Design of a Microcontroller based Fan Motor Controller for Smart Home Environment

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Abstract

Single phase induction motors are the most widely used motors for home appliances. The AC induction motor has a simple rugged design. Other advantages include low cost, low maintenance and can be connected directly to an AC power source. When power is supplied to an induction motor at the recommended specifications, it runs at its rated speed [1]. However, many applications need variable speed operation. One of them is a fan. This paper presents a design of a microcontroller based motor controller with heat sensor which is used to vary the speed of a motor in a smart home. The discussion includes the design of a controller that varies the speeds of the motor with respect to the ambient temperature in a smart home environment. The controller is embedded as an addition to a stand fan. A phase control method is selected to be implemented in this design. The power delivery to the motor is controlled by the firing angle of a Triac where it controls the AC power supply. With the firing time controlled by the Triac, the input power to the motor can be controlled accordingly. In addition, a hand-clap circuit is also introduced which acts as a switch to activate or deactivate the motor.

Keywords: *Single phase induction motor, phase control, triac, microcontroller*

1. Introduction

A single phase induction motor is the most common AC motor. In all single phase induction motor, the rotor is made of a squirrel cage type [2]. Permanent split capacitor (PSC) typed motor is one that is categorized under the single phase induction motors. It consists of three main parts which are the main winding in the stator, rotor and starting mechanism. In general, a single phase induction motor is not self-starting. Therefore, this is the reason why the PSC motor has a starting mechanism. The starting mechanism provides the starting kick for the motor to rotate which mainly adds a stator winding. It has a capacitor or a centrifugal switch in series [3]. The working principle of a PSC induction motor is very simple. When the supply voltage is applied to the motor, the supply voltage in the main winding leads the current due to the main winding impedance. Meanwhile, current in the starting winding may lead or lag the supply voltage depending on the starting mechanism impedance. Interaction between magnetic fields generated by the main winding and the starting mechanism produces a resultant magnetic field rotating in the specific direction depending on the resultant magnetic field [2].

The PSC induction motor is widely used in home appliances [4], especially the fan. The history of fan from its existence till the present moment shows that a vast majority of this equipment is controlled via a mechanical switch. Each of these mechanical switches corresponds to one speed that is selected by pulling a chain. For each time the chain is pulled, the motor circuit changes to a predefined coil winding. This is mainly done by using a potentiometer concept where different values of the voltage will be sent to the motor as the switches are being operated. This method requires an operator to control it. When a switch is pressed, the motor will rotate at a fix speed regardless of the ambient temperature. This implies that when the maximum speed switch is being pressed; the motor will rotate at the rated maximum speed even if the ambient temperature is very low (cold situation).

With the advancement of technology, mechanical switch system is no longer the only way to control speed of the fan. Speed control of a fan can be controlled by the electronic circuit system [5-7]. There are many articles that had addressed the improvements and innovations in AC drive. There are plenty of ways to control the speed of an induction motor such as Volts/Hertz (V/F) control [8-10], H-bridge inverter [11-14]; three phase Inverter Bridge [15-16], phase control [17-19] and etc. However in this paper, our interest is to review and apply the simplest speed control method for a PSC induction motor – implementation of phase control drive into the circuit system to vary the speed of the fan. In addition, all the logics are programmed in PIC microcontroller. Therefore, the whole system is automated.

Furthermore, environmental friendly is the main concern for the smart home. Hence in this paper, a microcontroller based motor controller with heat sensor is proposed. In this controller, the fan speed or single phase induction motor is varied with respect to the ambient temperature in the smart home environment. In addition, a hand clap circuit is embedded in the system as a switch to control the on and off of the system. Nevertheless, the speed of a stand fan is independent of the ambient temperature; hence there will be waste of power. In addition, each motor has its own lifespan. The lifespan of a stand fan motor is the total number of revolution made. As the motor speed does not change with the ambient temperature, there might be extra revolution (high speed in low ambient temperature) and hence the lifetime of a motor will be shortened.

2. System Architecture

In overall, the system consists of several components as shown in Figure 1. Firstly, the range of the highest and the lowest temperature are set in the microcontroller. Then a hand clap circuit is used to trigger the system to on or off state. When the system is on, the ambient temperature will then be sensed by the temperature sensor. The output of the sensor will then feed to the PIC Microcontroller. The PIC Microcontroller will generate the desired output signals which are correspondent to the difference ambient temperatures by comparing the output voltage from the temperature sensor with the preset values. These output signals will be sent to the firing angle control circuit to trigger certain relay to control the firing angle of the Triac. Therefore, the average power supply to the motor will be varied; hence, the speed of the motor can be controlled.

