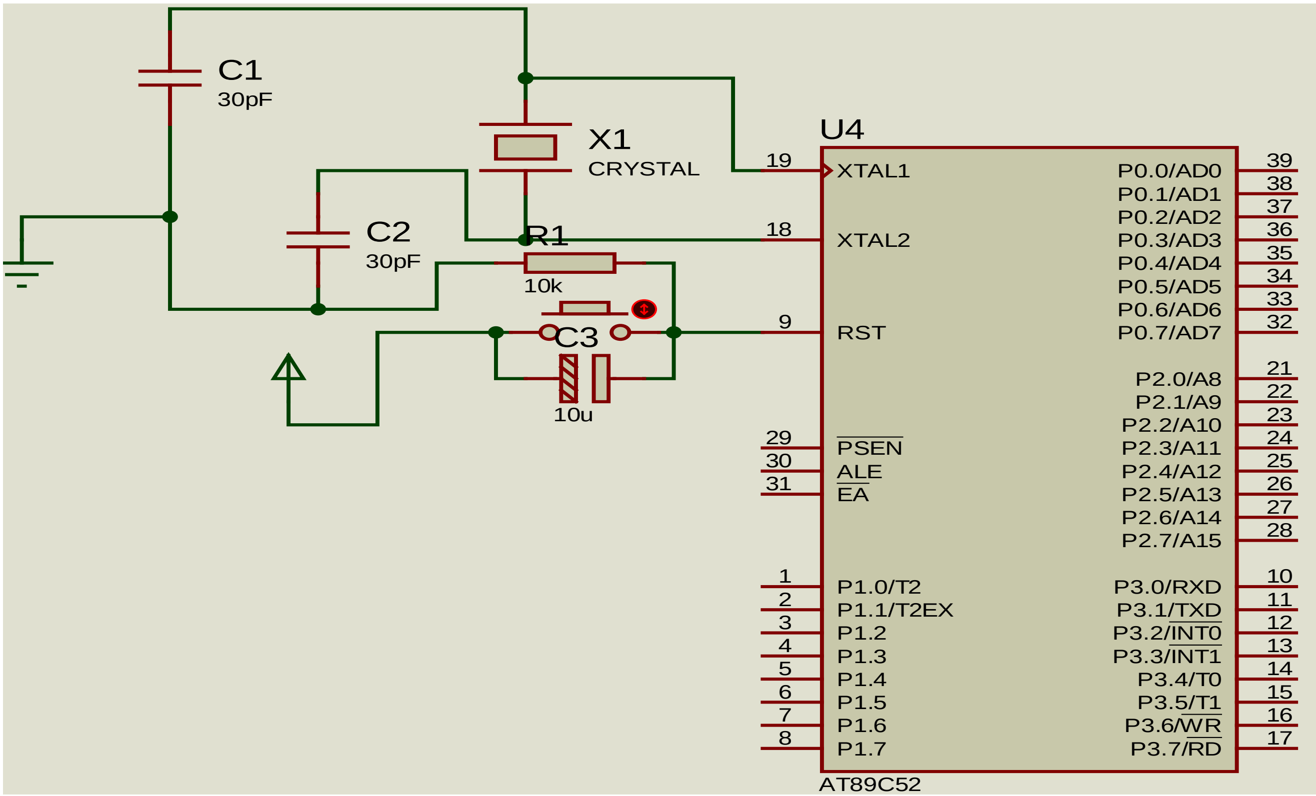

Figure 5. Control Unit Schematics

3.2.3.1. Features of At89c52 Micro Controller [1]

- 4k Bytes of In-System Reprogram-able Flash Memory
- Advance: 1,000 write/Erase Cycles
- Full Static Operation: 0 HZ to 24 MHZ
- 128x 8-bit Internal RAM
- 32 Programmable I/O Lines
- two 16-bit Timer/Channel
- Six interrupt Sources
- Programmable Serial Channel
- Low power Idle and Power-down Modes.

