Design and Implementation of Automatic Air Flow Rate Control System

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Abstract. Venturimeter is an apparatus that can be used to measure the air flow rate. In this experiment we designed a venturimeter which equipped with a valve that is used to control the air flow rate. The difference of pressure between the cross sections was measured with the differential pressure sensor GA 100-015WD which can calculate the difference of pressures from 0 to 3737.33 Pa. A 42M048C Z36 stepper motor was used to control the valve. The precision of this motor rotation is about 0.15 º. A Graphical User Interface (GUI) was developed to monitor and set the value of flow rate then an 8-bit microcontroller was used to process the control system. In this experiment, the venturimeter has been examined to get the optimal parameter of controller. The results show that the controller can set the stable output air flow rate.

1. Introduction

On measuring the air flow rate, several methods such as differential pressure (obstruction-type) meters, variable area flowmeters, positive displacement flowmeters, turbine meters, and others methods are used [1]. Among the aforementioned methods commonly used to determine flowrate, venturimeters that utilize differential pressure are widely used. These devices have a prevalent usage because of some advantage, such as the ease of fabrication and minimum pressure loss. To control the air flow rate output, a venturimeter must be equipped with a valve to adjust the desired flow rate. This air flow rate control is useful for various applications such as supplying the air stream to a high-resolution small ion spectrometer [2], keeping the air quality of heating, ventilating, and air conditioning system (HVAC) [3], and maximizing the power output of a fuel cell [4].

There are several methods to control the air flow rate such as using ultrasonic flow meter [5] and using a blower that driven by a single phase induction motor [6]. Most experiments that used venturimeter only focused on the development of the air flow rate measurements [7], without a control system. Hence the suitable air flow rate needed for specific requirements is hard to obtain. Therefore, a controllable system for measurement purposes is required. This paper proposes a method to control the flow rate using venturimeter by utilizing the differential pressure sensor. A valve was mounted on venturimeter to adjust the volume of air that streamed from the blower. All process control is handled by the 8-bit microcontroller and a GUI (Graphical User Interface) to ease the process of monitoring and recording data.
2. Design and Implementation

The design of venturimeter consists of mechanical, electrical, and GUI design. The mechanical design was developed to allow it to operate in the range of pressure sensor of 0-3736 Pa. Therefore it was designed by using the parameters calculated from the following equation.

\[ Q_1 = Q_2 \]  

\[ \frac{P_1 + \frac{V_{1}^2}{2}}{\rho} = \frac{P_2 + \frac{V_{2}^2}{2}}{\rho} \]  

\[ P_1 - P_2 = \frac{1}{2} \rho \left( V_{1}^2 - V_{2}^2 \right) \]  

\[ \Delta P = \frac{\rho Q^2}{2} \left( \frac{1}{A_1} - \frac{1}{A_2} \right) \]  

Based on Equation (4), to build a venturimeter which can fulfill the requirement, the volumetric flow rate \(Q\), the smaller area \(A_1\) and also the larger area \(A_2\) have to be properly arranged. Therefore, for this experiment, the area \(A_1\) and \(A_2\) of the venturimeter were designed with radius 0.028 m and 0.014 m, respectively. A blower which can propel the air up to 3 m³/min. has also been used to make the air flow through the venturimeter. From this design, the differential air pressure of 3709 Pa was obtained, in which it fits the range of the used differential pressure sensor. The design of venturimeter is shown in Figure 1.

![Figure 1. Design of venturimeter.](image1)

![Figure 2. Block diagram of venturimeter control.](image2)

For the electrical and electronic parts, it consists of a 42M048C stepper motor and L293D motor driver to drive the valve of the venturimeter, a 2x16 liquid crystal display (LCD) to show the activity of the stepper motor, GA 100-015WD differential pressure sensor to monitor the pressure difference in the venturimeter, and a USB serial to transfer the read data to the personal computer (PC). All the electrical and electronic parts are controlled by the 8-bit microcontroller, AVR ATMega8.