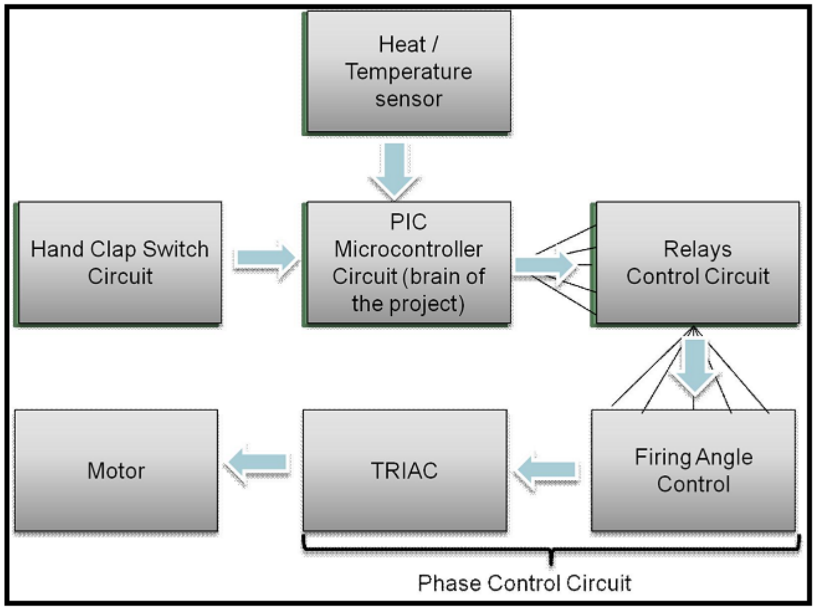

Figure 1. The System Architecture

3. Hand Clap Switch

A hand clap switch is used to permit the current flow across two or more terminal to allow interaction between electrical components. In addition, it is also used to terminate the flow when necessary. This switch is normally used to provide means for connecting two or more terminals in order to permit the flow of current across them to allow the interaction between electrical components. The proposal of having such a switch is to alleviate the problem faced by the aged and physically challenged persons in trying to control some household appliances [20]. Figure 2 shows the schematic diagram of hand clap circuit. The main processes in the circuit include the input transducer, amplifier, memory, changing state and output stage.

The clap sound is first picked up using an electret microphone. The film inside the electret microphone will be vibrated in symmetry with any sound falling on it. These vibrations cause the electrical charge on a perforated plate nearby to change, and a field effect transistor converts these into corresponding changes in current. In transistor stage, the signal which is received from the microphone will be amplified by the biased near cut-off. The output of the microphone is coupled to the base of the transistor by using an electrolytic capacitor. On the first time the microphone detect clap sound; the microphone output will go to positive. This causes the current that flows through the transistor to be increased. When the current increases up to the threshold current, it will trigger the transistor to be activated and thus causing the voltage at the collector to fall nearly zero.

A bistable multivibrator is formed by connecting two cross transistors. This bistable multivibrator has the function of storing memory. It will store the state of either on or off until the end of time. Once the clap on, the state of the bistable changed. The output of the amplifier is converted to a sharp pulse by passing it through a low valued capacitor, 0.1μF. With the help of IN4001 diodes which helps it to be connected together steers the pulse to the base of the transistor. When the first transistors stop conducting, the other transistor which is already at the off state will remain off. Then, those two capacitors across the base resistors will start to action. The capacitor that connected to the base of the transistor which was ON has voltage across it. In the other hand, the transistor that was off has no voltage across the capacitor that is connected to it.

In the output stage, there are a relay and a transistor. The relay is used as a switch to trigger another circuitry. One of the coil terminals of the relay is joined to the collector of the transistor, and remain coil terminal will be joint to a relay triggering source. The base of the transistor is joined to the collector of one of the transistors in the bistable multivibrator. As the transistor is in off state, the current from the source that nearby the collector will be flowed to the base and hence the transistor is in on state and the relay triggering source can be flowed to the relay and hence, the relay will be on and able to triggering the third party circuit.

