Experimental implementation of a new multi input multi output fuzzy-PID controller in a poultry house system

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ABSTRACT

Broiler house systems are operated for the primary purpose of providing the appropriate conditions suitable to have a significant efficiency of animal production. The major environmental conditions in the poultry building are controlling the hygro-thermal parameters (temperature and relative humidity) and contaminant gases (NH3, CO2). In this paper, a poultry house prototype is monitored and controlled using the Supervisory Control and Data Acquisition (SCADA) tool like LabVIEW. A full prototype is designed and an efficient hybrid control strategy is implemented to control in real-time the poultry house climate. In the suggested approach, a Multi-Input Multi-Output (MIMO) fuzzy logic controller (FLC) is combined with a proportional, integral, derivative (PID) controller tuned by fuzzy rules. The proposed method, fuzzy logic, and On/Off controllers were tested by experimental measures and studies in a prototype model over 30 days during hot climates. The comparison results showed that the root mean square error of temperature and relative humidity response with the MFLPID controller (0.8°C, 1.34%) were lower than that of FLC (1.16°C, 1.86%) and On/Off controller (2.09°C, 3.08%). The mean value of CO2 concentration with MFLPID (2461 ppm) was lower than that of FLC (3294 ppm) and On/Off controller (3624 ppm). However, the mean value of NH3 concentration was limited in small value (<5 ppm) for all controllers. The performance of the daily weight gained by the chickens for the MFLPID system was found to be 97%, which is higher than that of FLC (88%) and On/Off (80%). The energy consumption of the actuators can be saved at 43% and 14% with MFLPID compared to the On/Off and fuzzy controllers. These results indicate that the proposed control strategy is more efficient in the application of the poultry farming sector.

1. Introduction

In the last decades, population development is expanding at a much faster rate than sustenance supply in all parts of the world. According to the Food and Agricultural organization of the United Nations (FAO) and the United States Department of Agriculture (USDA) [1, 2], the world population is expected to grow by over a third (around 2.3 billion people) between 2009 and 2050. The agricultural sector faces multiple challenges; it needs to deliver more food to fulfill the enhancing demands of a growing world population, add to embrace progressively efficient and manageable strategies, and adjust to environmental change.

At present, the micro-climate conditioning of agricultural buildings for plantation, livestock building, and especially the poultry industry is one of the most dynamic pillars that contribute to the productive activities and the national economic development of the territory of Morocco. Therefore, the demand for chickens is yet extending relatively with the growth of the population [3, 4].

Additionally, one of the main constraints to livestock development is heat stress in summer because of the high temperature, excessive humidity, or high concentrations of ammonia and carbon dioxide, which is the case for example in Morocco [5]. In practice, large portions of farmers use conventional control strategies with low performance, inferable from overlooking the strong interactions between broilers and their environment (outside climate). In this sense, they have to pay an additional cost for the energy consumption utilized by the actuators, which in many cases can be avoided. Thus, this tends to be inefficient, unhealthy and can lead to significant economic losses.
On the one hand, maintaining the interior micro-climate inside the animal building at the desired conditions in a humid and hot climate appeared as a big challenge. However, poor management of the ventilation system, heating, and evaporative fan-PAD cooling systems could produce a disproportionate level of the indoor temperature and humidity. These could affect serious outcomes, for example, heat stress, respiratory disorders, high dust levels [6] and higher energy consumption.

On the other hand, eliminating the concentrations of noxious gases and maintaining the thermal comfort of chickens under changing climate control is a complicated task, in general.

It is against these foundations that we have effectively focused on designing a new control strategy that allows us to ensure a concurrent control of temperature, relative humidity, and toxic gases (NH3, CO2) in poultry farming.

Considerable efforts on climate control systems for animal houses have been addressed in the literature [7, 8, 9, 10]. These studies demonstrate the requirement of the development of new techniques for the control design problem of micro-climate control just as for the utilization of new modern microprocessor devices for the achievement of an optimal environment in closed animal buildings.

In this way, recent research studies show an inclination to the use of increasingly various advanced strategies for control techniques and simulation for a livestock building. From classical control theory like the conventional On/Off controller [11] to the modern control theory such as nonlinear adaptive temperature and humidity control in animal buildings [12]; modern supervisory control for closed broilers house [13]; predictive control for temperature and humidity in a naturally ventilated pig building [14] and optimal control essentially as Ant Colony Optimization (ACO) used to regulate the thermal requirement of the poultry house [15, 16]. These methodologies are essential to actual engineering applications in poultry house production. Be that as it may, several of these approaches are either theoretically perplex or challenging to implement in a real poultry house system.

