Fuzzy Logic Based Ventilation for Controlling Harmful Gases in Livestock Houses

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Abstract— There are many factors that influence the health and productivity of the animals in livestock production fields, including temperature, humidity, carbon dioxide (CO_2), ammonia (NH_3), hydrogen sulfide (H_2S), physical activity and particulate matter. High NH_3 concentrations reduce feed consumption and cause daily weight gain. At high concentrations, H_2S causes respiratory problems and CO_2, displace oxygen, which can cause suffocation or asphyxiation. Good air quality in livestock facilities can have an impact on the health and well-being of animals and humans. Air quality assessment is basically depend on strictly given limits without taking into account specific local conditions between harmful gases and other meteorological factors. The stated limitations may be eliminated. using controlling systems based on neural networks and fuzzy logic. This paper describes a fuzzy logic based ventilation algorithm, which can calculate different fan speeds under pre-defined boundary conditions, for removing harmful gases from the production environment. In the paper, a novel fuzzy logic model has been developed based on a Mamedani's fuzzy method. The model has been built on MATLAB software. As the result, optimum fan speeds under pre-defined boundary conditions have been presented.

Keywords—air quality, fuzzy logic model, livestock housing, fan speed

I. INTRODUCTION

There are many implications and potential impacts of air quality on human and animal health. Extensive research documents acute and chronic respiratory disease and dysfunction among workers, animal[2]s in livestock and poultry buildings due to particulate and gaseous pollutants.

Maintaining good air quality is not only important for the productivity of the animals, but also for the welfare of the animals. Air quality is also a concern to producers as well as rural residents. Confined Feeding Operations (CFOs) livestock air quality may have a regional, national and global impact on the environment. CFOs can affect air quality through emissions of gases (ammonia and hydrogen sulfide), particulate matter, volatile organic and odour. Especially, higher concentrations of ammonia (NH_3) and carbon dioxide (CO_2) in animal barns can negatively affect production and health of animals and workers.

Ammonia effects human and animal health in both gas and particle paheses. The particulate form of ammonia has broader implications for the public, whereas the gaseous form is a localized concern for the health of animals and agricultural workers. Ammonia gas is a highly hydrophilic base that has irritant properties when inhaled and when it is combined with water, it can injure and burn the respiratory tract [1]. The base form of ammonia, ammonium hydroxide, dissolves in the water of mucus membranes, hydrolyzes, and rapidly irritates tissues due to the high pH that results [2]. Ammonia can also alter the uptake of oxygen by hemoglobin due to the increase of pH within the blood, which leads to decreased oxygenation of tissues, and decreased metabolic function.

Typical ammonia levels in well-ventilated, environmentally regulated buildings are 10 - 20 ppm with liquid manure systems and 50 ppm where manure and urine are deposited on solid floors. Due to the side effects of ammonia gas exposure over 25 ppm (17 $mg.m^{-3}$), the American Conference of Governmental Industrial Hygienists (ACGIH) recommends 8-hour maximum exposure limit of 25 ppm to have protection against the chronic effects of ammonia exposure [3]. A 15 min short-term exposure limit of 35 ppm (24 $mg.m^{-3}$) has been established by ACGIH and it has also been adopted by OSHA to reduce irritant effects of ammonia exposure (i.e. eye and upper respiratory tract irritation). However, due to possible cumulative health effects over time, the recommended daily long-term occupational exposure limit of ammonia for agricultural workers is 7 ppm [3], and 300 parts per billion (ppb) for community exposure (community exposure must be stricter because communities contain very susceptible people such as the elderly and children) [4]. At moderate concentrations (50 to 150 ppm), ammonia exposure can lead to eye, throat and skin irritation as well as cough and mucus build up. Prolonged exposure at this level can result in the transfusion of ammonia from the alveoli into the bloodstream and a subsequent disruption of oxygen uptake by hemoglobin. At high concentrations (>150 ppm) ammonia can scar lung tissue, cause lower lung inflammation and pulmonary edema. Exposure to high concentrations of ammonia (500 to 5000 ppm) will cause death in a relatively short time period from prevention of oxygen uptake by hemoglobin [5]. These levels are rarely found near livestock operations, but it may occur in closed manure storage facilities and poorly ventilated buildings where ammonia concentrations can accumulate.