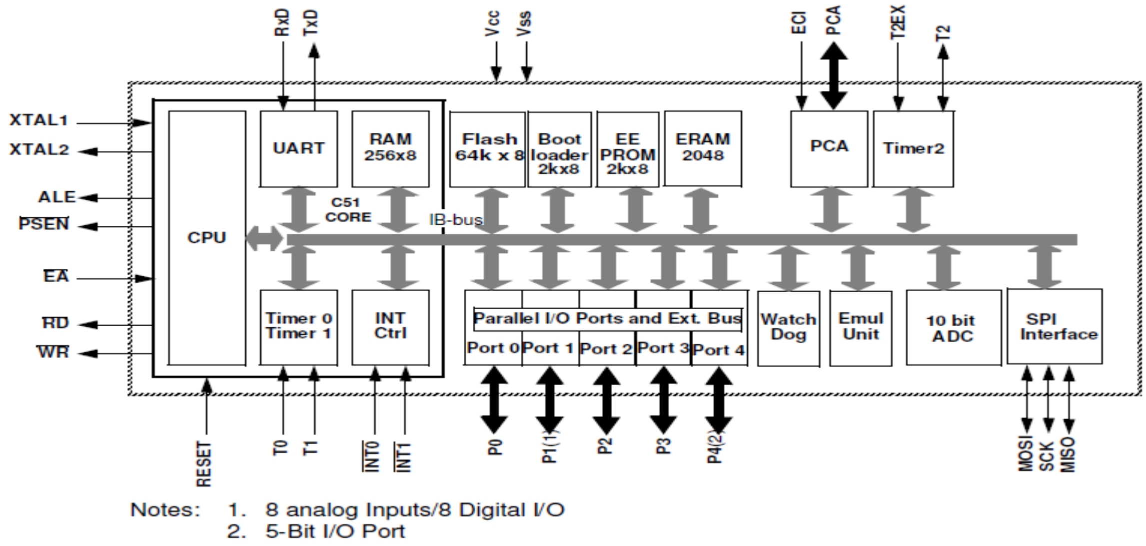

Figure 6. Block diagram of a microcontroller

Table 2. Microcontroller pin description[5]

PIN NO.	PIN NAME	DESCRIPTION	ALTERNATE FUNCTION
1	(XCK/T0) PBO	I/O PORT B, Pin 0	T0: timer 0 external counter input. XCK: USART External Clock I/O
2	(T1) PB1	I/O PORT B, Pin 1	T1: Timer1 External Counter Input
3	(INT2/AINO) PB2	I/O PORT B, Pin 2	AINO: Analog Comparator Positive I/P INT2:External Interrupt2 Input
4	(OC0/AIN1) PB3	I/O PORT B, Pin 3	AIN1: Analog Comparator Negative I/P OC0: Timer0 Output Compare Match Output
5	(SS) PB4	I/O PORT B, Pin 4	In System Programmer(ISP) Serial Peripheral Interface(SPI)
6	(MOSI) PB5	I/O PORT B, Pin 5	
7	(MISO) PB6	I/O PORT B, Pin 6	
8	(SCK) PB7	I/O PORT B, Pin 7	
9	RESET	Reset Pin, Active Low Reset	
10	Vcc	Vcc=+5V	
11	GND	GROUND	
12	XTAL2	Output to Inverting Oscillator Amplifier	
13	XTAL1	Input to Inverting Oscillator Amplifier	
14	(RXD) PDO	I/O PORT D, Pin 0	USART Serial Communication Interface
15	(TXD) PD1	I/O PORT D, Pin 1	
16	(INT0) PD2	I/O PORT D, Pin 2	External Interrupt INT0
17	(INT1) PD3	I/O PORT D, Pin 3	External Interrupt INT1
18	(OC1B) PD4	I/O PORT D, Pin 4	PWM Channel Outputs
19	(OC1A) PD5	I/O PORT D, Pin 5	
20	(ICP) PD6	I/O PORT D, Pin 6	Timer/Counter 1 Input Capture Pin
21	PD7 (OC2)	I/O PORT D, Pin 7	Timer/Counter 2 Output Compare Match Output
22	PC0 (SCL)	I/O PORT C, Pin 0	TW1 Interface
23	PC1 (SDA)	I/O PORT C, Pin 1	
24	PC2 (TCK)	I/O PORT C, Pin 2	JTAG Interface
25	PC3 (TMS)	I/O PORT C, Pin 3	
26	PC4 (TDO)	I/O PORT C, Pin 4	
27	PC5 (TDI)	I/O PORT C, Pin 5	
28	PC6 (TOSC1)	I/O PORT C, Pin 6	Timer Oscillator Pin 1
29	PC7 (TOSC2)	I/O PORT C, Pin 7	Timer Oscillator Pin 2
30	AVcc	Voltage Supply = Vcc for ADC	
31	GND	GROUND	
32	AREF	Analog Reference Pin for ADC	
33	PA7 (ADC7)	I/O PORTA, Pin 7	ADC Channel 7
34	PA6 (ADC6)	I/O PORTA, Pin 6	ADC Channel 6
35	PA5 (ADC5)	I/O PORTA, Pin 5	ADC Channel 5
36	PA4 (ADC4)	I/O PORTA, Pin 4	ADC Channel 4
37	PA3 (ADC3)	I/O PORTA, Pin 3	ADC Channel 3
38	PA2 (ADC2)	I/O PORTA, Pin 2	ADC Channel 2
39	PA1 (ADC1)	I/O PORTA, Pin 1	ADC Channel 1
40	PA0 (ADC0)	I/O PORTA, Pin 0	ADC Channel 0

The software part of the system is the program used to control the control unit.

