

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 (CO₂), ammonia (NH₃), hydrogen sulfide (H₂S), physical activity and particulate matter. High NH₃ concentrations reduce feed consumption and cause daily weight gain. In addition, at high concentrations, H₂S causes respiratory problems and CO₂, 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 model has been developed based on a Mamedani's fuzzy logic method. The model has been built on MATLAB software. As the result, optimum fan speeds under pre-defined boundary conditions have been presented.

Key words: Air quality, fuzzy logic model, livestock housing, fan speed

Hayvan Barınaklarında Zararlı Gazların Kontrolü için Bulanık Mantık Esaslı Havalandırma

Özet: Canlı hayvan üretim alanlarında sıcaklık, nem, karbondioksit (CO₂), amonyak (NH₃), hidrojen sülfür (H₂S), fiziksel aktivite ve partiküler madde gibi hayvanların sağlığını ve verimliliğini etkileyen birçok faktör vardır. Yüksek NH₃ konsantrasyonları, yem tüketimini azaltır ve günlük kilo alımına neden olmaktadır. Ayrıca, yüksek konsantrasyonlarda H₂S solunum problemlerine ve CO₂'ye neden olur, oksijenin yerini alır, boğulma veya boğulmaya da neden olabilir. Hayvancılık tesislerinde iyi hava kalitesi, hayvanların ve insanların sağlığı ve esenliği üzerinde etkili olabilmektedir. Hava kalitesinin değerlendirilmesi, temelde zararlı gazlar ve diğer meteorolojik faktörler arasındaki yerel koşulları göz önünde bulundurmaksızın sıkı bir şekilde verilen sınırlara bağlıdır. Belirtilen sınırlamalar, sinir ağlarına ve bulanık mantığa dayalı kontrol sistemleri kullanılarak ortadan kaldırılabilir. Bu yazıda, önceden tanımlanmış sınır koşulları altında farklı fan hızlarını hesaplayabilen, üretim ortamından zararlı gazları gidermek için bulanık mantık tabanlı havalandırma algoritması açıklanmaktadır. Makalede Mamedani bulanık mantık metoduna dayalı yeni bir model geliştirildi. Model, MATLAB yazılımı üzerine kurulmuştur. Sonuç olarak, önceden tanımlanmış sınır koşulları altında optimum fan devirleri sunulmuştur.

Anahtar kelimeler: Hava kalitesi, bulanık mantık model, hayvan barınağı, fan hızı

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, animals 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. In particular, higher concentrations of ammonia (NH₃) and carbon dioxide (CO₂) in animal barns can negatively affect production and the health of animals and workers.

Ammonia affects human and animal health in both gas and particle phases. The particulate form of ammonia has broader implications for the public, whereas the gaseous form is a localised 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 (Issley and Lang, 2008). 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 an 8-hour maximum exposure limit of 25 ppm to ensure protection against the chronic effects of ammonia exposure (Gay, 2009). 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 (Gay, 2009), 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) (Donham et al., 2000). At moderate concentrations (50 to 150 ppm), ammonia exposure can lead to eye, throat and skin irritation as well as coughing 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 (Merchant et al., 2003). 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: 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 (Webster, 1981) and the egg yield of laying hens (Charles, 1984). 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 (Henken et al., 1991), food energy level and intake, feathering (Macleod, 1984), stocking density (Burmeister, 1986), bedding system, etc. The CIGR commission (CIGR, 1984), recommends 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.

Fuzzy logic control is one of the most useful approaches for utilising 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 (Wang et al., 1996).

This paper describes a fuzzy logic based automatic fan speed control for conditions required for a livestock house ventilation, considering optimum temperature, humidity, CO₂, NH₃, and H₂S parameters. The Fuzzy Logic Toolbox in MATLAB software has been used to develop this algorithm. In the algorithm, five inputs and a single output have been considered. As a result, optimum fan speeds under pre-defined boundary conditions have been presented.

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 parameters (temperature, humidity, CO₂, NH₃, H₂S) and a single parameter was chosen - the output speed of the 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 (Mendel, 1995).

The process of fuzzy logic was explained in Algorithm: Firstly, a fresh 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. Subsequently, an inference was made based on a set of rules. Lastly, the resulting fuzzy output was mapped to a fresh output using the membership functions, in the defuzzification step.