In general, an optimal thermal environment is defined for each species in terms of its effects on production:

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there are a few specific recommendations in terms of disease. Several authors have discussed and reported the effects of temperature on the milk yield of dairy cows [6] and the egg yield of laying hens [7]. The lower critical temperature defines the lower limit of the range of optimal temperature: the upper limit is given by the upper critical temperature. The lower critical temperature is affected by factors such as age, sex, breed [8], food energy level and intake, feathering [9], stocking density [10], bedding system, etc. The CIGR commission [11], recommended maximum and minimum values of RH as a function of indoor temperature, for example, an RH of 50-90% at 0°C followed by a steady decrease of RH to a tolerable range of 40-60% at 30°C.

The fuzzy logic control is one of the most useful approaches for utilizing the qualitative knowledge of a system to design a controller. Fuzzy logic control is generally applicable to plants that are mathematically poorly modelled and where the qualitative knowledge of experienced operators is available for providing qualitative control. On the basis of this idea, some fuzzy models based fuzzy control system design methods have appeared in the fuzzy control field [12].

This paper describes a fuzzy logic based automatic fan speed control for optimum conditions required for a livestock house ventilation considering optimum temperature, humidity, CO_2, NH_3, and H_2S parameters. The fuzzy Logic Toolbox in MATLAB software has been used to develop this algorithm. In the algorithm, five inputs and single output have been considered. As the result, optimum fan speeds under pre-defined boundary conditions have been presented.

II. MATERIALS AND METHODS

Fuzzy control input and output values were defined in three linguistic expressions as “Low (L)”, “Medium (M)” and “High (H)”. Five parameters were chosen as input paramters (temperature, humidity, CO_2, NH_3, H_2S) and single parameter was chosen as output speed of exhaust fan. The features and fuzzy linguistics operations of input/output system variants are given in Table 1.

A fuzzy logic system (FLS) can be defined as the nonlinear mapping of an input data set to a scalar output data. A FLS consists of four main parts: fuzzifier, rules, inference engine and defuzzifier. These components and the general architecture of a FLS are shown in Fig. 1 [13].

The process of fuzzy logic was explained in Algorithm: Firstly, a crisp set of input data are gathered and converted to a fuzzy set using fuzzy linguistic variables, fuzzy linguistic terms and membership functions. This step is known as fuzzification. Afterwards, an inference wass made based on a set of rules. Lastly, the resulting fuzzy output was mapped to a crisp output using the membership functions, in the defuzzification step.

TABLE I. THE FUZZY LINGUISTIC EXPRESSIONS OF SYSTEM VARIANTS

Parameter	Linguistic Expression	Min.	Max.
Temperature (°C) *(input)*	Low, Medium, High	10	30
Humidity (%) *(input)*	Low, Medium, High	20	95
CO_2 (ppm) *(input)*	Low, Medium, High	400	2000
NH_3 (ppm) *(input)*	Low, Medium, High	5	25
H_2S (ppm) *(input)*	Low, Medium, High	0	10
Speed of fan (min^{-1}) *(output)*	Low, Medium, High	0	2000

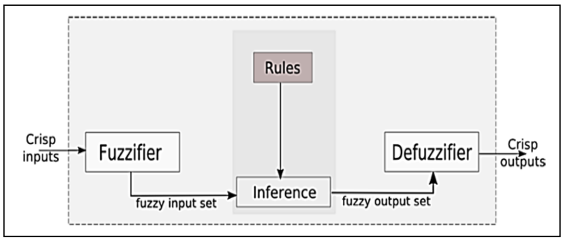


Figure 1. Fuzzy Logic System (FLS).

