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Fuzzy logic approach to provide safe and comfortable indoor environment

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Abstract

The paper presents a fuzzy logic approach that aims to control the indoor air quality to provide a safe and comfortable environment. The proposed approach evaluates the current situation based on installed sensors and consequently provides the proper action(s) to keep the indoor environment safe and comfortable for living. Inputs for the fuzzy controller include measurements from temperature and humidity sensors to boost comfort, and that from toxic odors sensors to enhance safety. Controller's outputs include signals to the air conditioning unit (AC), ventilation system, and humidifier/de-humidifier, in addition to visual/audio warning alerts in case of dangerous situations. To validate the usability of the controller, various combinations of buildups of heat, humidity, and odors are investigated. Results obtained from the simulation studies illustrate the robustness of the proposed controller at the different input scenarios.

Keywords: Indoor air quality; thermal comfort; safe environment; fuzzy logic.

1. Introduction

Recently, several studies concerning providing safe or comfortable indoor environment have been conducted. Qi and Deng (2009) developed a multi input, multi output control strategy for simultaneously controlling the indoor air temperature and humidity. They used the linear quadratic Gaussian technique in designing the controller. Li *et al*. (2006) developed a simulation study on the characteristics of space cooling load and indoor humidity control for residences in the subtropics using a building-energy simulation program.

The Fuzzy set theory is a generalization for the classical set theory and was introduced by Lutfi Zadieh in 1965. It allows linguistic variables whose values are words rather than numbers to map input space to output space where a variable can partially belong to the set with a membership value between 0 and 1 (Zadeh, 1992). Fuzzy controllers allow the interaction of multiple inputs to approximate the value of the output. Hence, Fuzzy controllers are largely employed in various applications. Recently, fuzzy control techniques have become an alternative design direction for many control problems. The main advantage of the fuzzy controllers is its ability to deal with nonlinear systems. Fuzzy controllers find many applications in industry, appliances, and security applications. Jaradat and Al-Nimr (2009) utilized a fuzzy controlled vacuum fan to control levels of unwanted gases and odors in naturally ventilated environments. Al-Araidah *et al*. (2010) presented a fuzzy Poka-yoke based controller that prevent, alert and control toxic gas levels in confined areas. The controller provides the appropriate amount of fresh air to the polluted indoor environment based on the levels of the oxides sensed by gas detectors. The aforementioned system consists of gas sensors, a bush-pull fan set mounted at an air inlet, and a controller to control the speed and cycle time of the DC-motorized fans. Examples from the literature on existing studies focusing on the use of Heating Ventilation and Air Conditioning (HVAC) systems where the quality of the air is monitored and controlled by various classical control methods or intelligent approaches can be found in Jaradat and Al-Nimr (2009), Al-Araidah *et al*. (2010), Al-Jarrah (2004), and Hamdi and Lachiver (1998).

The paper presents a control system to enhance safety and comfort in indoor environments. The proposed controller utilizes Fuzzy logic to control the levels of indoor temperature, humidity, and toxic odors measured by sensors mounted in the targeted indoor space. Outputs signals from the controller target the air conditioning system (AC), humidifier/dehumidifier, and the evacuation fan system. The system aims at providing a safe and comfortable living/operating space while at the same time saving energy.

The rest of the paper is organized as follows. Section 2 presents the required measurements that will be needed for the controller. Section 3 discusses the fuzzy controller. Section 4 provides results attained from experiments to assess the performance of the model. Concluded remarks are presented in the last section.

2. Methods and Materials

In this system, the values of indoor temperature, humidity, and concentration levels of toxic gases are the needed inputs. The following subsections describe in more details the required measurements and the fuzzy logic controller used in this study.

2.1 Required Measurements: High or low humidity makes people feel uncomfortable especially when it is associated with uncomfortable temperature levels. It is recommended to keep humidity within certain limits especially for people who suffer from health problems such as asthma. Hence, a humidifier (de-humidifier) is needed in case of low (high) humidity levels. Recommended relative indoor humidity values range between 30% and 60% (Engineering Toolbox. Relative Humidity, 2010). Several humidity sensors are available in the market including capacitance humidity sensors and resistance humidity sensors. It is recommended to use the capacitance humidity sensor for it is more rugged, less dependent on temperature and provide linear capacitance change with relative humidity. To calculate the value of absolute moisture, such as vapor pressure or dew point, a measurement of the temperature is required for all relative humidity sensors (Doebelin, 2003). Several types of temperature sensors are available in the market with electrical resistance thermometers being most recommended. Electrical resistance thermometers exhibit an increase in the electrical resistance as temperature increases (Figliola and Beasley, 2006). The optimum indoor temperature value would be around 20 – 22 °C (Engineering Toolbox. Indoor Temperature, 2010).