- The hex file is generated using M.I.D.E STUDIO
- It is burn into the microcontroller using a TOPWIN programmer
- The microcontroller will be programmed in assembly language using M.I.D.E studio. This is illustrated in the figure below.

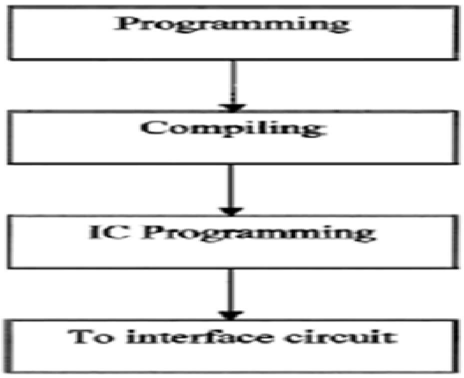

Figure 7. Microcontroller programming process

3.2.4. Output Unit (LCD)

The output unit is the liquid crystal display (LCD). The LCD screen is used to display the angular speed of the DC fan. This is possible due to its data terminals and command register that the microcontroller is connected to. The fan is switched on by the microcontroller when the button is pressed. The speed is measured in one second and multiplied by sixty to give the value for one minute. it can be used to display the operating status at any time for various applications without using PC. A LCD contains of two lines and each line can display 16 characteristics, and is known as 16 x 2 LCD. Table 3 below shows the LCD pin configuration and funtions [4].

Table 3. Table showing LCD Pin Configuration and Functions [4]

Pin Number	Name	Functions
1	GND	Ground (0V)
2	Vcc	Supply voltage; 5V (4.7V-5.3V)
3	V_{EE}	Contrast Adjustment; through a variable resistor
4	RS (register select)	Selects command register when low; and data register when high
5	RW (Read/Write)	Low to write to the register; High to read from the register
6	E (Enable)	Sends data to data pins when a high to low pulse is given
7	DB0	HL data bus line
8	DB1	HL data bus line
9	DB2	HL data bus line
10	DB3	HL data bus line
11	DB4	HL data bus line
12	DB5	HL data bus line
13	DB6	HL data bus line
14	DB7	HL data bus line
15	Led+	Backlight Vcc 5V (LED Negative Voltage output)
16	Led-	Backlight Ground (0V)