In this study, Mamdani fuzzy system was used for the illustration which uses Center of Gravity for Singletons algorithm (COG) for defuzzification (1) [14].

$$\mathrm{COG} = \frac{\sum_{i=1}^{p}[u_i.\mu_i]}{\sum_{i=1}^{p}[\mu_i]} \qquad (1)$$

Where u is output variable, p is number of singletons, μ is membership function after accumulation, i is index.

The FIS (Fuzzy Inference System) Editor in Fuzzy Logic Toolbox Graphical User Interface Tools defines the Fuzzy Base Class, five inputs which are Temperature, relative humidity (RH), CO_2, NH_3, H_2S and one output which is Fan Speed (Fig. 2). To control the inside values, the fuzzy controller reads the inside temperature, humidity, CO_2, NH_3, H_2S after every sampling period and after that they are calculated. The fuzzy variables are represented in Figures 3 - 8 respectively. The fuzzy output signal with a range of 0 to 2000 has three membership functions which are "Low", "Medium", and "High" (Fig. 7).

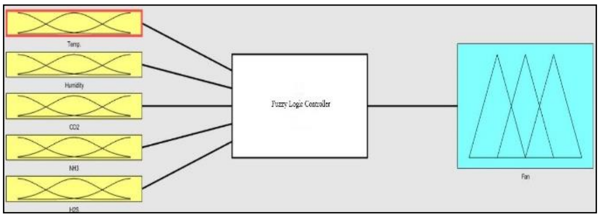


Figure 2. FIS Editor

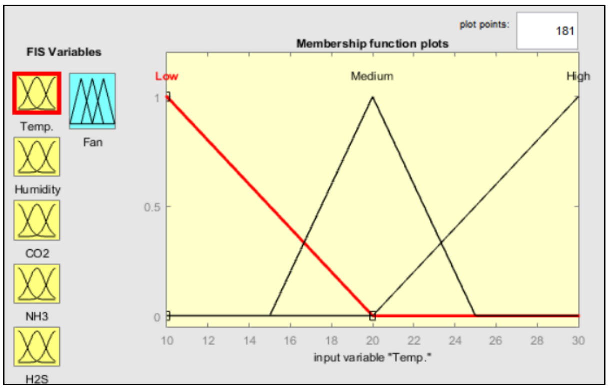


Figure 3. Membership of fuzzy set in temperature