Toxic odors may be produced by various recourses including heating and sewer systems, fire, dry cleaning, products outgassing, outdoor pollution, or other activities. Carbon monoxide (CO) and carbon dioxide (CO_2) are among the most common toxic matters indoor odors. CO is a significantly toxic gas responsible for 50% of fatal poisoning in many industrialized countries (Omaye, 2002). CO forms from the partial combustion of organic matter when there is a reduced availability of oxygen present during the combustion process and has no odor, taste, or color that makes it hard to people to detect. Common types of CO detectors include biomimetic, electrochemical, and semiconductor sensors (Al-Araidah *et al*., 2010). CO_2 is a colorless, odorless gas generated during respiration and as a byproduct of the combustion of fossil fuels. Common types for CO_2 detectors include infrared gas sensors and chemical gas sensors. Infrared CO_2 measures the concentration of the gas based on the change of the characteristic wavelength of the infrared light. A chemical CO_2 gas sensor consists of layers sensitive to the presence of CO_2. Increased levels of CO and CO_2 are fatal for people inside confined spaces and symptoms experienced by people depend on the concentration level of the gas. Since these gases are hard for people to detect and judge the severity of such situations, sensors are required to measure the concentration of the gas so that proper actions can be taken before any loss can happened (Al-Araidah *et al*., 2010).

2.2 Fuzzy logic controller: Fuzzy controllers are largely employed in industry for they allow the interaction of multiple inputs to approximate the values of multiple outputs. Recently, Fuzzy control techniques have become an alternative design direction for many control problems. The main advantage of the Fuzzy controllers is its ability to deal with nonlinear systems (Al-Jarrah, 2004). In this paper, we utilize Fuzzy logic to signal the AC, humidifier/de-humidifier, ventilation system (evacuation fan), in addition to an audio/visual alert system in case of dangerous situations.

The proposed controller aims to provide a safe and comfortable environment with highest priority goes to safety. For instance, in the presence of toxic matters, the system gives priority to warning people indoor and exchanging air by turning on the evacuation fan at its highest capacity, while at the same time turning off all other devices regardless of humidity and temperature levels. On the other hand, the evacuation fan is turned off if the concentration level of odor is very low and the fuzzy controller decides on the working capacities of the other devices. If odor levels are at its low to medium ranges, then the fuzzy controller decides on the speed of the evacuation fan. In addition, the humidifier/dehumidifier is turned off if humidity is at its acceptable level range. These measures help save energy while maintaining safety and comfort.

Fuzzy controllers use verbal IF-THEN rules to express relationships among inputs and outputs. A standard form of a verbal rule is **IF** $\boldsymbol{X}$**=** $(x_1, x_2, \ldots, x_n)$, **THEN** $\boldsymbol{Y}$**=** y_1. Furthermore, Fuzzy logic utilizes **AND**, **OR**, and **NOT** to describe relationships and hence action is executed by the controller if all rules are satisfied. Input values are converted to values between 0 and 1 using membership functions for input values. The values of output variables are then estimated based on the embedded expert knowledge of the behavior of the system. Subsequently, the inference mechanism computes the degree to which input data fits the conditions of the Fuzzy rules and rules' conclusion based on the matching degree combining all inferred rules into a single conclusion. Finally, Fuzzy outputs are mapped to a specific action.

In this research, five Gaussian membership functions describe the levels of temperature and humidity. These five Gaussian membership functions include "Low" (*L*), "Medium Low" (*ML*), "Medium" (*M*), and "Medium High" (*MH*); and "High" (*H*); $\mu_L, \mu_{ML}, \mu_M, \mu_{MH}, \mu_H$ (μ denotes the membership function), respectively. Two Gaussian membership functions describe the odor level. These two Gaussian membership functions include "Low" (*L*), and "Medium" (*M*); μ_L, μ_M (μ denotes the membership function), respectively.