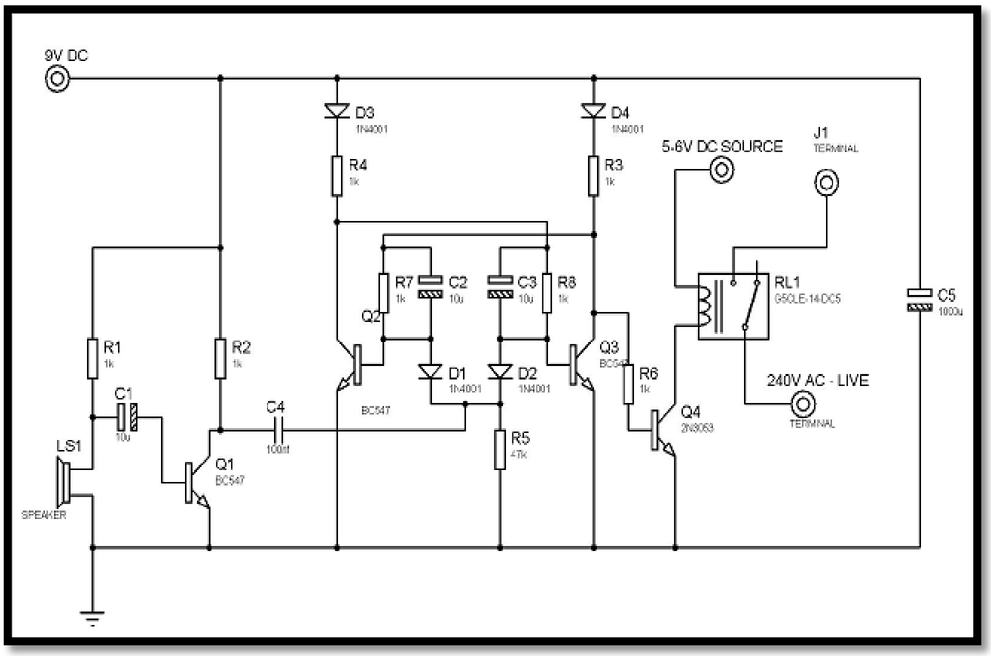

Figure 2. Hand Clap Switch Circuit

4. PIC Microcontroller Circuit

Figure 3 shows the PIC microcontroller circuit (PIC18F4520 from Microchip Technology). The voltage regulator is used to supply the required voltage for the circuit where in this case, a 5v supply is required. When the temperature sensor, LM35 sensed the surrounding ambient temperature, it will produce a very small output voltage. This output voltage will then be fed to the PIC microcontroller. PIC microcontroller will perform as a digital signal process medium where it takes the output voltage and converts it into digital form for further processing. Before the system works, it requires the highest and the lowest reference temperatures to be set. These values are crucial in this project. The highest reference temperature will be set to a limit boundary temperature where there should be no temperature higher than it. If the output voltage from temperature sensor is found to be higher than the highest preset reference temperature value, it indicates that there might be fire breakout occurring or there are some faulty errors occurred in the circuit, for example, a short circuit could causes the circuit's temperature to go higher and cause the ambient temperature sensed by the sensor to reach an abnormal level.