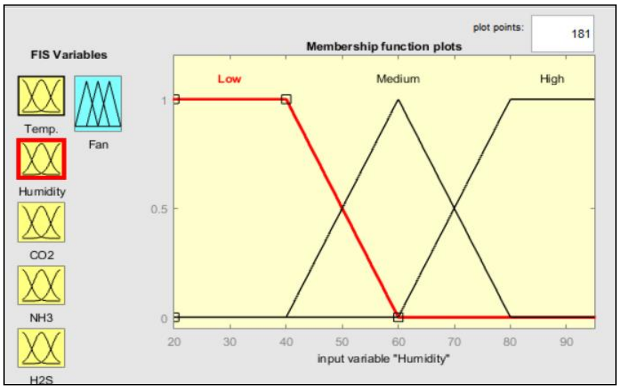


Figure 4. Membership of fuzzy set in humidity

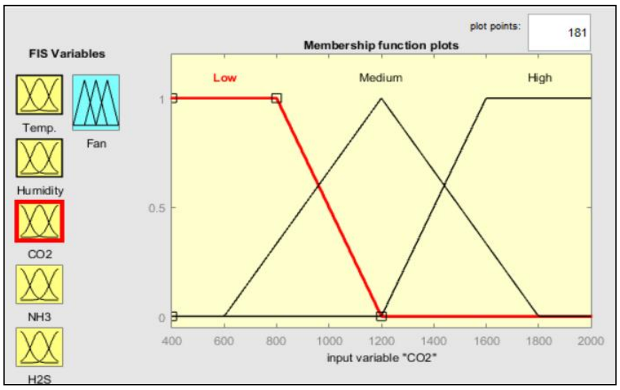


Figure 5. Membership of fuzzy set in CO_2

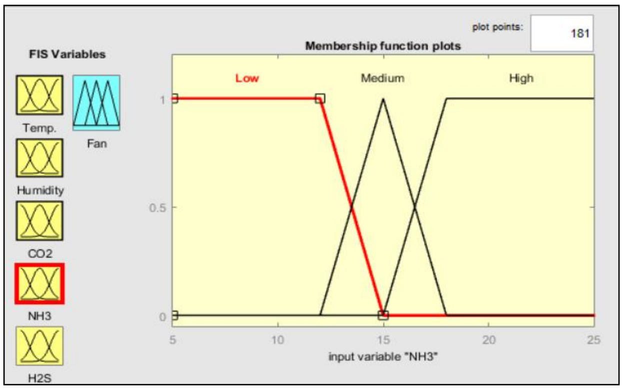


Figure 6. Membership of fuzzy set in NH_3

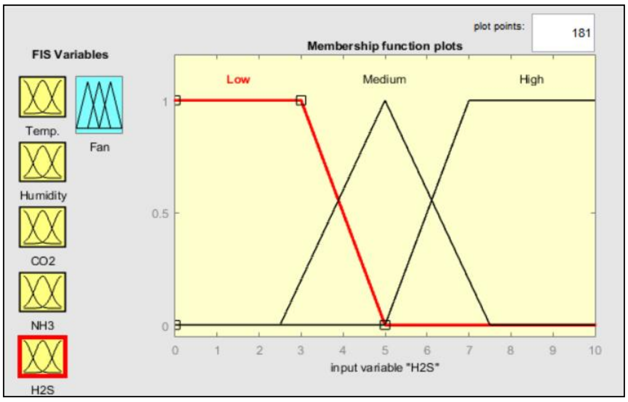


Figure 7. Membership of fuzzy set in H_2S

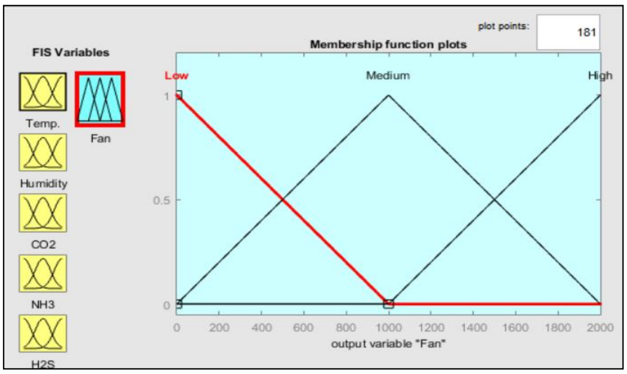


Figure 8. The fuzzy output

III. RESULTS AND DISCUSSION

Fuzzy rules were designed manually. Related rules were generated for all combinations of selected input variable and consequent fuzzy terms was opertaed by the Rule Editor. These rule sets were put in a form according to input paramters and output paramters were obtained. The fuzzy rule sets of this designed fuzzy system include 243 rules are shown in Table 2. The Rule Viewer shown in Fig. 9 is represention of the fuzzy member functions according to input values of the simulation.

Every rule can be deactivated and independent rule weight can be defined for each consequent variable. The rules were defined by selecting the right sequence in the *IF-THEN* sequence.

The example of fuzzy rule is:

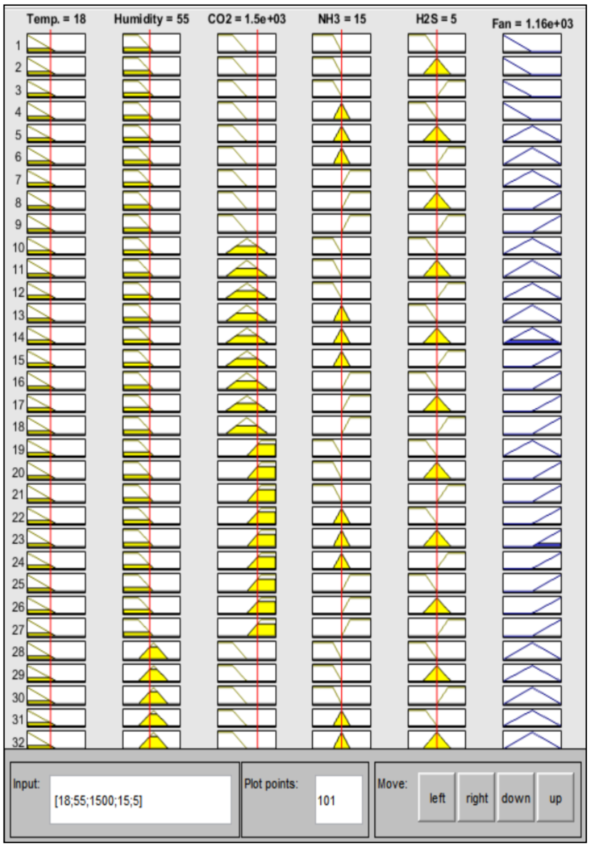
"*IF* Temperature is High *AND* Humidity is Medium *AND* CO_2 is Low *AND* NH_3 is Medium *AND* H_2S is High *THEN* Fan Speed is High".

The MATLAB fuzzy logic toolbox was used for fuzzy air condition system design. The signal value of temperature (18°C), relative humidity (55%), CO_2 (1500 ppm), NH_3 (15 ppm) and H_2S (5 ppm) were considered to design the proposed air conditioning system. The signal values of pre-defined environment factors were calculated as fuzzy variables. At the defuzzification process, eight input parameter values from the inference engine which are R_{014}, R_{023}, R_{041}, R_{050}, R_{095}, R_{104}, R_{122}, R_{131} have been determined. At the end of the solve process, defuzzified output signal of "Fan Speed" were calculated (Table 2).

TABLE 2. SINGLETON VALUES FOR THE FUZZY OUTPUT

Rules	**Inputs**					**Output**
	Temp.	**RH**	**$C0_2$**	**NH_3**	**H_2S**	**(min^{-1})**
14	L	L	M	M	M	M
23	L	L	H	M	M	H
41	L	M	M	M	M	M
50	L	M	H	M	M	H
95	M	L	M	M	M	M
104	M	L	H	M	M	H
122	M	M	M	M	M	M
131	M	M	H	M	M	H
						1160

(L: Low; M: Medium; H: High)



Input: [18;55;1500;15;5]

Plot points: 101

Figure 9. Fuzzy rule viewer

The following Table 3 demonstrates 16 test pairs to validate the fuzzy model as well as collect qualitative information on it. Additionally, a simulation graph was obtained according to the test outputs (Figures 10-13). The graph was generated through the Surface Viewer the Fuzzy Logic Toolbox.

