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Development of a Digital Air Flow Regulator for Agro-Allied Processes

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Abstract. The aim of this work is to develop a digital air flow regulator for agro allied processes. Microcontroller (MCU) based air flow regulators are needed in order to fulfill the rapidly changing electronics products specification, needed for both industrial and domestic applications. In this work, a microcontroller-based air flow regulator was developed. The flow regulator selects, varies, and displays air velocities within the range of 0.5 to 4.5 m/s. It was calibrated with a standard air anemometer of model (Luitron: AM-4206). The percentage error of instrumentation for the regulator, when tested at no load was determined as 13%. The air flow regulator when tested with different depths of corn showed that the velocities at the exit point of the corn layer decreased with increase in the layer depth of the corn. Also the velocities from both the flow regulator and the standard anemometer increased with increasing rotational speeds (rpm) of the fan.

Index Terms— anemometer, drying systems, fan speed, Induction motors, microcontroller, rotational speed, instrumentation

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1 Introduction

Flow measurement is a necessary task in such diverse fields as medical instrumentation, process control, environmental monitoring and forced convection drying systems. A current application for air mass flow sensors is part of the intake system of internal combustion engines of automobiles and power generating sets. Flow meters are used in fluid systems (liquid and gas) to indicate the rate of flow of the fluid. They can also control the rate of flow if they are equipped with flow control valves, or microcontroller-monitored motor fan systems.

Air flow is normally achieved artificially by fans and air pumps, which are incorporated into flow systems. The flow rate of air in such systems is normally a function of the speed of the fan. Fans which are normally installed in homes, mechanical systems involving air flow, internal combustion engines, and forced convection dryers, are normally designed and installed to rotate at varying speeds, which correspond to different air flow rates. The velocity of flow of air affects the drying rate and quality of dried agricultural materials [1]; [2].

Single phase induction motors are the most widely used motors for home appliances (Pang *et al*., 2013). When power is supplied to an induction motor at the recommended specifications, it runs at rated speed [3].

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However, many specifications need variable speed operation, one of which is a fan. Most of the fan speed control systems are analogue systems, which are very difficult to operate. Readings from such analogue systems are normally accompanied with parallax error and other errors arising from the nature and weakness of the spring used in the dial system. A lot of losses had been incurred in the drying of agricultural crops, arising from improper selection of air flow velocities for the drying process. This study involves the development of a microcontroller-monitored digital air flow control system.

The methods of controlling fan speed include: Linear regulation, DC-DC regulation, Pulse-Width Modulation (PWM) method, ASIC solution and Micro Controller Unit (MCU) solution (Lun, 2006). The microcontroller fan speed regulator in this work was developed, using the Pulse-Width Modulation method.

The Pulse-width modulation (PWM) method of fan speed control directly involves turning the fan's power supply on and off at a fixed frequency. The PWM method was introduced to overcome the efficiency problem in the linear and DC-DC regulations. The speed of the fan is controlled by the duty cycle of fixed PWM signal that was applied to the external switching device (transistor / FET). The speed of the fan is directly proportional to the duty cycle of the PWM. Increasing the percentage in duty cycle of the PWM signal will increase the speed of the fan. But one important consideration in this method is the choice of PWM frequency. Higher PWM frequency will cause the malfunction of the internal commutation circuit inside the fan, while lower PWM frequency will cause the fan to oscillate. The best range for the PWM frequency is around 30 – 150 Hz so as to avoid the mentioned problems [4]. The advantages of this method include a very simple drive circuit, good startup

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characteristics, and minimal heat dissipation in the pass transistor.