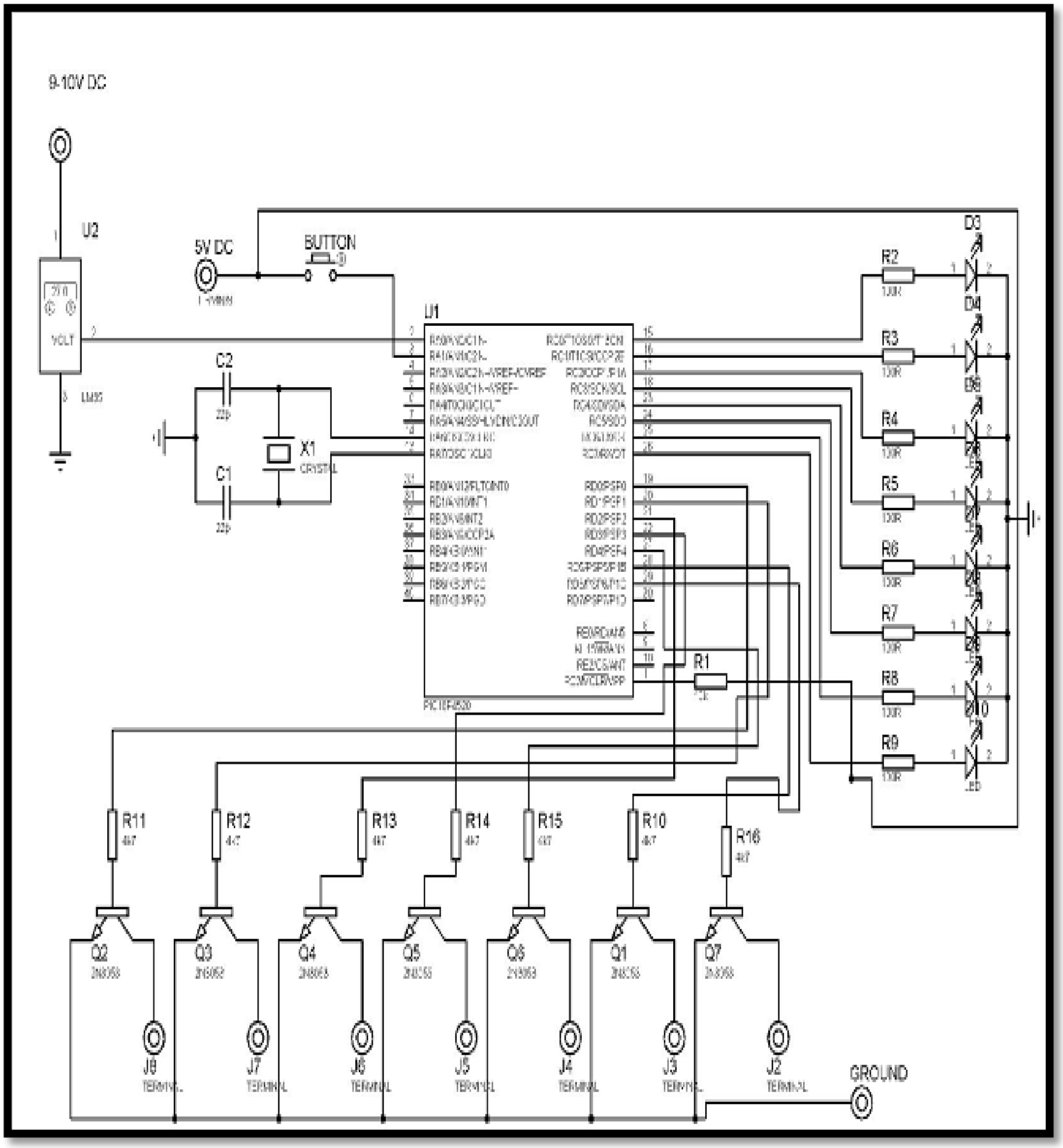

Figure 3. PIC Microcontroller Circuit

The lowest reference temperature is used to set the maximum requirement temperature in order to stop the motor. When the ambient temperature of the smart home environment is found to be lower than the lowest reference temperature, the motor will be stopped. Besides that, some of the preset values for difference temperatures are also being set in the microcontroller. The temperature sensor is connected to RA0, hence the output voltage from the sensor will be sent to RA0. After that, the PIC microcontroller will digitalize the analogue signals. Then, it will compare the ambient temperature to each of the reference temperatures as shown in Figure 4. The comparison results will then be used to generate different signals at the PortD (RD0-RD6) to trigger the BJT transistor where the BJT transistors are link to the relays in the phase control circuit as shown in Figure 5. With the firing angle controlled, the motor speed can also be controlled. In addition, the temperature will also be indicated in PortC. Table 1 summarizes the proposed speeds for difference ambient temperatures in tropical countries such as Malaysia.

