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A MIMO system –Design to Test using Lab VIEW

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ABSTRACT

Chemical reaction, Ventilation system, central heating systems, dryers, hot balloon and other applications are required for precise control of hot air. The design and test of a real time MIMO system for automatic air temperature & airflow control using Lab VIEW is presented. The airflow and air temperature is controlled using fan speed & input voltage to heater. Manipulated variables are variable voltage to heater and variable voltage to DC fans. Controlled variables are airflow and temperature at the outlet. Disturbances are room temperature, inlet air temperature and DC fan speed. The designed MIMO system can be easily interfaced with Lab VIEW by using NI my DAQ. Here the authors mostly focus on the design of the system, which can later be controlled by various control technique like PID, MPC, IMC etc. The performance of the system is studied by subjecting it to various tests conditions.

KEYWORDS: Multi-input Multi-output, MIMO system, Linear Flow, MPC, PID

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INTRODUCTION

System with more than one controlled variable and manipulated variable is called multivariable or multi-input and multi-output (MIMO) system¹. The modern industrial application such space heating, ventilation system², incubation chamber and chemical mixer where temperature and ventilation in a precise manner is essential. These have motivated the authors to design a real time temperature and flow system with the help of LABVIEW and myDAQ, which in the later part can be controlled by various control methods like Proportional-Integral-Derivative (PID), Model Predictive Control (MPC), Internal Model Control (IMC) etc. The aim is to design a MIMO system for temperature and flow control.

EXPERIMENTAL SETUP

This experimental setup shown in figure 1, is developed with 2-Y junction stainless steel pipe. One end of the structure is fixed with two 12V DC blowers. One blower is for flow control inside the system. Second blower is to produce process error for air flow. Other end of the structure is embedded with temperature sensor and flow sensor. The analogue output port of my DAQ- AO0 is connected to a 500-watt heater. As the heater is to run with 230-volt AC, and the my DAQ maximum output voltage is 10 V DC, so for isolation, a silicon control rectifier (SSR) is used in between my DAQ and the air heater. For temperature sensing, a thermistor of 10 kΩ has been placed and connected to the DAQ multi meter input port.

Similarly, analogue output port of myDAQAO1 is connected to one of the blower which is responsible for flow control inside the pipe. For flow measurement, indirect principle has been introduced. A CPU modified fan has been placed at the end of the pipe with a small white mark on one of its blade to be detected by an IR sensor. RPM of the CPU fan varies as per the flow rate and can be counted by the IR sensor. The linear flow and volumetric flow can be formulated. The IR sensor is connected to the analogue input port of my DAQ- AI0 (+) port.



Fig 1: Hardware setup

1. Temperature measurement

In this MIMO system, the temperature sensor used is thermistor NTC k +/-10% 10k ohm,having temperature range from -40°C to 200°C. Thermistor is connected to myDAQ Digital Multi meter port as shown in figure 2. This Thermistor is placed after the air heater. With the increase or decrease in temperature there is a change in resistance. This resistance is converted to temperature using Steinhart –hart equation.

$$\frac{1}{T} = A + B \ln(R) + C [\ln(R)]^3$$

The DAQ assistant has been chosen with the optimum setting under resistance mode to receive the data from thermistor. The graphical programing for temperature measurement is shown in figure 3. The constant values for A,B,C has been calculated.