2 MATERIALS AND METHODS

2.1 Description of the System

The microcontroller-based air flow regulator works on the principle of Pulse Width Modulation method of fan (motor) speed control. It alters the speed of the fan by pulsing the rotation of the fan at various frequencies. It consists of the power supply, the microcontroller unit, the Transistor, the Liquid Crystal Display (LCD) unit, and the Matrix keypad (Fig. 1)

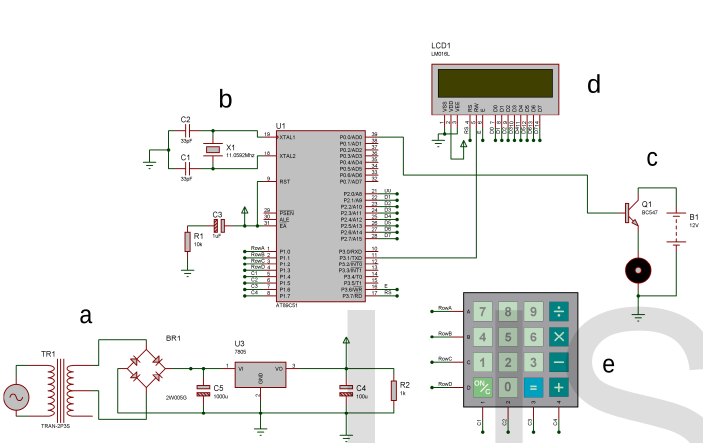

Fig1: Circuit Diagram of the Microcontroller-Based Air Flow Regulator

a. Power Supply

The main aim of this power supply is to convert the 230V AC into 5V DC in order to give supply for the TTL (transistor to transistor logic) or CMOS (complementary metallic oxide semiconductor) devices. In this process, a step down transformer, a bridge rectifier, and a smoothening were used.

b. Microcontroller

The microcontroller AT89C51 with a crystal oscillator of 11.0592 MHz crystal in conjunction with a couple of capacitors are placed at 18th & 19th pins of 89C51 to make it work (execute) properly.

c. Transistor

This module is output to the microcontroller. The motor was designed to be driven by an npn transistor, and its input pin was connected to the pin 39 of the microcontroller.

d. Liquid Crystal Display (LCD)

The LCDs used exclusively in watches, calculators and measuring instruments are the simple seven-segment displays, having a limited amount of numeric data. The recent advances in technology have resulted in better legibility, more information displaying capability and a wider temperature range [5]. The circuit diagram for the LCD interfacing is shown in Figure (2)

e. Matrix KeyPad

In the case of matrix Keypad, both the ends of a total of 16 switches were connected to the port Pin 1. A 4 x 4 matrix keypad (four rows and four columns) was used, resulting to a total of sixteen switches, which had been interfaced using just eight lines [6].

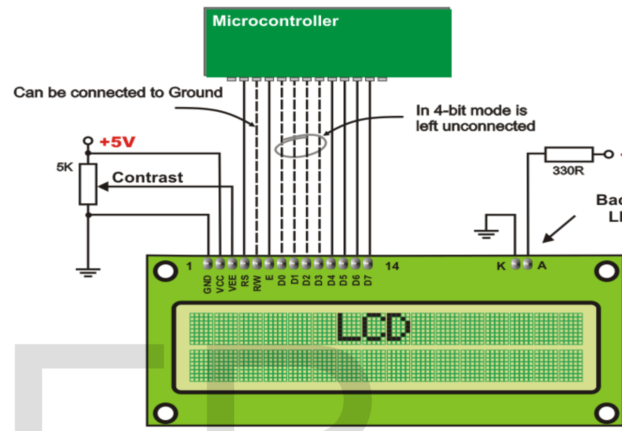

Fig2: Circuit Diagram of the LCD Interfacing

2.2 Testing and Calibration of the Air Flow Regulator

After the completion of the circuit connection of the air flow regulator, it was tested and calibrated, using a standard digital air flow meter (anemometer) of model (Luitron: AM- 4206). This was done by coding the readings in the matrix keypad of the developed air-flow regulator to fit the values of the air-flow meter. Also the rotational speeds of the fan in rounds per minute (rpm), corresponding to varying air flow velocities were measured using a digital laser-contact Tachometer of model (Luitron: DT – 2236C). Each velocity measurement done on the air-flow regulator was replicated 3 times and the average of these values was used as the velocity for the particular measurement. Also the air flow regulator was tested with a bed of corn at moisture content of 25% (dry basis), cross-sectional area of 12 cm x12 cm, and layer depths of 5, 7.5 and 10 cm. The air velocities at the exit point of each of these layer lengths were determined using the standard air anemometer. This work was done at Federal University of Technology, Owerri, Nigeria, in August, 2014.