Block diagram of venturimeter control scheme is demonstrated in Figure 2. For the purpose of keeping at a certain value of flow rate, the proportional control action is used and all the control processes are managed in the microcontroller. The input of this system is a desired air flow rate which is produced by a single phase blower. When the process is started, the microcontroller will read the input and also the reading value from the differential pressure. If the predetermined value of air flow rate different with the calculated value obtained from differential pressure reading, the microcontroller will adjust the valve so that the difference between them can be minimized and the actual flow rate achieved. To obtain the better result on reading the differential pressure sensor, high accuracy ADC is required. While the ADC resolution of microcontroller is only 10 bits, it is necessary to increase the resolution of ADC by oversampling technique [8].

Graphical User Interface (GUI) was created to facilitate the communication between the user and microcontroller that control the venturimeter. GUI serves to input the predetermined set point value of the air flow rate and it is also used to monitor and display the differential pressure sensor reading. The display of GUI is shown in Figure 3. It is shown that the GUI has two main menus. The first menu
allows user to adjust the valve manually, including the closing and opening the valve partially or fully which is used to calibrate the venturimeter. The second menu is an air flow rate control system menu that is used to get the appropriate air flow rate on the venturimeter with the given value. In this second menu, there are facilities to input the set point value of air flow rate and the values of PID constants, and record the experimental data.

![Display of GUI](image)

**Figure 3.** Display of GUI.

### 3. Results and Discussion

As described before, this control system used the proportional parameter, which is ordinary denoted by Kp and this parameter is used when a controller action is relative to the obtained error [9]. The venturimeter action control could be described by Equation (5).

$$U(t) = K_p e(t) + U_b$$  

(5)

where $U(t)$ is the control action, $U_b$ is the bias, $e(t)$ is the difference between the set point and the sensor reading value (error) and $K_p$ is the proportional constant [10]. The control response to the specific air flow rate is described in Figure 4. It is shown that the output quality of the venturimeter depends on the proportional constant. When the proportional constant is too small, the set point cannot be reached by the controller because there is an error called by steady state error. Steady state error is the difference between set point and actual air flow rate after the controller already in steady state. The steady state error depends on the proportional constant. The higher the value of proportional constant is set, the lower the steady state error will be achieved [11].

Figure 5 shows the response of controller on several variations of air flow rate with the proportional constant of 0.1. The trend resulted by each air flow rate is similar, in which it also shown in Figure 4. With the same value of proportional constant, the controller’s response for reaching the set point would be similar. The difference of each graph is only on the time when reaching the set point. Therefore, to get the higher set point, it would need a longer time.

Disturbance is an input which is not expected in a controller. Because it is not expected, then a robust controller should be able to resist the disturbance [12-14]. Therefore, the interruption test has been done on the controller. Disturbance is given by closing the output of the blower and then reopened rapidly. Figure 6 shows the response of the venturimeter to the disruption. While the blower is closed, the air flow rate decreased extremely, and when it is reopened, venturimeter will observe for a set point position by controlling the venturimeter valve. From the result, the process only takes about 7 seconds for the device to be able to reach the set point value. It has been shown that the system control was resistant to the disturbance.
4. Conclusion
The air flow rate on the venturimeter has been automatically controlled. The experiment was done by varying the proportional constant and set point to see the response of the controller. The results showed that the device could generate the air flow rate ranging from 10 to 20 L/minute. It also showed that the proportional constant affects the air flow rate in which the best result occurred when the

Figure 3. Controller responses to set point air flow rates of (a) 14 L/s; (b) 16 L/s; (c) 18 L/s; and (d) 20 L/s.

Figure 5. Various set point values for a proportional constant of 0.1.

Figure 6. System response to disturbance.
proportional constantan was 0.1. Moreover, the predetermined set point can be reached by the system with only a small error especially when the set point is large.

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