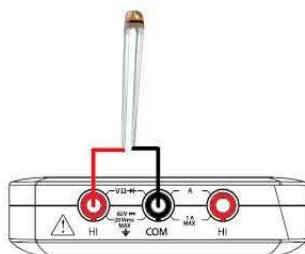


Fig 2: Thermistor wiring to NI myDAQ

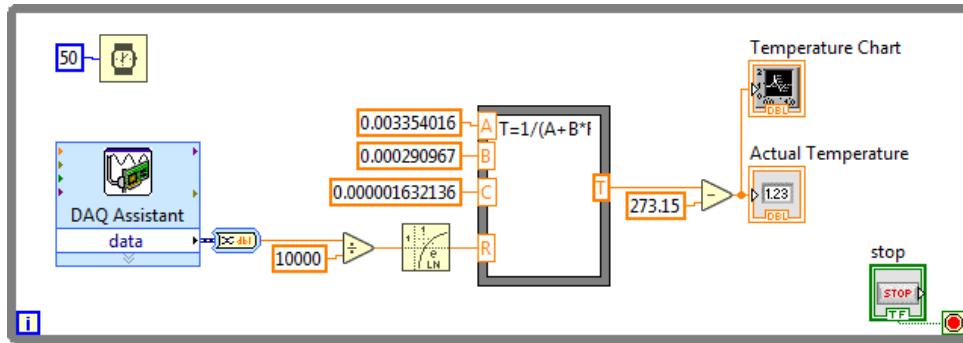


Fig 3: Temperature measuring block diagram in LabVIEW

2. Temperature loop

Electric heating is a process in which electrical energy is converted to heat. Air heater is used to heat the air with the following specification.

Type: Double ended type

Maximum Operating Temperature: Room temp to 150°C

AC Voltage Required: 230V

Wattage: 500W

Dimensions: 20 cm length

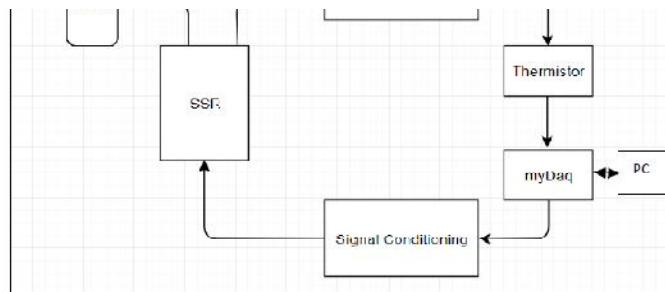


Fig 5: Temperature loop

Temperature loop shown in figure 5, consist of heater, thermistor, my DAQ, signal conditioning circuit, solid state relay (SSR), AC power. SSR is an electronic switching device that is used to control the AC loads as per the DC control signal. NI my DAQ Analog Output channel current specification is only 2 mA, which is not sufficient to drive the solid state relay (SSR) as the minimum current require is 9 mA. The input impedance is high in case of SSR and the knee Voltage is 1.8 voltage. Transistor DC biasing for the SSR is implemented to enhance the myDAQ voltage

signal. 230V power supply established across the air heater, when SSR is ON. LabVIEW continuously controls the air heater through SSR according to the temperature set point and measure the outlet air temperature and inlet air temperature with thermistors.

Disturbances like external heat provided by hot blower, environmental temperature, cool air from different sources etc. can be considered.

3. Flow measurement

In this system flow measurement is done by a flow meter designed with the help of a DC fan by removing its stator and rotor magnet to make it more frictionless. A white line mark has been provided to detect by IR sensor for RPM. 3.3 voltage is the output of IR sensor under ideal condition and 0 voltage under active condition.

Linear Flow rate and volumetric flow rate can be formulated from RPM value. According to the general fan law governing axial fans, linear flow rate, Foot per Minute (F/M) rate can be calculated by fan blade pitch (blade tilt or attack angle) with RPM³. Volumetric flow rate, Cubic Feet per Minute (CFM) to be calculated by knowing the fan blade diameter, pitch along with the rpm.

In this system, the fan to be used as flow meter shown in figure 6 has a Diameter of 7.3 cm /0.239501 foot and Blade tilt is 0.9 cm/0.0295276 foot.

Linear Flow Rate can be adjusted as: -RPM * 0.0295276 foot

Volumetric flow rate can be adjusted as: -Linear Flow Rate * $\pi*(D/2)^2$.

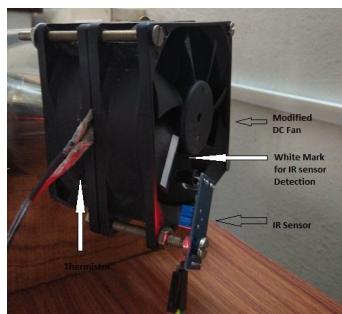


Fig 6: Flow meter design

The graphical programming for flow measure is designed by taking the voltage out from the IR sensor. Edge triggered concept have been introduced to find the number of times the white mark has detected by IR sensor. RPM is deducing by comparing the input voltage from IR sensor with a lower and upper value.