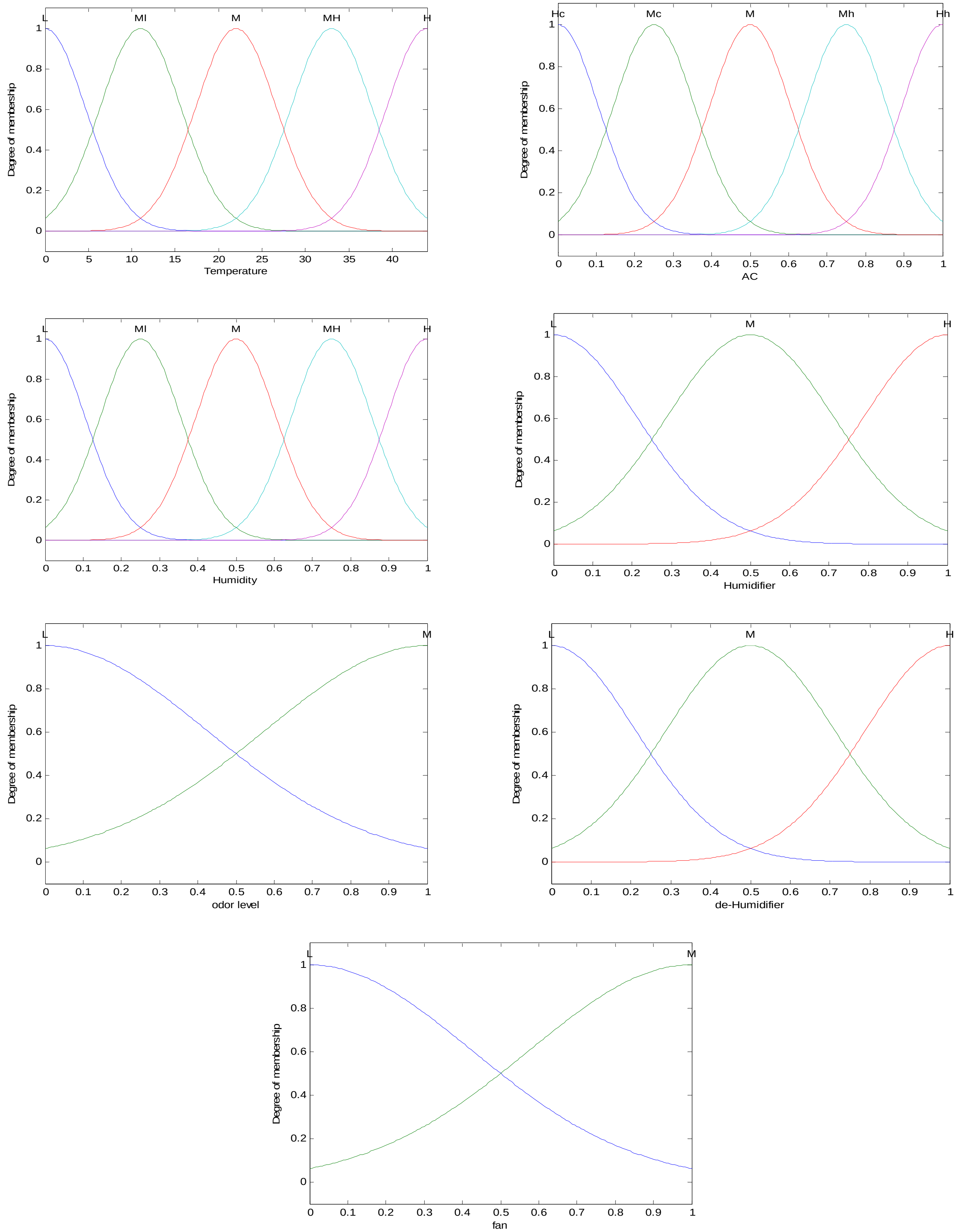

Figure 1. Membership functions for input and output variables.

