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Fuzzy-Controlled Humidity Variation by Silica Gel and Nitrogen Gas in an Atmospheric Chamber

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ABSTRACT

Controlled humidity environment is of significance in many scientific researches and experiments. In most laboratory-scale atmospheric chambers, an electrical temperature-based control system is used to adjust humidity. Since these chambers are not affordable in every laboratory, other low cost chambers using nitrogen gas or silica gel are used to adjust humidity. In this paper, a mechanism was developed to control the relative humidity in closed lab-scale chambers. Humidification is done by spraying water through a blower fan while de-humidification is by pumping air through silica gel as well as nitrogen gas injection. A Mamdani type fuzzy controller was designed to control the components and relative humidity. The results show the proposed system and controller can adjust and maintain relative humidity from 41% to 100% with maximum overshoot of 1% and the maximum range of error of steady state of 1.2 %.

Keywords: Atmospheric chamber, humidity, silica gel, nitrogen gas, fuzzy controller

INTRODUCTION

In many laboratory processes, the effects of ambient humidity can have detrimental effects on research quality, effectiveness, visual appearance and results. Controlled humidity environments are important in many scientific researches and experiments such as electronics and semiconductors, chemistry, food processing, corrosion tests, and solar cell researches (Hoshino et al., 2013; Kim, 2012; Mekhilef et al., 2012). Humidification is done by heating or spraying water as well as through ultrasonic vaporisation (Yasuda et al., 2011). Since these chambers are usually expensive, other physical and chemical ways are used to reduce and control humidity.

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Injecting nitrogen gas, N_2 is a method of dehumidification in closed chambers. The vapour-air mixture is pushed or eliminated out of the chamber by gradually injecting nitrogen gas into the chamber. Since N_2 is logically a dry gas and neither reacts with stored materials nor carries moisture, it has a wide usage in controlling and maintaining humidity levels in its surrounding environments such as dry boxes, archives and cleanroom (Yeager, 2008). Another solution, which is used for de-humidification in laboratories, is absorbent materials. Saturated salt solutions are a traditional way to absorb water vapour in a closed box or chamber (Young, J. F., 1967; Collins, A., 2012). Silica gel is an adsorbent when the relative humidity is in the range of 50–80% (Pramuang et al., 2007). Silica refers to a naturally occurring mineral that consists of silicon dioxide (SiO2), which is a product of a chemical reaction between silicon and oxygen (Waksmundzka-Hajnos et al., 2010). An important characteristic of silica gel is that it can reversibly adsorb large volumes of vapour through regeneration (Zhang et al., 2011), which offers a low-cost solution for de-humidification in closed environments (Brody et al., 2008).

This work presents a new control system, which has not been done before, for controlling the relative humidity in a closed atmospheric chamber. A control system is developed using these low-cost materials for having an inexpensive humidity controlled chamber since the traditional way does not provide a precise and easy-to-use solution for controlling humidity in closed chambers. N_2 and silica materials are good for humidity setting in the chamber and therefore, a proper control and monitoring should be set up for this chamber.

METHODOLOGY

Relative humidity (RH) of an air-water mixture is described mathematically as the ratio of the partial pressure of H_2O vapor (e_w) in the air-water mixture at a certain temperature to the saturated vapour pressure of H_2O (e^*_w) at that temperature. The RH is normally represented as a percentage (RH %). Equation (1) shows how RH % is calculated:

$$\text{RH\%} = \frac{e_w}{e^*_w} \times 100\% \quad (1)$$

According to (1) and definition of RH, the saturated vapour pressure of water (e^*_w) is a constant parameter and it depends only on the temperature. Therefore, to increase and decrease the RH % at a constant temperature, a certain amount of water vapour needs to be injected or removed from the air-water mixture. The humidity control system consists of two parts: humidifier and dehumidifier.

Overall Operation

The RH control system consists of humidifier and de-humidifier parts, which can add and absorb water vapour respectively. A closed-loop control system is needed for adjusting and maintaining the amount of RH inside the chamber. A standard humidity/temperature meter (TES-1360A) was used to provide the feedback of RH% and the temperature respectively at every 300 milliseconds. The sensor was installed on the test bed and near the tested sample.