Table 1. 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 ₂ S (ppm) (input)	Low, Medium, High	0	10
Speed of fan (min ⁻¹) (output)	Low, Medium, High	0	2000

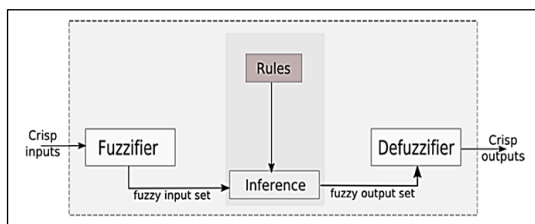


Figure 1. Fuzzy Logic System (FLS).

In this study, Mamdani fuzzy system was used for the illustration which uses Centre of Gravity (COG) for Singletons algorithm for defuzzification (Equation 1) (Mamdani and Assilion, 1974).

$$COG = \frac{\sum_{i=1}^p [u_i \cdot \mu_i]}{\sum_{i=1}^p [\mu_i]} \tag{1}$$

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), CO₂, NH₃, H₂S and one output which is Fan Speed (Fig. 2). To control the inside values, the fuzzy controller reads the inside temperature, humidity, CO₂, NH₃, H₂S after every sampling period following which 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).

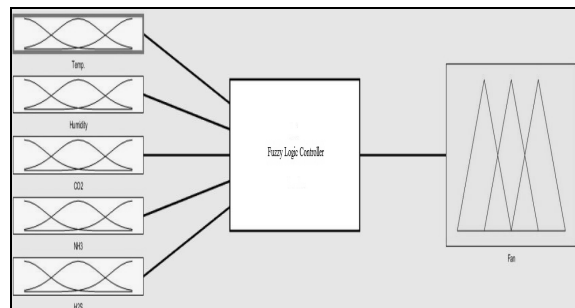


Figure 2. FIS Editor

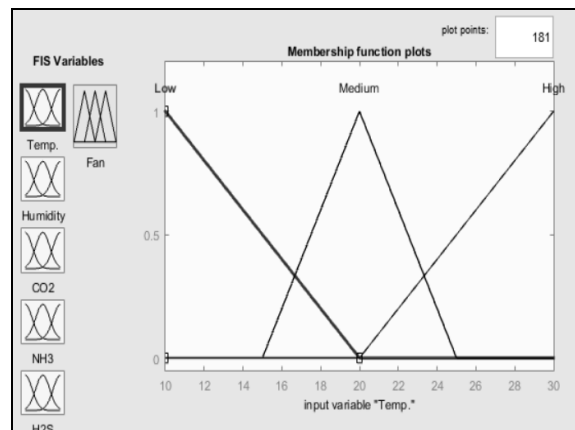


Figure 3. Membership of fuzzy set in temperature

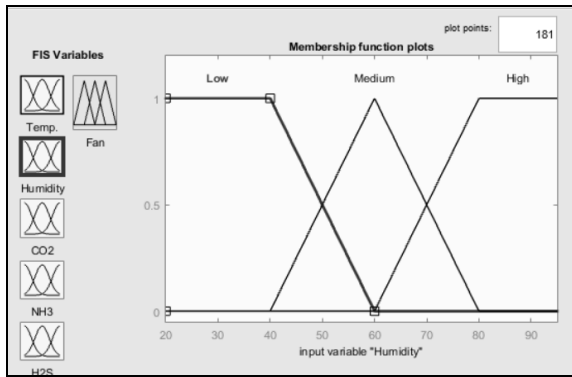


Figure 4. Membership of fuzzy set in humidity

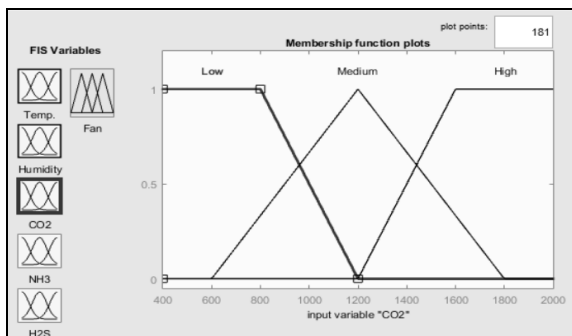