The AC system is described by five Gaussian membership functions including "High cooling" (*Hc*), "Medium cooling" (*Mc*), "Medium" (*M*), "Medium heating" (*Mh*), and "High heating" (*Hh*); $\mu_{Hc}, \mu_{Mc}, \mu_{M}, \mu_{Mh}$, and μ_{Hh} (μ denotes the membership function), respectively. The humidifier and dehumidifier are described by three Gaussian membership functions include "Low" (*L*), "Medium" (*M*), and "High" (*H*); $\mu_{L}, \mu_{M}, \mu_{H}$, respectively. The evacuation fan is described by two Gaussian membership functions include "Low" (*L*), "Medium" (*M*); μ_{L}, μ_{M} , respectively. The fan can also switch into its highest capacity as mentioned before in case of dangerous situation to provide safe environment. Figure 1 illustrates the membership functions for the input and output variables. The alert system will be either off or on. Table 1 illustrates sample environment conditions at each level of inputs and the action(s) required at each scenario.

Table 2 presents the Fuzzy rules used in this research. Twenty seven expert rules are developed based on possible scenarios of input states. For instance, if the temperature is high, humidity is high and odor level is low then the AC will be operating on high cooling mode, the dehumidifier will be operating on its high mode and the fan will operating in its low capacity. However, if the temperature is high, humidity is high and odor level is high, then the evacuation fan works at its highest capacities and the AC and dehumidifier are turned off. The relationships between inputs and outputs are selected based on user expert information, these relations in addition to the comfortable ranges can be user defined. Table 2 shows all the expert rules required to provide the appropriate Fuzzy output for the system by the Fuzzy engine. The Mamdani min-max inference engine is used throughout the simulation time. The bisector is used to map Fuzzy outputs to a single point. Figure 2 shows the resulting Fuzzy surfaces representing the relationship between the inputs and outputs.

Table 1. Sample environmental conditions associated with inputs to controller and proposed actions to enhance safety and/or comfort

Temperature	Humidity	Odor	Environment Condition(s)	Action
low	low	Very low	very cold & very dry with very low concentration of odor	AC: heating at high capacity Humidifier: high capacity Dehumidifier, fan & alert: Off
medium low	low	Very low	Cold & very dry with very low concentration of odor	AC: heating at high capacity Humidifier: high Dehumidifier, fan & alert: Off
medium	high	Low	Acceptable temperature & very moist, with low concentration of odor	AC: Medium Dehumidifier: medium Fan: low Humidifier and alert: Off
medium high	medium high	Medium	Hot and moist with medium concentration of odor	AC: cooling at medium capacity Dehumidifier: medium Fan: medium Humidifier and alert: Off
medium	medium high	Medium	Acceptable temperature & moist with medium concentration of odor	AC: medium capacity Dehumidifier: low Fan: medium Humidifier and alert: Off
high	low	Very low	Very hot & very dry with very low concentration of odor	AC: cooling at high capacity Humidifier: high Dehumidifier, fan & alert: Off
high	high	High	Very hot and moist in with high concentration of odor	AC, Humidifier, & dehumidifier: Off Fan: high capacity Alarm: On
low	low	High	very cold and very dry environment with high concentrations of odor	AC, Humidifier, & dehumidifier: Off Fan: high capacity Alarm: On

3. Experimental Results

In this section, we present results obtained from simulating the performance of the proposed controller. To this end, three scenarios are conducted to evaluate the proposed approach in a similar real life situation. Each scenario is detailed and the results are presented. The first scenario represents the situation in winter where it is cold and dry. At the same time, a buildup of odor gases is taking place possibly due to the presence of a heating unit. The second scenario illustrates the case an early summer day where temperature measures medium to high, humidity measures low to medium during the time interval. At the same time, a buildup of the odor gases is taking place but stays below threatening levels. The third scenario represents a hot and humid summer day and odor gases are building up to threatening levels at the end of the time-period.

Figure 3 presents the first scenario; the suggested profiles for inputs during a time interval are shown in figure 3a and 3b. During this time interval, temperature and humidity are at their low levels while the odor level is increasing but not approaching a high threatening level. This situation represents a cold and dry environment with a buildup of odor gases; this usually occurs during winter times. The controller actions are shown in figure 3c: the AC unit is turned on to heat the space; first, AC starts at high heating capacity and as temperature increases heating capacity decreases. Likewise, the humidifier is turned on at its highest capacity and as humidity increases humidification capacity decreases. As odor level increases, fan is turned on at a capacity changing from low to medium depending on the odor level. The dehumidifier and the alarm are turned off at this situation.