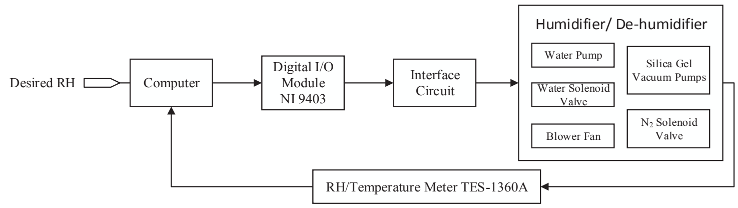


Figure 1. Block diagram of interconnection between components

Figure 1 shows the interconnection between components. The desired RH is the input of the control system, which is defined by the user. The control system algorithm is implemented using LabVIEW 2012 software and Fuzzy Toolbox. The output of the control system commands the humidifier and de-humidifier using NI cDAQ-94 and the interface circuit. The design of the controller will be discussed in in the next section.

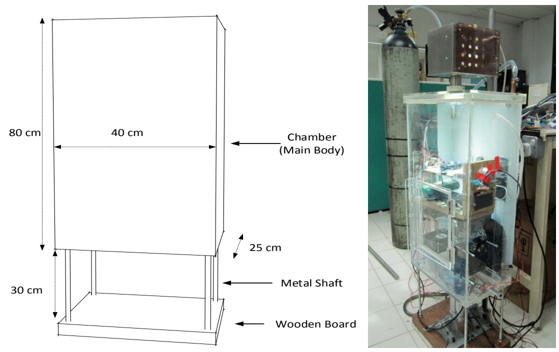
Physical Characteristics of the Chamber

The chamber which is used here is a close cube made from acrylic glass with 12mm thickness. The size of the cube is 80 cm × 40 cm × 25 cm (Height × Width × Length) as shown in Figure 2. The cube was installed with the distance of 30 cm from the wooden panel by using 4 metal shafts. The chamber was designed to be isolated from the air entering from the outside. There are two ways to access inside the chamber i.e. from the top and from the front door. The topside of the chamber is designed like a cap, which is used for installation of components. The front door has been designed to put the samples (such as a solar cell device) inside the chamber. The doors are isolated with isolation strips.

RESULTS AND DISCUSSION

The humidifier and de-humidifier components are connected to data acquisition module by using the interface circuit shown in Figure 3. The entire system is controlled by the computer (controller). The RH/Temp meter device provides the feedback. In order to design the controller, the whole of the chamber is considered as a black box. In science and engineering, a black box is a device, system or object which can be viewed in terms of its input, output and transfer characteristics without any knowledge of its internal workings (Ljung, L., 1998).

A fuzzy controller was designed to control the Relative Humidity (RH) inside the chamber. The fuzzy controller was set up in LabVIEW as a two-input, one-output structure. Figure 3 shows the two-input single-output fuzzy controller. The assembled fuzzy system is Mamdani type. The Mamdani method (most commonly used) was among the first fuzzy control systems built using the then new fuzzy set theory. It is widely accepted because it utilises expert knowledge and represents the expertise in a more intuitive, human- like manner. It provides an additional degree of freedom and expects the output membership functions to be fuzzy and use the centroid de-fuzzification method (Radakovic et al., 2002). Fuzzification helps us to evaluate the rules, but the final output of a fuzzy system has to be a crisp number. The input for defuzzification is the aggregate output fuzzy set and the outcome is a single number. There



(a) (b)

Figure 2. (a) Physical dimensions of the chamber; (b) A total view of the constructed chamber

are several defuzzification methods but the most popular is the centroid technique (or centre of gravity). Here, the first input is the Relative Humidity error (RHe), which is calculated by subtracting the current value of RH% from the desired RH%. The second input is the derivative of RH (dRH/dt), which presents the changing rate of the error. The output variable is the increment of power of the humidifier and de-humidifier.

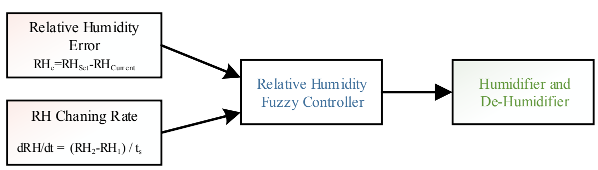


Figure 3. Inputs and output of the relative humidity Mamdani-type fuzzy controller

Membership Functions

Figure 4 shows the membership functions of the RH error. The functions information is tabulated in Table 1. The fuzzy variable RH error consists of negative, zero and positive values. For example, if the negative values show the set point of the RH is less than the current RH in the positive values mean the system needs to increase the RH to reach the set point.