Figure 5. Membership of fuzzy set in CO₂

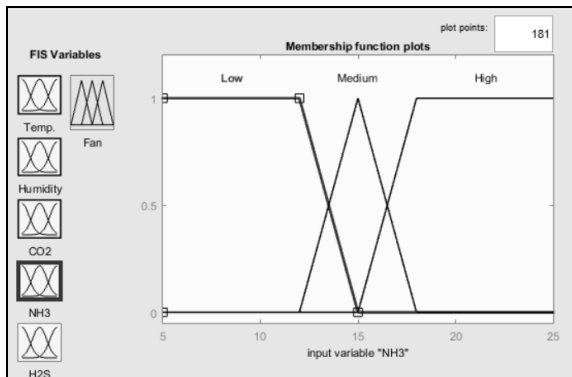


Figure 6. Membership of fuzzy set in NH₃

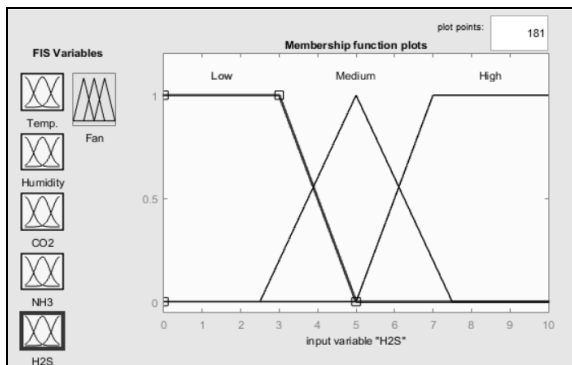


Figure 7. Membership of fuzzy set in H₂S

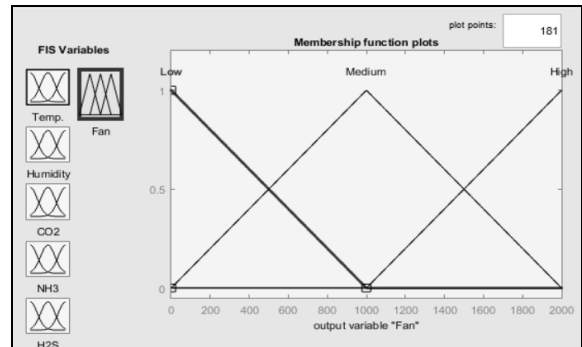


Figure 8. The fuzzy output

RESULTS and DISCUSSION

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

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

The example of fuzzy rule is:

"IF Temperature is High *AND* Humidity is Medium *AND* CO₂ is Low *AND* NH₃ is Medium *AND* H₂S 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%), CO₂ (1500 ppm), NH₃ (15 ppm) and H₂S (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 R₀₁₄, R₀₂₃, R₀₄₁, R₀₅₀, R₀₉₅, R₁₀₄, R₁₂₂, R₁₃₁ have been determined. At the end of the solve process, defuzzified output signals of "Fan Speed" were calculated (Table 2).

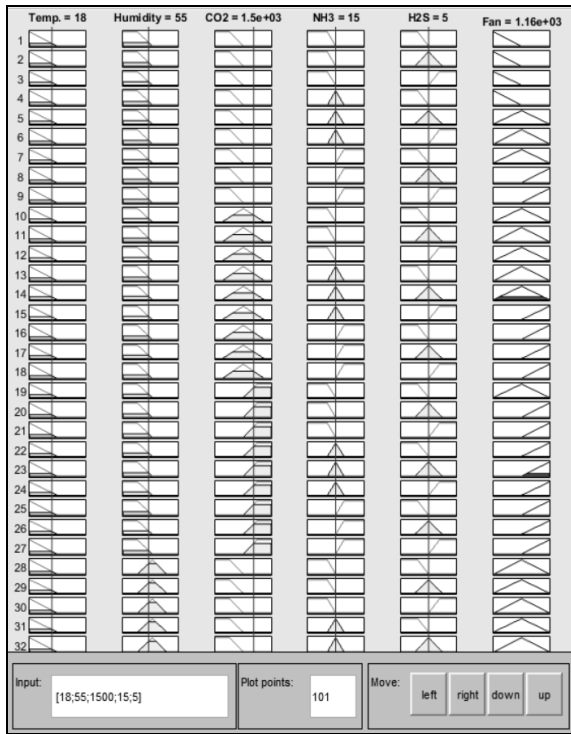


Figure 9. Fuzzy rule viewer

Table 2. Singleton values for the fuzzy output

Rules	Inputs					Output (min ⁻¹)
	Temp.	RH	CO ₂	NH ₃	H ₂ S	
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)