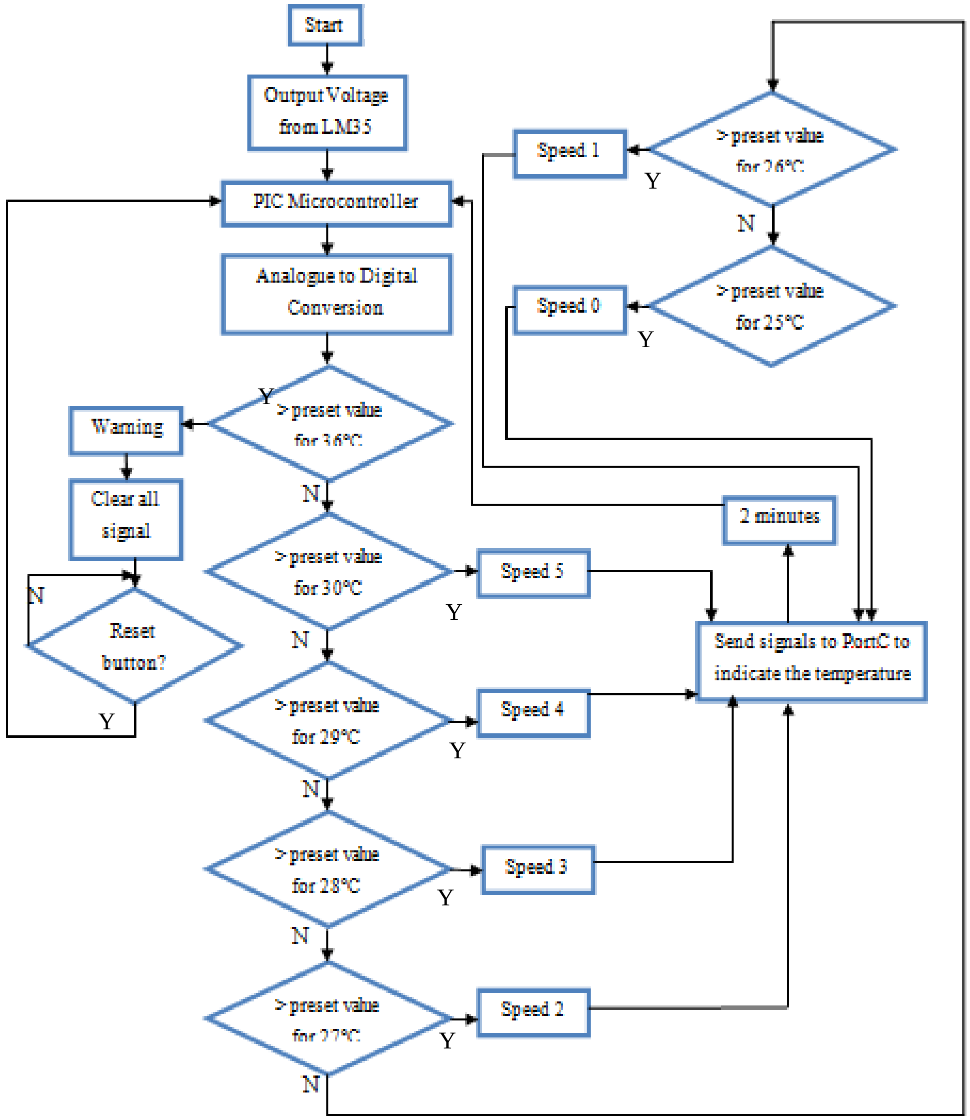

Figure 4. PIC Microcontroller Processing Flow Chart

Table 1. The Propose Speeds for Difference Ambient Temperatures

Ambient Temperature (^{o}C)	Temperature Sensor Output (input to PIC) (mV)	The Propose Speed
20	200	Stop
26	260	1
27	270	2
28	280	3
29	290	4
30	300	5
38	380	Stop

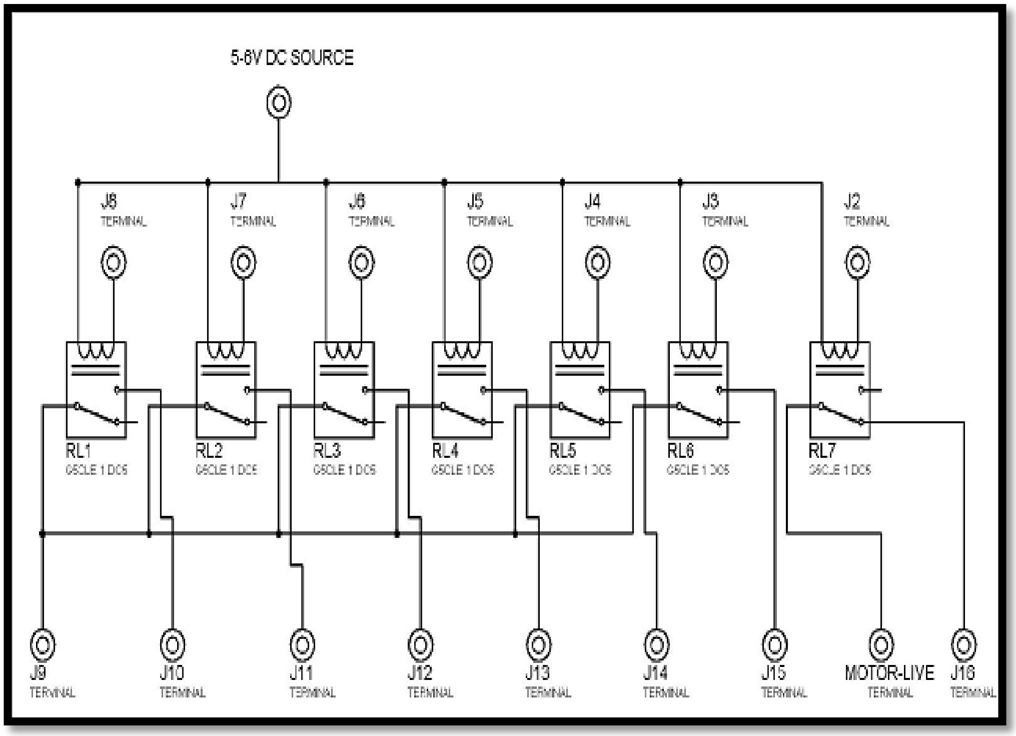

Figure 5. Schematic for Relays Board

4.1. Analog to Digital Conversion (ADC)

As discussed early, the PIC microcontroller acts as a medium for digital signal processing. However, only a binary code can be read in the PIC microcontroller. Hence, the small analogue output voltage generated from the heat sensor, LM35 has to be converted into digital form so that the PIC microcontroller can use it to perform a simple comparison task. Each time the result is obtained from the LED indicator; it has to be divided by 2 in order to get the actual ambient temperature reading. The resolution of the ADC is given by the equations:

$$ADC = \frac{Vin\ (analog\ input)}{Step\ size\ (resolution)} \tag{1}$$

$$ADC = \frac{Vin\ (analog\ input)}{Vref / 2^{bit\ of\ the\ PIC\ microncontoller}} \tag{2}$$

5. Phase Control Method of a PSC Induction Motor

Basically, phase control method is one of the simplest ways to control a PSC induction motor. The triac which acts as a single switch that is in series with the AC line. The duration of on time of the triac control the AC voltage supply to the motor by chopping the AC waveform. It causes the power to shut off during a portion of the AC Cycle. Figure 6 shows the schematic diagram of a Triac controlled drive [21]. The motor in the figure is a PSC motor which has two windings and a capacitor for phase shift.