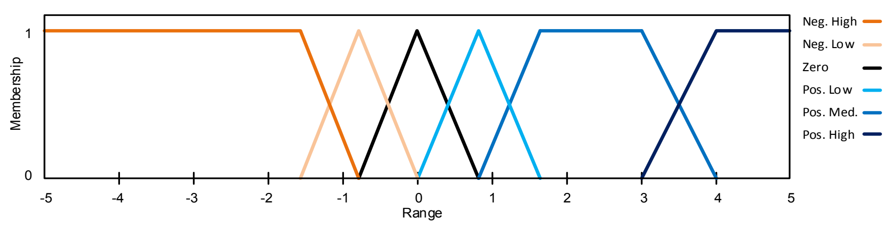


Figure 4. Membership functions of the relative humidity Error

Table 1
Membership functions of the relative humidity error

Membership function	Shape	Points
Negative High	Trapezoid	-100 ; -100 ; -1.6 ; -0.8
Negative Low	Triangle	-1.6 ; -0.8 ; 0
Zero	Triangle	-0.8 ; 0 ; 0.8
Positive Low	Triangle	0 ; 0.8 ; 1.6
Positive Medium	Trapezoid	0.8 ; 1.6 ; 3 ; 4
Positive High	Trapezoid	3 ; 4 ; 100 ; 100

The membership functions of the RH changing rate was designed by using the calculated derivative of RH increment and decrement. Figure 5 shows the membership functions of the second fuzzy input. Table 2 presents information regarding membership functions.

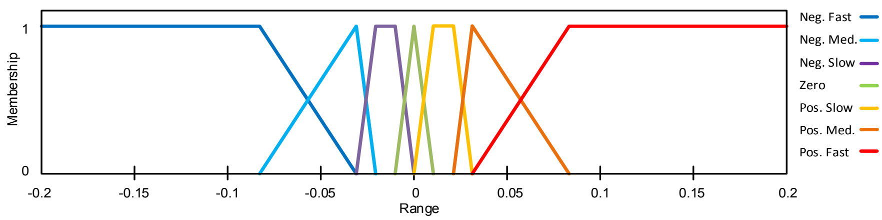


Figure 5. Membership functions of the relative humidity changing rate

Table 2
Membership functions of the relative humidity changing rate

Membership function	Shape	Points
Negative Fast	Trapezoid	-1 ; -1 ; -0.08 ; -0.03
Negative Medium	Triangle	-0.08 ; -0.03 ; -0.02
Negative Slow	Trapezoid	-0.03 ; -0.02 ; -0.01 ; 0
Zero	Triangle	-0.01 ; 0 ; 0.01
Positive Slow	Trapezoid	0 ; 0.01 ; 0.02 ; 0.03
Positive Medium	Triangle	0.02 ; 0.03 ; 0.08
Positive Fast	Trapezoid	0.03 ; 0.08 ; 1 ; 1

Figure 6 shows the membership functions of the output. The output of the controller is divided into six integer values, which is described in Table 3. Each output value enables one or two components of the humidifier or de-humidifier as well as disables other components.

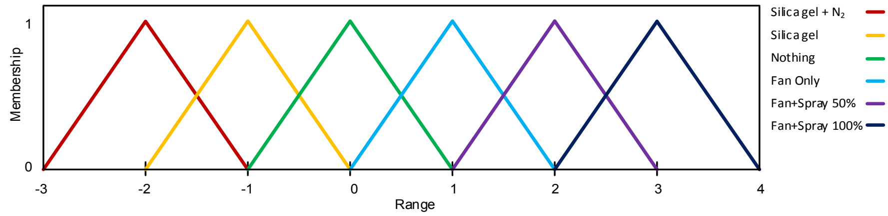


Figure 6. Membership functions of the output of the relative humidity controller

Table 3
Membership functions of the output of the relative humidity controller

Membership function	Shape	Points
Silica Gel Vacuum Pumps + N2 Injection	Triangle	-3 ; -2 ; -1
Silica Gel Vacuum Pumps	Triangle	-2 ; -1 ; 0
Nothing	Triangle	-1 ; 0 ; 1
Humidifier Fan Only	Triangle	0 ; 1 ; 2
Fan + Water Spraying at Duty Cycle 50%	Triangle	1 ; 2 ; 3
Fan + Water Spraying at Duty Cycle 100%	Triangle	2 ; 3 ; 4

Fuzzy Rules

The initial rules are defined based on the expert's knowledge regarding how to control the system using the linguistic quantifiers. There is a finite number of possible rules since we used a finite number of linguistic variables and values (Aguilar et al., 2012). Table 4 shows the initial rules that were selected for the fuzzy controller.