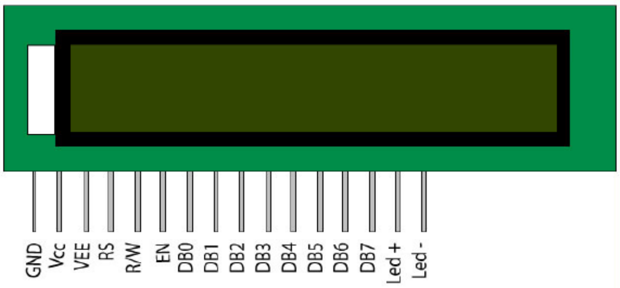

Figure 8. LCD Module

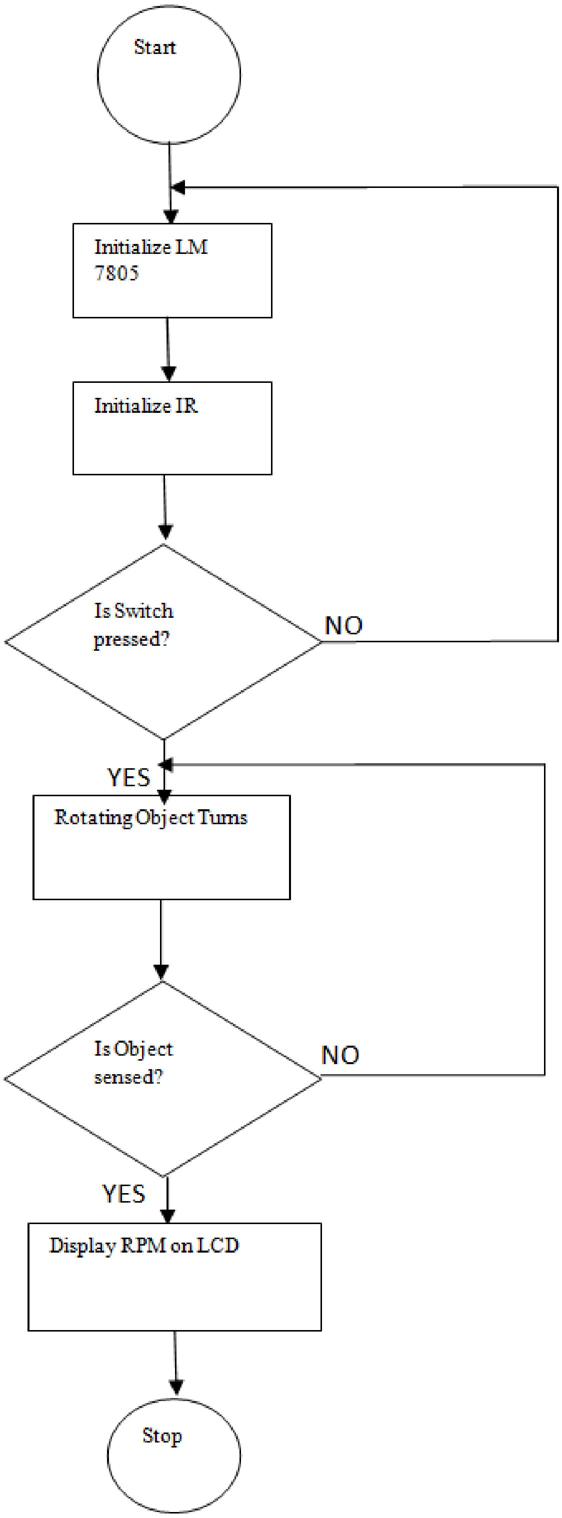

Figure 9. Operational Flow Chart

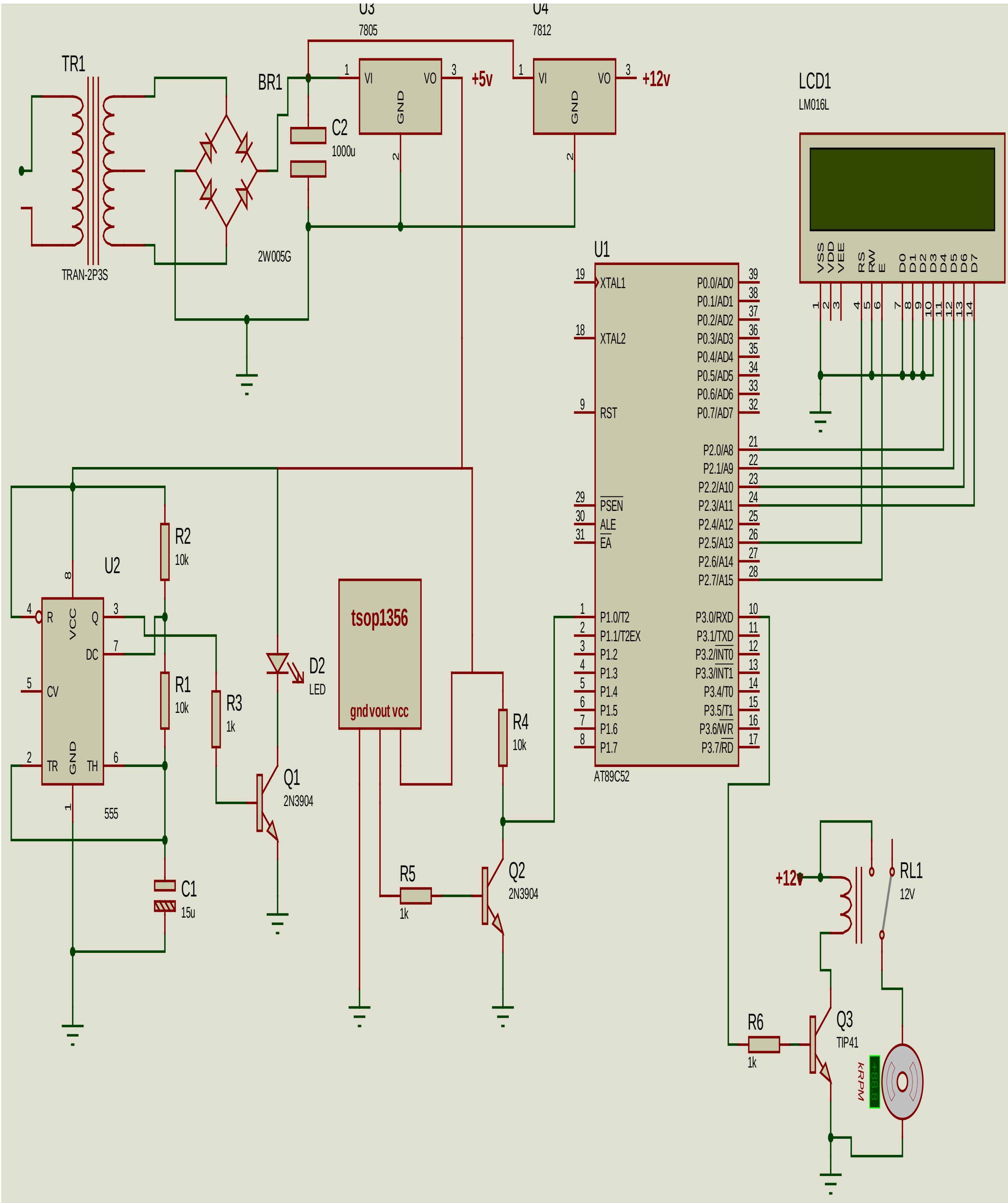

Figure 10. complete circuit diagram

4. Results and Discussions

A motor rated 3000rpm was used as a testing tool. And an existing tachometer and the microcontroller based tachometer were both used for four readings at different Pulse Width Modulation (PWM) [7]. This is shown in Table 4 below. It is therefore shown that the percentage error of our microcontroller based tachometer is 1.02% and the percentage error of the existing tachometer is 2.41%.

Table 4. Comparism between two tachometers

PWM	RPM measured with existing tachometer	RPM measured with a microcontroller based tachometer
14%	490	513
33%	1550	1599
90%	2795	2820
100%	2900	2970

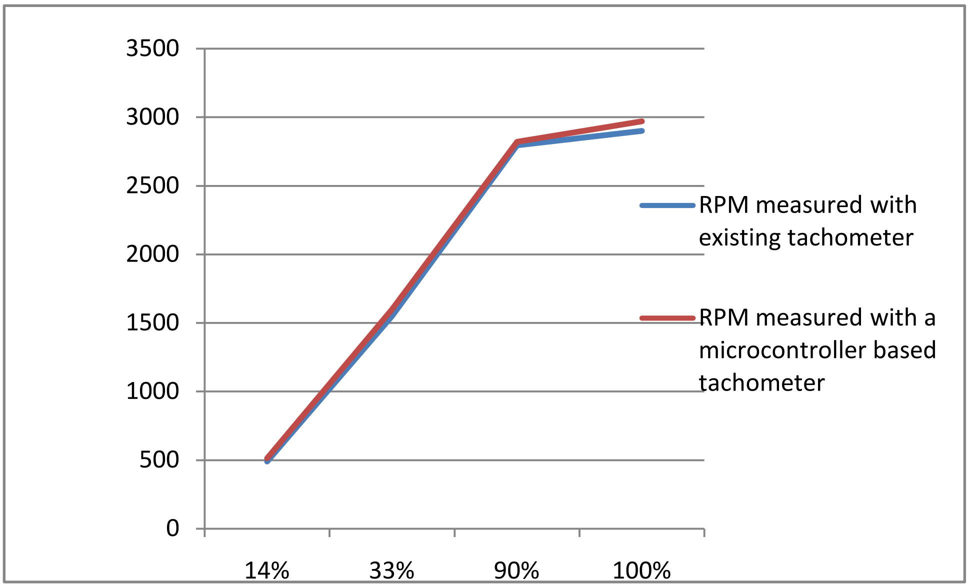

Figure 11. Plot of average RPM values obtained by designed device and standard tachometer for various readings

5. Conclusions and Recommendation

5.1. Conclusions

The circuit is an innovative device that is active in measuring the speed of a rotating object. This device is nothing but a simple electronic digital transducer. Normally, it is used for measuring the speed of a rotating shaft. The number of revolutions per minute (rpm) is valuable information for understanding any rotational system.

5.2. Limitations

- The limitation of the project is that it incorporates wireless communication components which are susceptible to noise.
- The availability of materials and technical know-how for the project is not readily available.
- Limited research materials.

5.3. Recommendations

- This project can further be improved by means of packaging and the use of miniaturized electronics component.
- Further research should be done to enhance the design of the overall system.

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