Table 2. Fuzzy rules applied to the control system.

Expert rules used by the fuzzy system for AC.						
		Temperature level				
	Output AC	L	ML	M	MH	H
Humidity	L	*Hh*	*Hh*	*M*	*Hc*	*Hc*
	ML	*Hh*	*Mh*	*M*	*Mc*	*Hc*
	M	*Hh*	*Mh*	*M*	*Mc*	*Hc*
	MH	*Hh*	*Mh*	*M*	*Mc*	*Hc*
	H	*Hh*	*Hh*	*M*	*Hc*	*Hc*

Expert rules used by the fuzzy system for Humidifier.						
		Temperature level				
	Output Humidifier	L	LM	M	MH	H
Humidity	L	*H*	*H*	*M*	*H*	*H*
	ML	*H*	*M*	*L*	*M*	*H*
	M	*none*	*none*	*none*	*none*	*none*
	MH	*none*	*none*	*none*	*none*	*none*
	H	*none*	*none*	*none*	*none*	*none*

Expert rules used by the fuzzy system for de-Humidifier.						
		Temperature level				
	Output de-Humidifier	L	ML	M	MH	H
Humidity	L	*none*	*none*	*none*	*none*	*none*
	ML	*none*	*none*	*none*	*none*	*none*
	M	*none*	*none*	*none*	*none*	*none*
	MH	*H*	*M*	*L*	*M*	*H*
	H	*H*	*H*	*M*	*H*	*H*

Expert rules used by the fuzzy system for evacuation fan.			
		Odor level	
	Output Fan	L	M
		L	*M*

Figure 4 presents the second scenario. The suggested profile for inputs during the time interval is shown in figures 4a and 4b. During the time interval, temperature measures medium to high, humidity measures low to medium, and odor increases to levels below threatening. Controller actions are shown in figure 4c: the AC unit is turned on at medium to low heating capacity until the desired temperature level is met. Likewise, the humidifier starts at its medium capacity that decreases as humidity increases. At acceptable humidity range, the humidifier is turned off. On the other hand, fan' capacities increase from low to medium as odor level increases. The dehumidifier and the alarm system are turned off at this situation.