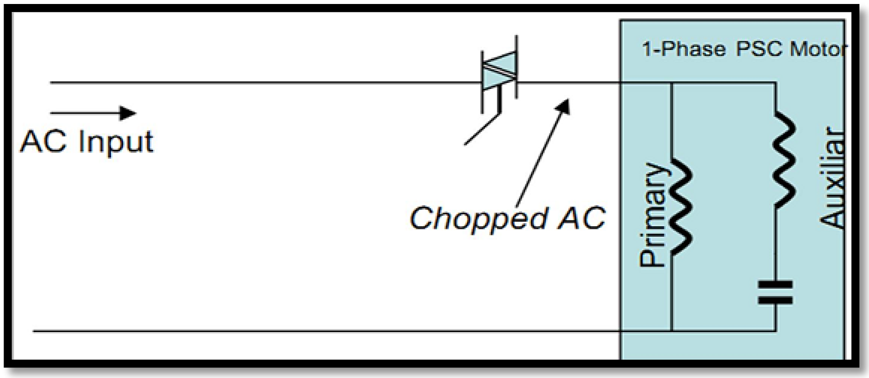

Figure 6. AC Chopper/Triac Control of 1-Phase AC Motor

Generally, the AC motor acts as a low pass filter causing the resulting current waveform to be sinusoidal at the same operating frequency with a slight lag [21]. The slip to the motor will be increased by the lower root mean square (RMS) voltage that being created by the chopper. The slip is defined as the difference between synchronous speed and the base speed. It is expressed as a percentage and can be determined with the following equation:

$$Percentage\ Slip = \frac{N_s - N_b}{Ns} \times 100 \tag{3}$$

Where N_s = synchronous speed in revolution per minute (RPM)

N_b = the base speed in RPM

As a result, the motor speed is reduced if the slip to the motor increased. It starves the motor of its power, the motor slows down. Eventually the motor stops after there is not enough energy to maintain its rotational speed [21]. The speed of the motor can be controlled by the conducting period of the Triac where the conducting period depends on the firing angle that is controlled by the circuit at the gate of the Triac.

5.1. Phase Control Circuit

The phase control circuit is the combination of Triac with the firing angle control circuit. Figure 7 shows the basic full-wave Triac phase control circuit. It requires five components which consist of a Triac, Diac, potentiometer, capacitor and also resistors. The resistance component and the capacitor are a single-element phase-shift network. When the voltage across capacitor reaches the breakover voltage (VBO) of the Diac, capacitor is partially discharged by the Diac into the Triac gate. Then the Triac is triggered into the conduction mode for the remainder of that half-cycle.

As shown in the Figure 7, there is a potentiometer connected parallel with the resistors. This potentiometer is used to set the minimum speed for the motor. To do this, all the relay will be turn off (no output signal from PIC microcontroller) initially so that the resistance for the bottom side will be maxima, then adjusts the potentiometer (with the yellow knob) to obtain the minimum speed desired. Before the Triac gets triggered, it will be in the off state. When there is no voltage passing to the motor, no energy or power being transfer to the motor hence the speed of the motor will decrease. The input power, P_{in} to the motor can be calculated by the formula,

$$Pin = Power\ factor\ \times\ input\ voltage, V_{in}\ \times input\ current, I_{in} \tag{4}$$

In this circuit, the triggering is in the Quadrants I and III. This circuit suitable for the applications with small control range. The firing time is given by $R_{eq}C$ where

$$R_{eq} = \left((Ra + 100k)||1M\right) + 4.7k \tag{5}$$

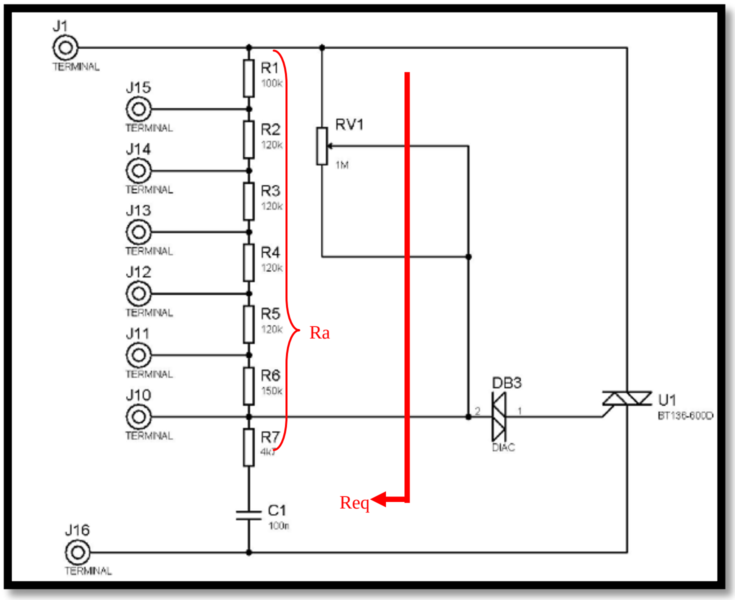

Figure 7. Schematic Diagram of Phase Control Circuit

6. Results and Discussions

A few tests were carried out to evaluate the performance of the controller system such as volumetric flow rate test, thermal flow simulation, hand clap response test, and the overall performance test.