Table 4
Fuzzy rules of the relative humidity fuzzy controller

Error change Error	Negative High	Negative Low	Zero	Positive Low	Positive Medium	Positive High
Negative Fast	Silica Gel + N2	Silica Gel	Nothing	Fan + spray 100%	Fan + spray 100%	Fan + spray 100%
Negative Medium	Silica Gel + N2	Silica Gel	Nothing	Fan + spray 100%	Fan + spray 100%	Fan + spray 100%
Negative Slow	Silica Gel + N2	Silica Gel + N2	Nothing	Fan + spray 100%	Fan + spray 100%	Fan + spray 100%
Zero	Silica Gel + N2	Silica Gel + N2	Nothing	Fan + spray 100%	Fan + spray 100%	Fan + spray 100%
Positive Slow	Silica Gel + N2	Silica Gel + N2	Nothing	Fan + spray 100%	Fan + spray 100%	Fan + spray 100%
Positive Medium	Silica Gel + N2	Silica Gel + N2	Nothing	Fan only	Fan + spray 50%	Fan + spray 100%
Positive Fast	Silica Gel + N2	Silica Gel + N2	Nothing	Nothing	Fan only	Fan + spray 100%

Control Diagram

Figure 7 shows the final block diagram of the designed RH controller. The input of the control system is the desired value of the relative humidity and the output is the actual value of RH. A function is used to round the output values since the output should be an integer value, which is between -2.49 and 3.49 to the nearest integer values.

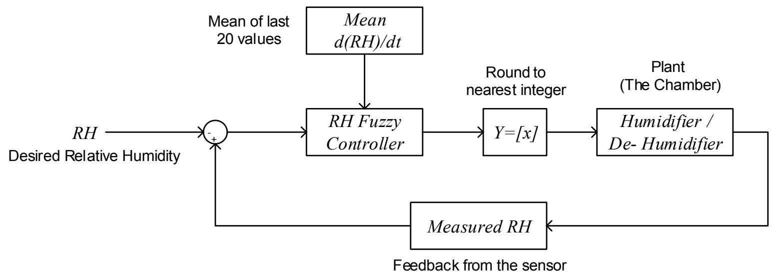


Figure 7. Control diagram of the relative humidity control system

Operation and Analysis

In this experiment three different set points of RH% were selected to be controlled; 60%, 100% and 80%. The temperature was kept at 26.5 °C (the lab temperature).

Achievable Relative Humidity Values

Another experiment was designed to find the achievable amount of relative humidity at the laboratory's temperature. First, the humidifier was conducted without the controller to reach the maximum amount of RH. Then, using the de-humidifier and without controller, the system was performed until the minimum amount of RH was reached. At the laboratory's temperature (26.5°C), the maximum and the minimum achievable amount of relative humidity were obtained as 100% and 41% respectively.

Maximum Overshoot, Steady-State Error and Settling Time

The maximum overshoot and steady state error values are of significance to find the precision of the proposed RH control system at steady-state mode. Table 5 shows the measured maximum overshoot and range of steady-state error plus settling time at 26.5°C and different RH set-points. The maximum overshoot and the maximum range of error of steady state are obtained as 1.1% and 1.4% respectively.

Table 5
Overshoot and steady-state error and settling-time of the RH control system

Temperature (°C)	RH% set-point	Maximum Overshoot	Steady-State Error (Range)	Settling-Time (Seconds) From 41%	Settling-Time (Seconds) From 100%
	60	1	1.2	128	532
26.5	80	0.9	1.1	320	186
	100	0	0.5	1140	0

CONCLUSION

This paper has presented a new mechanism to control relative humidity in atmospheric chambers without changing the temperature. A mechanism was designed to absorb water vapours and de- humidify the chamber which decrease RH by pumping air through silica gel as well as by using N_2 gas injection. In order to have precision RH adjustment, a Mamdani fuzzy controller was employed in LabVIEW platform. It is to control the components using the digital output module and designed interface circuit. The results have shown that the proposed system and controller can adjust and maintain RH from 41% to 100% (most working activities) with maximum overshoot of 1% and the maximum range of error of steady state of 1.2 %.

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