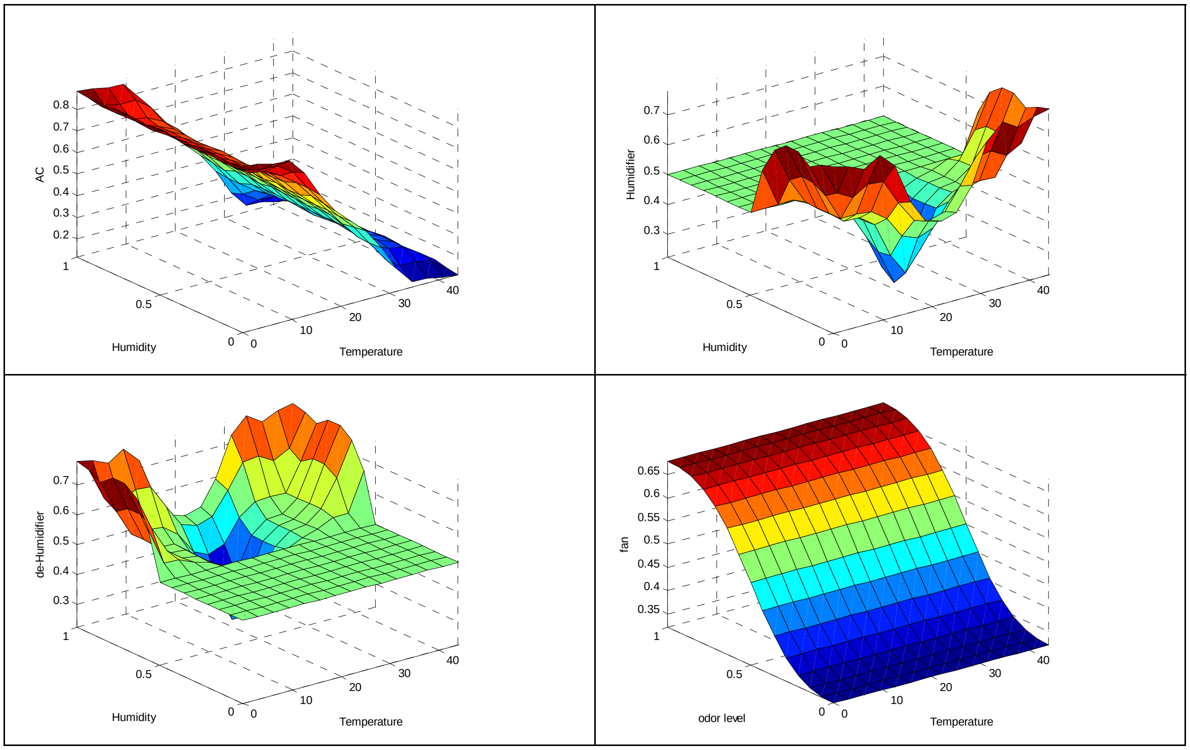

Figure 2. Fuzzy surfaces and output inferences for Fuzzy rules.

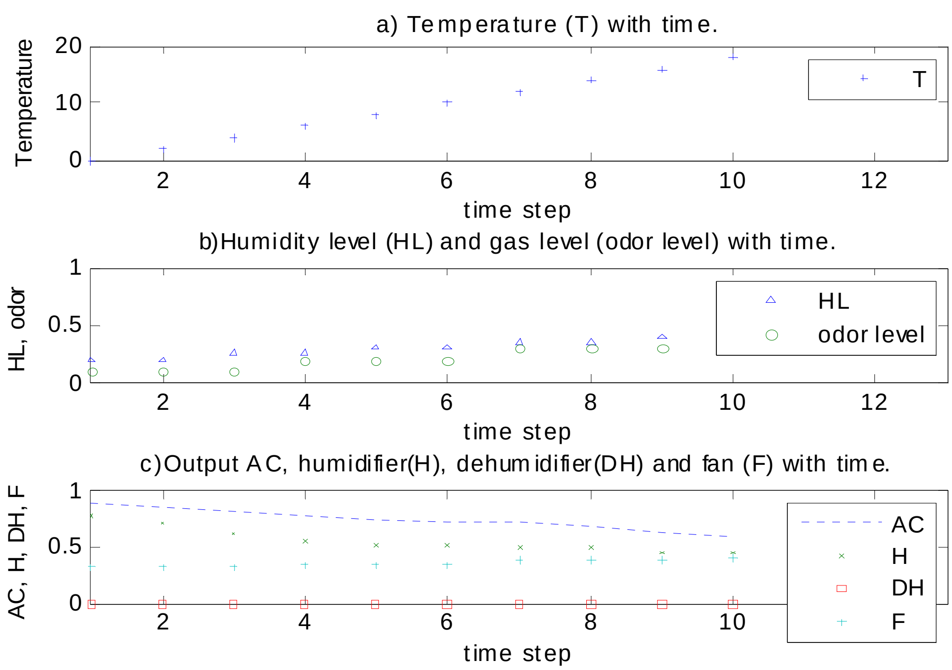

Figure 3. Controller inputs and outputs during a time interval for the first scenario.