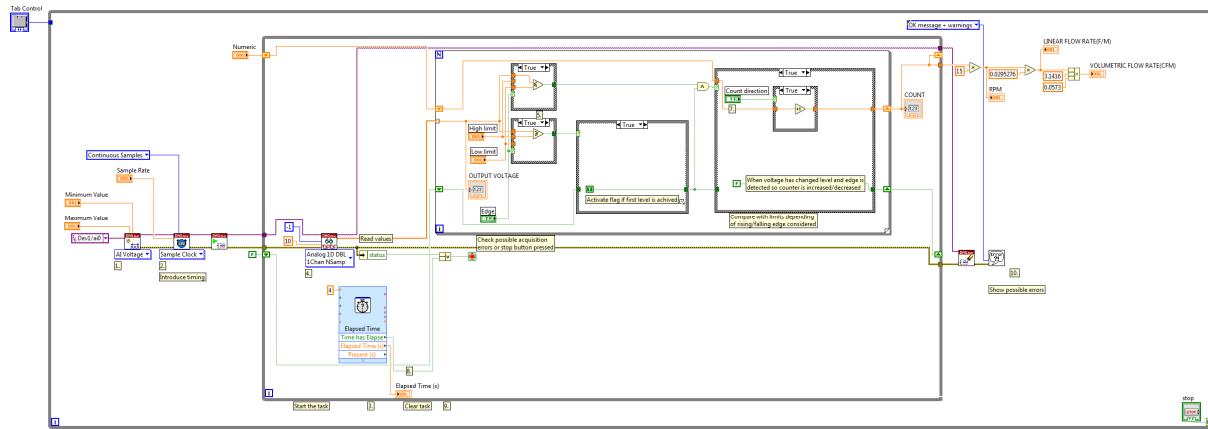


Fig 7: Flow measuring block diagram in LabVIEW

4. Flow loop

Flow loop shown in figure 8 consists of two blowers, flow meter, my DAQ, motor driver. One blower (fan 1) is used to control the flow of air inside the system during the process. Second blower (fan 2) is used as a flow disturbance inside the system. The second blower can be manually controlled by varying the input voltage through a potentiometer connected to it. As per the set point of linear flow or volumetric flow, LabVIEW transmits the pulse width modulated (PWM) signal to the motor driver to control the speed of blower.

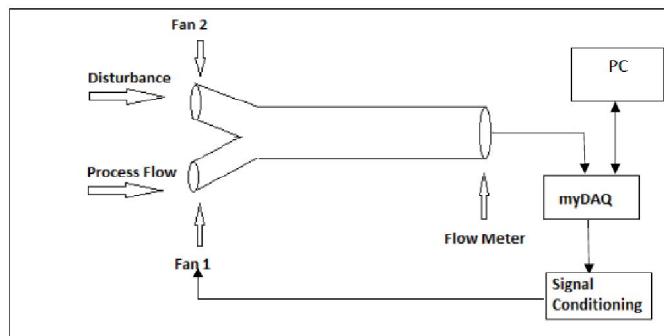


Fig 8: Flow loop

TEST, RESULTS AND DISCUSSION

1. Temperature test

We developed and tested our system with various way under minimum and maximum load. It should be noted that the test values are random numbers to analyse the response of each and every part of the system. We tested the system response for both the flow loop and temperature loop under open loop condition and closed loop condition.

Open loop test for temperature measurement as well as heater response is done by providing some random voltage signal to the my DAQ, in result it controls the input DC voltage of the SSR. As per the SSR voltage level, the heater voltage and corresponding temperature can be controlled. During the entire test the linear flow rate and volumetric flow rate were constant at 23.47 F/M and 4.22 CFM respectively.

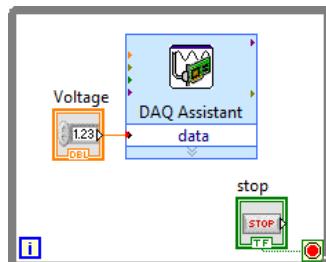
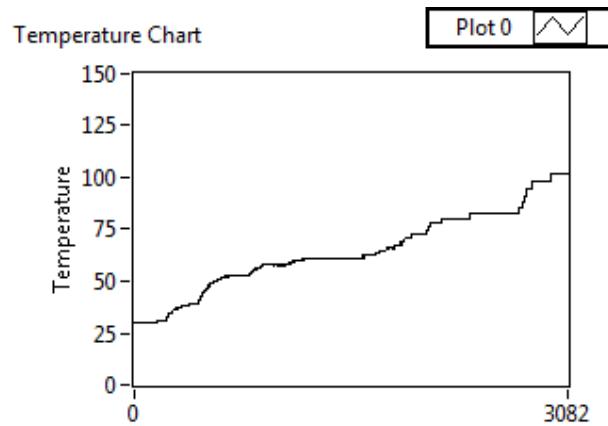