6.1. Volumetric Flow Rate Test

This test is important as the speed of a fan does not affect the temperature but volumetric flow rate does. The purpose of this experiment is to see the approximate relationship between the volumetric flow rates and the speed (revolution per minute) of the fan. This test was carried out by using a tachometer. Figure 8 shows the corresponding volumetric flow rate (m^3/minute) to the speed (RPM) of the fan. The output voltage produced by the motor is linearly proportional to the speed of the motor with a constant which is approximately 0.88.

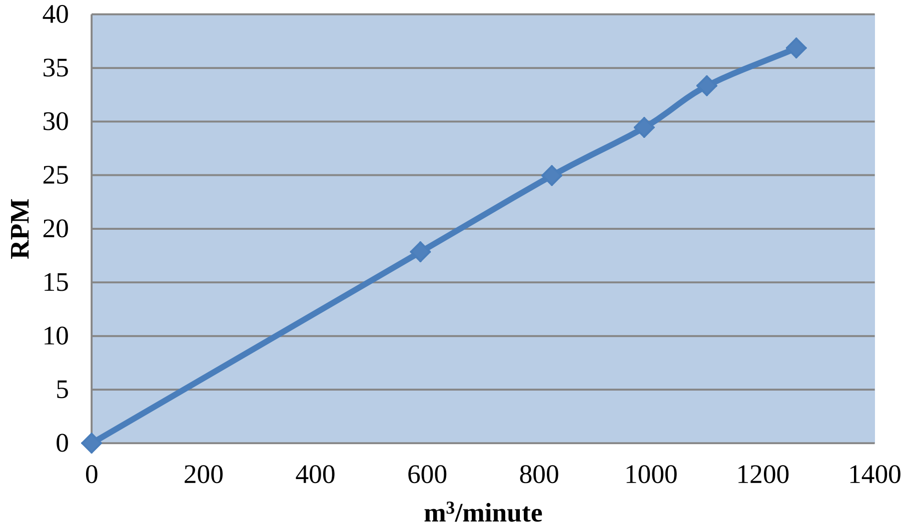

Figure 8. Speed vs. Volumetric Flow Rate

6.2. Thermal Flow Simulation

Besides that, a thermal flow simulation was carried out to show the importance of volumetric flow rate of a fan in controlling the ambient temperature. The thermal flow simulation was carried out by using the SolidWork Flow Simulation software. The 4 boxes in both the Figures 8 and 9 represent the heat sources. As this project is designed to be used in stand fan, hence, the heat sources are set to be similar with house appliance devices. When there is low volumetric flow rate, the heat produced by the heat sources will be accumulated as shown in Figure 8. If this accumulated heat is not circulated out or removed, the temperature will keep increasing, and cause of discomfort or hazard. In addition, the heat sources will bring problems to the devices surrounding. If the high temperature exceeds the maximum rated temperature which can be sustained, the lifespan of the devices will be reduced by half for every excess of 1 degree Celsius. Note that the red color represents a high temperature whereas blue color represents low temperature in the figures shown.

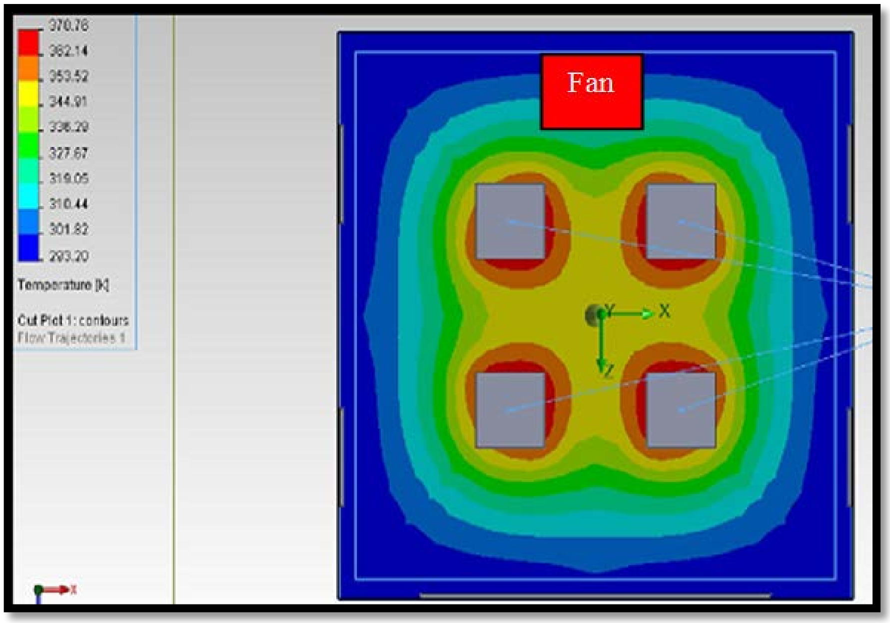

Figure 8. Temperature Distribution by using the Cut Plot in the Situation of Low Volumetric Flow Rate