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3.1 RESULTS

The results of the preliminary tests conducted on the air flow regulator are summarized in Table (1). This table shows the various values of air flow rate of the air flow regulator, compared to the flow velocity readings from the standard air anemometer, corresponding to the different rotational speeds (rpm) of the DC motor. The graphical relationship between the values of air flow velocities and the rotational speed of the fan is shown in Figure 3. The results of testing the air flow regulator with a bed of corn are summarized in Table (2). The relationship between the tachometer reading and air flow velocities at varying depths of corn is shown in Figure (4).

Table 1: Values of Air Flow Velocities Corresponding to Different Rotational Speeds of the Fan

Air velocity (m/s)		Tachometer reading
Air flow regulator	Anemometer	
0.5	0.75	132
1.0	1.25	350
1.5	2.01	560
2.0	2.30	750
2.5	2.75	880
3.0	3.15	1000
3.5	3.55	1100
4.0	3.82	1250
4.5	4.25	1400

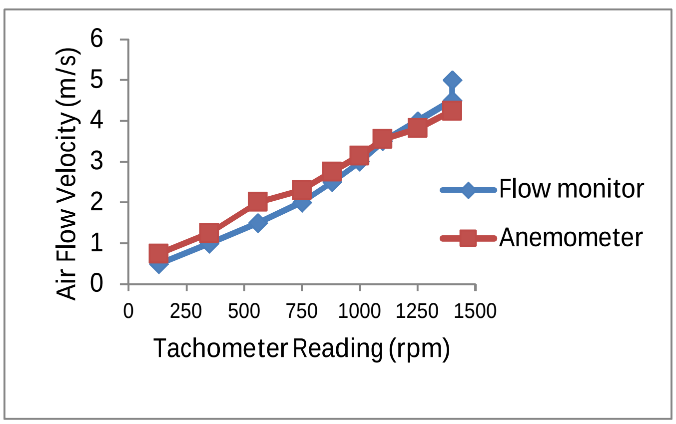

Fig 3: The effect of the rotational speed (rpm) of the fan on the air flow velocity

Table 2: Values of Air Flow Velocities Corresponding to Different Layer Thicknesses of Corn

Flow regulator	Velocity Values (m/s) Anemometer Readings at different depths of corn			
	0 cm(no load)	5 cm	7.5 cm	10 cm
0.5	0.75	0.45	0.32	0.15
1.0	1.25	0.90	0.75	0.42
1.5	2.01	1.65	1.15	0.70
2.0	2.30	1.85	1.35	0.85
2.5	2.75	2.40	1.90	1.35
3.0	3.15	2.80	2.35	1.85
3.5	3.55	3.25	2.75	2.15
4.0	3.82	3.62	3.25	2.55
4.5	4.25	4.05	3.71	2.95

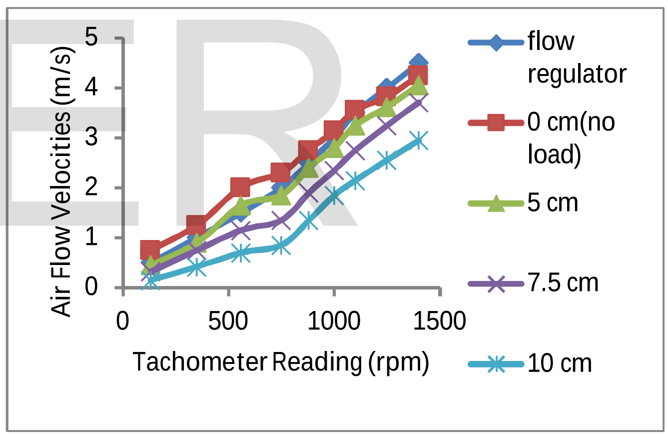

Fig 4: The Relationship between the tachometer reading and air flow velocities at varying depths of corn

3.2 Determination of Instrumentation Error

The percentage Error of instrumentation (E) was calculated using Equation (1)

$$E = \frac{V_m - V_t}{V_t} \times 100\% \qquad (1)$$

Where V_m = measured value, V_t = true value

From the test conducted, measured value is the velocity indicated by the air flow regulator, while true value is the velocity indicated by the standard anemometer. The various instrumentation errors corresponding to different velocities of flow are summarized in Table (3).