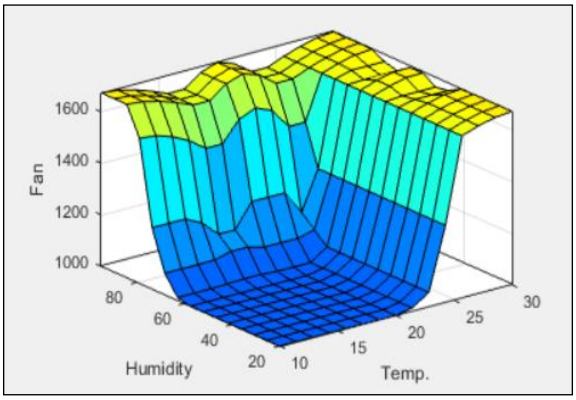


Figure 10. Temperature – Humidity

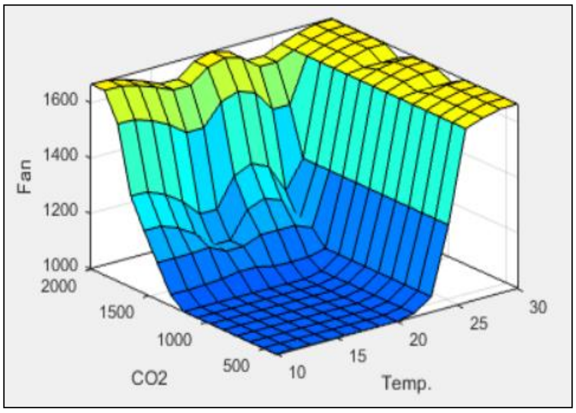


Figure 11. Temperature - CO_2

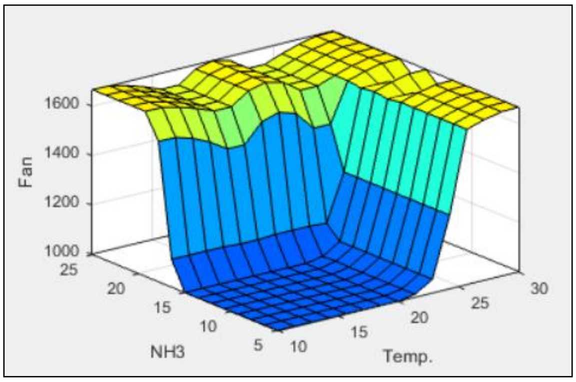


Figure 12. Temperature - NH_3

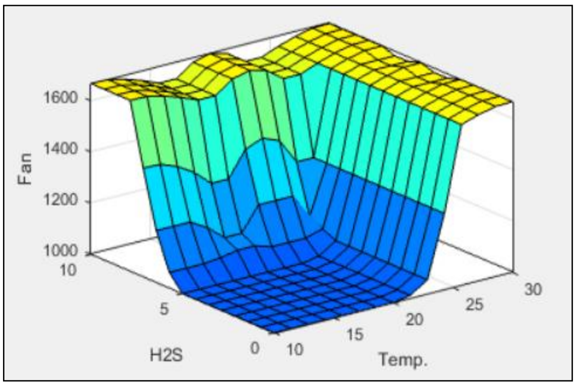


Figure 13. Temperature - H_2S

TABLE 3. TEST OUTPUTS OF FUZZY MODEL

Simulation Scenario No	Temp. (°C)	RH (%)	CO_2 (ppm)	NH_3 (ppm)	H_2S (ppm)	Fan Speed (min^{-1})
1	10	20	400	5	0	327
2	12	30	500	5	5	339
3	15	55	1050	15	5	1000
4	16	70	1000	17	5	1100
5	17	65	1100	15	15	1170
6	18	55	1500	15	5	1160
7	20	95	1800	20	10	1670
8	20	87	1550	15	10	1670
9	21	78	1870	25	10	1660
10	23	50	1100	12	10	1170
11	24	80	1600	23	0	1600
12	26	63	1650	21	7	1630
13	28	45	1400	5	1	1640
14	28	85	1825	12	3	1660
15	30	70	1600	17	4	1620
16	30	95	2000	25	10	1670

IV. CONCLUSIONS

In this paper, a novel algorithm was described for fuzzy air condition controller system in livestock buildings. Relationships between physical variables which are effected on ventilation systems can be defined and complex ventilation can be succesfully operated thruough developed fuzzy logic approaches. Intuitive knowledge of input and output parameters would be enough to design an optimally performing system.

Specific to this study some output (fan speed) paramters can be highlighted as folowings;

- In the simulation scenario no: 6 (Table 3), the fan speed was calculated as 1160 min^{-1} (in the range of "medium").
- In the simulation scenario no: 15 (Table 3), the fan speed was calculated as 1620 min^{-1} (in the range of "high").
- the simulation scenario no: 7, 8 and 16 (Table 3), the fan speed was calculated as 1670 min^{-1} (in the range of "high").

This study also extracted that temperature and humity parameters were the most effected input paramters on the fan speed than the others .As a chemical compound NH_3 paramters were also found as the important parameter on the fan speed.

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