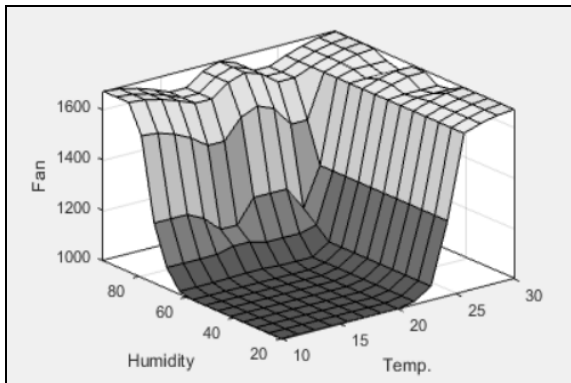


Figure 10. Temperature - Humidity

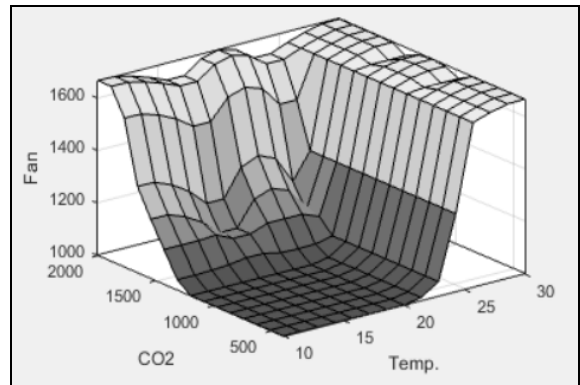


Figure 11. Temperature - CO₂

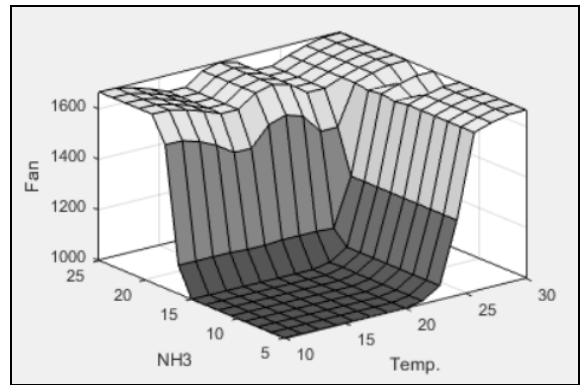


Figure 12. Temperature - NH₃

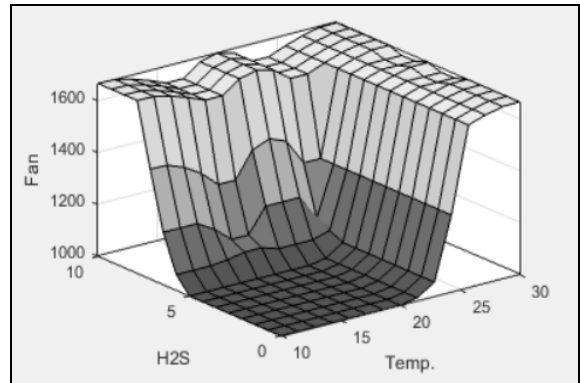


Figure 13. Temperature - H₂S

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 of the Fuzzy Logic Toolbox.

Table 3. Test Outputs of the Fuzzy Model

Simulation Scenario No	Temp. (°C)	RH (%)	CO ₂ (ppm)	NH ₃ (ppm)	H ₂ S (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

CONCLUSIONS

In this paper, a novel algorithm was described for a fuzzy air condition controller system in livestock buildings. Relationships between physical variables which are effected in ventilation systems can be

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defined and complex ventilation can be successfully operated through 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) parameters can be highlighted as follows;

- 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 confirmed that the temperature and humidity parameters were the most affected input parameters on the fan speed than the others. As a chemical compound, NH₃ parameters were also found to be an important parameter on the fan speed.