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Table 3: The Various Instrumentation Errors that Correspond to the Different Velocities Measured.

Air velocity (m/s) (Air flow regulator)	(Anemometer)	Percentage Error (%)
0.5	0.75	33.3
1.0	1.25	20
1.5	2.01	25
2.0	2.30	13
2.5	2.75	9.1
3.0	3.15	4.8
3.5	3.55	1.4
4.0	3.82	4.7
4.5	4.25	5.9

The mean percentage error for the test was obtained from Table 3 as 13%.

3.3 DISCUSSION

From Table 1, it was observed that the values of air flow velocities, obtained from the air flow regulator were close to the corresponding values obtained from the standard anemometer. The closest range is for the air flow velocity of 3.5 m/s for the air flow regulator, which corresponded to the value of 3.55 m/s for the standard anemometer. Also the values of the air flow velocities (m/s) both from the air flow regulator and the standard anemometer increased with increasing values of the rotational speed (rpm) of the fan. The air flow regulator gave air flow velocity range of 0.5 m/s to 4.5 m/s with minimal error. The maximum rotational speed of the fan obtained is 1,400 rpm, and this corresponded to the maximum air velocity of 4.5 m/s.

It was observed from Figure 3 that the air flow velocities had a linear relationship with the rotational speed of the fan. The curve of the air velocity versus rotational speed gave a linear curve which sloped upwards from left to right. This trend is in agreement with a similar work by Pang *et al*. [7], which showed that the rotational speed of a fan was linearly proportional to the volumetric air flow rate of the fan. Also the air flow velocities measured by the standard anemometer were slightly higher than the values indicated by the air flow regulator for velocities between 0.5 and 3.5 m/s, with the velocities from the two sources becoming the same at velocity of approximately 3.6 m/s. However after the velocity of 3.6 m/s, the air flow velocities measured by the anemometer became slightly lower than the values indicated by the air flow regulator. This reversal in the trend, and also coupled with the uneven variation in velocity values from the two sources may be as a result of the Pulse Width Modulation method that was used to vary the speed of the fan.

From Table 2, it was observed that the values of air velocity, obtained at the exit point of the layer of corn, decreased with increase in the thickness of the corn, for all the velocities selected by the air flow regulator. This could be as a result of resistance to air flow by the grains of the corn which increased with the increase in the thickness of the corn layer.

From Figure 4, it was evident that the air-flow velocities at different depths of corn varied linearly with the rotational speeds of the fan as recorded by the tachometer. Also the slopes of the linear curves varied with the depths of corn that was investigated. The air velocities decreased from the highest values of 0.75 to 4.25 m/s, obtained when the fan was under no load, to the lowest values of 0.15 to 2.95 m/s obtained for when the fan was investigated at a depth of 10 cm. This reduction could be as a result of resistance to air motion that was developed by the layer of corn.

4 CONCLUSION AND RECOMMENDATIONS

The microcontroller based air-flow regulator is a very useful instrument in engineering processes involving flow measurement of air at different velocities. This air-flow regulator was produced using locally available materials. It regulates and displays air velocities within the range of 0.5 m/s to 4.5 m/s with mean percentage error of 13%. The air velocities measured by a standard anemometer varied linearly with the rotational speed of the fan. Also the air velocities were highest when the regulator was tested under no-load conditions; and eventually reduced with increase in the depth of material, when the regulator was tested with a bed of corn.

I recommend that future work on this device should further calibrate and recode the air flow monitor so as to improve on its precision and reduce the percentage error of instrumentation.

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