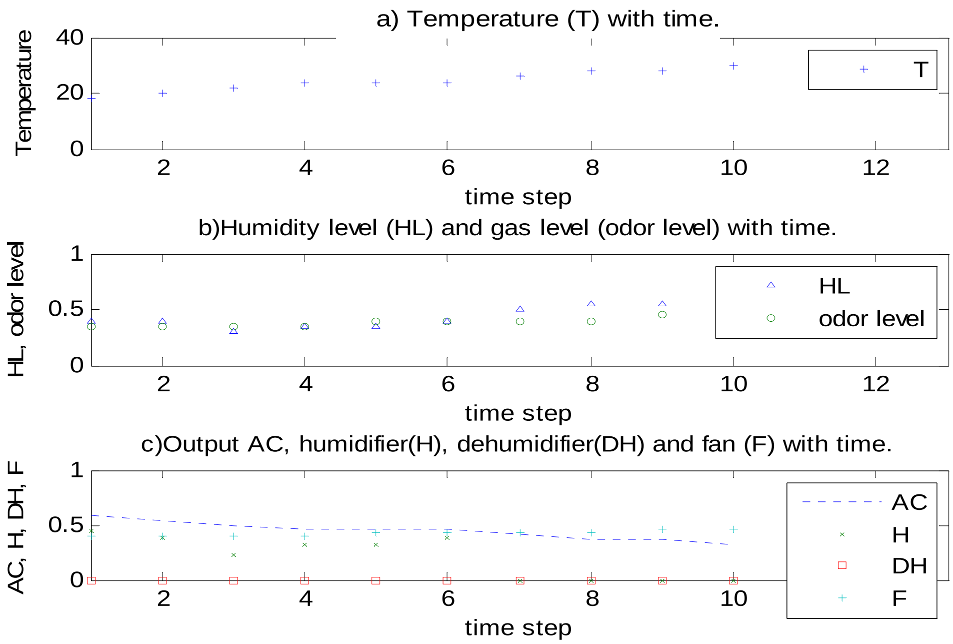

Figure 4. Controller inputs and outputs during a time interval for the second scenario.

Figure 5 presents the third scenario; the suggested profile for inputs during the time interval are illustrated in figures 5a and 5b. During this time interval, temperature and humidity are increased representing a high and moist environment. At the same time, the odor level increases to a threatening at the end of the period. Controller actions are shown in figure 5c: the AC is turned on at the required cooling capacity based on the temperature, the dehumidifier is turned on to decrease the humidity level, and the fan is turned on to evacuate unwanted matters. When the odor level becomes threatening, the AC and dehumidifier units are turned off while the fan operates at its highest capacity. In addition, an alert is issued to warn the people indoor of the dangerous situation. The humidifier is turned off at this situation.

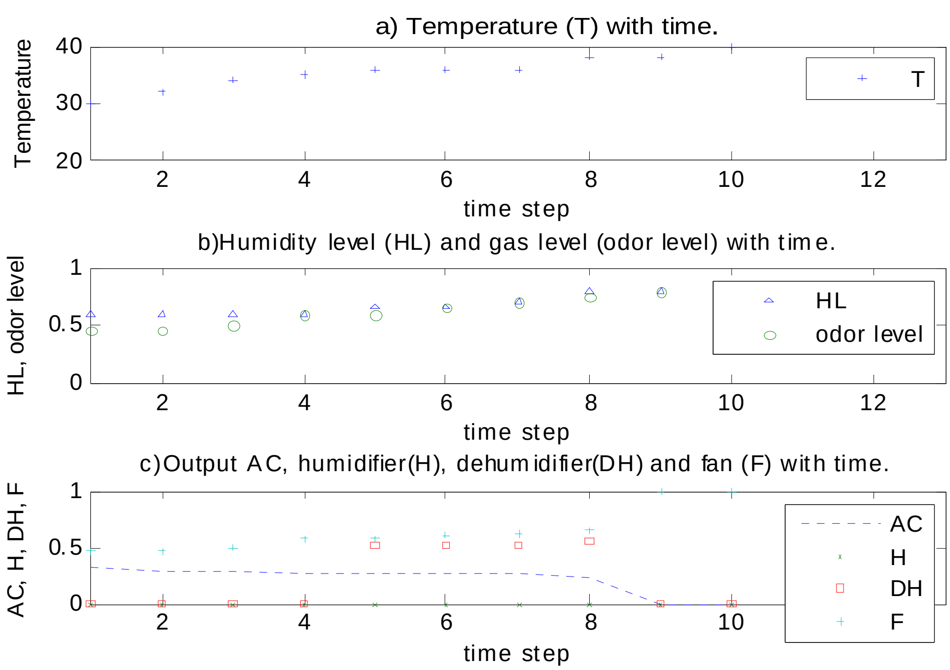

Figure 5. Controller inputs and outputs during a time interval for the third scenario.

4. Summary and Conclusions

In this paper, we present a fuzzy logic based air quality controller to provide a safe and comfortable indoor environment. The proposed system overcomes limitations of human senses in evaluating temperature and humidity levels in addition to detecting the presence of toxic odors through the use of artificial sensors. Furthermore, the system provides proper actions taken by the air conditioning system, humidifier, dehumidifier and the evacuation fan in order to keep the indoor environment safe and comfortable for occupants. Unlike classical controllers, fuzzy logic controllers allow the interaction of multiple inputs and multiple outputs. Results obtained from testing the model on simulated scenarios show the effectiveness of the proposed system. The system is easily expandable to control multiple inputs at the same time.

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