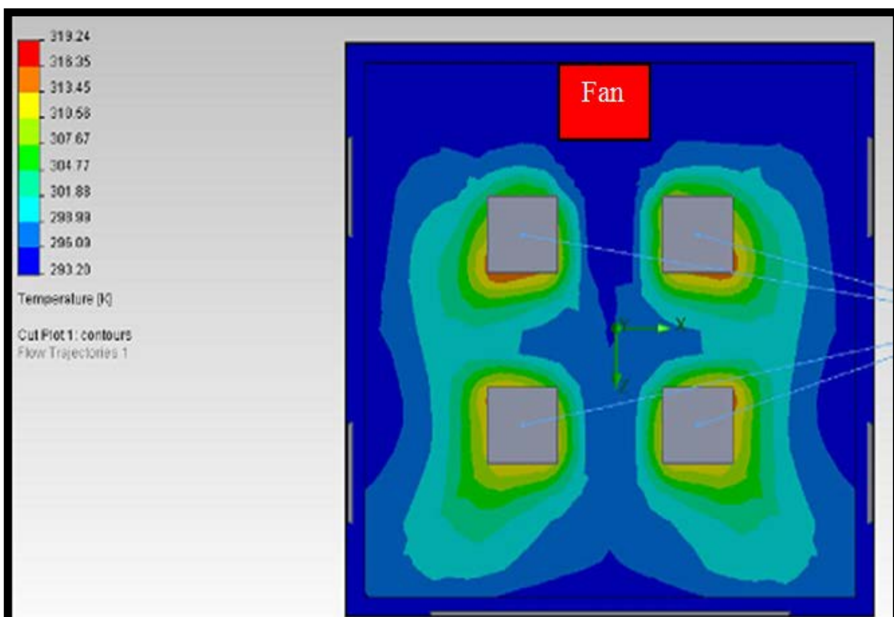

Figure 9. Temperature Distribution by using the Cut Plot in the Situation of High Volumetric Flow Rate

6.3. Hand Clap Response Test

The hand clap response test is to verify the hand clap functions. This experiment was carried by placing a LED at the output stage in the hand clap circuit. A few hand claps were performed and the light's condition of the LED was observed. Table 3 shows the responses of the LED.

Table 3. Result for the Hand Clap Circuit

Hand Clap	Result
0 (initial Stage)	The LED light does not light up; the relay is in off mode. The circuit is opened.
1st Clap	The LED light on; the relay is triggered on. The circuit is closed.
2nd Clap	The LED light off; the relay is triggered off. The circuit is now opened.

6.4. Overall Performance Test

The overall performance test is the most important test among all the experiments. The experiment is to control the input power flow to the fan, which affects the speed of the fan and eventually save the power effectively. This test was carried out by embedding the system into a real fan. Different temperatures were applied to the temperature sensor. The corresponding speeds of the fan to the difference temperatures applied were measured by a tachometer. Furthermore the input voltage and input current to the fan motor were measured by a digital multimeter for calculating the input power proposes. Table 4 shows the result of the system performance.

Table 4. Overall Performance Result for the Whole System

Ambient temperature	Speed	Ampere, I (A)	Voltage to the fan (V)	RPM	CFM m^3/minute	Power to the fan Watt
≤25	0	0	0	0	0	0
≥26	1	0.05	52.3	588.9	17.85	2.65
≥27	2	0.06	76.5	823.7	24.96	4.59
≥28	3	0.08	105.9	988	29.94	8.472
≥29	4	0.09	141.1	1100	33.33	12.699
≥30	5	0.11	195.8	1216	36.85	21.538

Form the result, the power required to run at high speed is more than running in the low speed. Hence, if the motor speed controlled according to the ambient temperature, the power is saved effectivelly.

7. Conclusion and Future Work

The result indicates this control method can provide energy saving for home appliances in the smart home environment. It works effectively in term of energy saving compared to the existing fan speed controlling method. However, it has room for improvement in this project. In the future, the system will be intergrated with zero cross detection so that more precise input power to the fan's motor can be controlled. As a result, more precise speeds of the fan can be controlled. In a nutshell, this project is highly potential for application purposes in other fan motor speed control; hence improvement will be carried out continuously so that in one day, it will become the norm for the motor speed control and the energy can be saved effectivelly in a smart home.

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