Fig 9- Open loop temperature test

Table 1: Input voltage vs temperature (°C)

SL NO	Voltage from myDAQ (V)	Drop Across SSR (V)	Temperature (°C)
1	0	0	28.7(room temperature)
2	1	1.16	28.7(room temperature)
3	3	1.68	28.7(room temperature)
4	3.6	1.82	28.7(room temperature)
5	3.7	1.84	34.9
6	3.8	1.86	41.32
7	3.9	1.88	54.4
8	4	1.90	59.9
9	4.1	1.92	63.21
10	4.2	1.94	63.21
11	4.3	1.96	64.39
12	4.4	1.98	74.42
13	4.5	2.00	82.20
14	4.6	2.02	84.6
15	4.7	2.04	100.01
16	4.8	2.06	104.20
17	4.9	2.08	104.20
18	5	2.10	106.4

**Fig 10: Temperature variation chart (°c)**

It is observed that the system is having large dead time, as the heater gets turn ON only, when the voltage is equal or above 3.7 V. The minimum temperature is obtained through this system is the room temperature and the maximum is 106.4 °C. When the voltage is 3.7 V, 34.9 °C is measured when the room temperature is 28.7 °C, but under the same voltage, 38.7 °C is measured when the room temperature is 32.3 °C. The system is affected with the environmental temperature and is considered as a prime disturbance as stated earlier.

The system is nonlinear in nature as the measured temperature is not in proportional with the input voltage. Utmost care should be taken while designing the controller for the system due to its huge dead time, nonlinear nature, various disturbances and interaction.

2. Flow test

Open loop test for flow measurement and blower response is achieved by providing the pulse width modulated (PWM) signal from the LabVIEW to a motor driver. The first blower (fan 1) is connected to the motor driver. During the entire test the disturbance (fan 2) was kept zero. Pulse Width Modulation, or PWM, is a technique for controlling analog systems with digital control. It generates a square wave signal fast switching between on and off. This pattern can average the voltages level in between maximum and zero. For variable analog values, pulse width needs to be changed. The maximum and minimum linear flow rate and volumetric flow rate are expressed in table 2

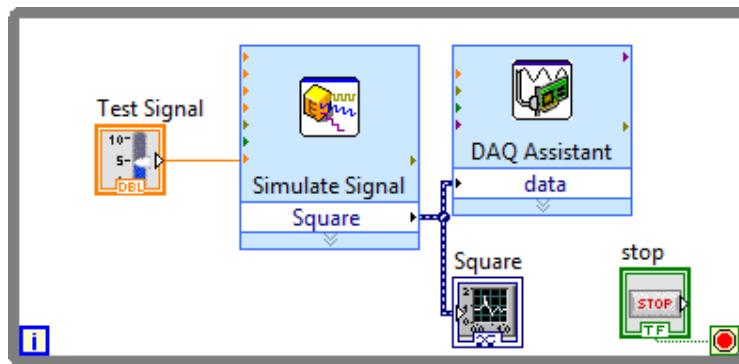


Fig 11: Open loop flow test

Table 2: Duty cycle vs linear & volumetric flow

Sl No	Duty Cycle	Linear Flow Rate	Volumetric Flow rate
1	100	23.47	4.22
2	90	15.05	2.71
3	80	13.28	2.39
4	70	10.95	2.15
5	60	10.62	1.91
6	50	8.85	1.59
7	40	7.08	1.27
8	30	3.98	0.71
9	20	2.27	0.39
10	10	NA	NA

Here the system is nonlinear in nature as the change of flow rates are not linear with the change in input PWM duty cycle. The designed flow measuring system is unable to measure any flow rate below 0.39 CFM.

CONCLUSION

The objective to design a MIMO system has been satisfied. Various test signals are used in temperature and flow control loop and got the expected response from the system. It has been found that the MIMO system is nonlinear in nature, which provides a good platform to design and test various control techniques.

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