During recent years, the fuzzy logic controller (FLC) has been used for various applications such as fuzzy systems used to assess the suitability of evaporative fan-pad cooling systems for broiler buildings in China [17], and the FLC developed for staged heating and ventilating systems [18]. This control strategy has demonstrated its preferences over the On/Off controller in the control of poultry house system [19] as it does not require a precise mathematical model, and it performs to set point changes.

In many cases, controller designs for the poultry house system chiefly adopt the ON/OFF switching owing to their uncomplicated architecture and simple implementation. But, in commercial and research livestock buildings, despite the widespread application of contemporary techniques, the effectiveness of the controller is often limited due to the required time for reaching the desired indoor parameters and to the high cost paid for energy consumption used for ventilation and heating [20, 21].

Motivated by the previously mentioned advantages of the fuzzy logic controller, a hybrid control scheme, combining the self-tuning PID parameters adjusted by fuzzy rules with a Multi-Input Multi-Output (MIMO) fuzzy controller, is introduced herein for poultry house climate control. It is foreseen that the junction will take advantage of the extra flexibility with past and future time required to eliminate the fluctuations of the system and the simplicity of implementing PID controllers. In the poultry house system, there are cross-coupling variables that are influenced by the outside climate. This strong interaction leads to create fluctuations in the stability of the system. So there is a requirement of controlling the system with high efficiency.

To our knowledge, there is no research work in the literature dealing with the automation of a poultry house model or that review the implementation of the MIMO Fuzzy-PID controller in a model poultry house.

The novelty of this research is to propose a powerful technique for simultaneous supervision and control of temperature, relative humidity, and contaminant concentrations in livestock farming. Furthermore, the enhanced approach guarantees accurate tracking in the whole operating range with a small deviation error. In addition to this, it is important to notice that the proposed method produces superior efficiency as compared to the existing control strategies (e.g. fuzzy and On/Off controllers) because it reduces the energy dissipation of the actuators (i.e. Electric heater, Fan,...etc.) and optimally affects the animal growth.

The purpose of this work is to control the indoor climate and track the performance of the chickens using the developed controller and to monitor the system by employing LabVIEW tool. These objectives can be accomplished fundamentally by three steps: the first by designing a good livestock building structure (thermal insulation, suitable materials), the second by implementing a satisfactory measurement and instrumentaition system to predict satisfying measures of the inside parameters, the last by developing an intelligent control law adapted to manage and regulate the recommended values of chickens production.

This paper has been developed based on the practical work and the experimental measures on a poultry house prototype in Rabat province of Morocco. Thus, the main contributions of this paper are as follows:

1. Reduce the energy consumption of the poultry farming system and increase chicken productivity.
2. Improve the stability of the system and decrease the frequency oscillations resulting from the variations of the set-point parameters during the breeding period of chickens.
3. Create an automated poultry house and develop an interface platform for the novice farmer.

2. Materials and methods

2.1. Experimental poultry house system

After the ethics approval of the committee composed of both the laboratory responsible Professor Nacer SEFIANI and the head of the poultry system company of Rabat Doctor Tarik EL FHRI CHEMAOU. The experimentation was conducted in the laboratory of instrumentation and measurements of Superior School of Technology of Salé, Rabat, Morocco. Tests were done in a prototype model with a length × width × height of 1.50 m × 0.9 m × 1.1m, with the production capacity of 15/m² broilers per crop (Figure 1).

The house system includes five main subsystems, namely:

- Ventilation system: is equipped with five ventilation fans using DC Brushless fan series (12V) installed at the rear end of the house.
- Evaporative Cooling system: Two cellulose pads (25 cm × 80 cm for each one) are placed in one wall, the pad system works in conjunction with two fans placed on the opposite wall of the PAD Cooling system. A pump of a capacity of 180L/h recirculates the water in the cellulose panels to humidify the internal air.
- Heating system: is provided with two electric heaters of 300W installed in the middle of the house.
- Inlet system: Two windows are installed in the longitudinal sides of the house, where the opening and closing mechanism is assured with servomotors Futuba S3003 series, the inlet system is used for refreshing the inside air.
- Lighting system: Three lamps of (12V, 45W) are fixed in the roof allows to growing chickens.

A drinking water and feeding system were used to extend the growing production of broilers (see Figure 2).

Data collection was started at the first age of chickens (1 day), and it continuously measured for five weeks in July 2019. The prototype design and the experiment measured were endorsed by the society of the poultry system of Rabat, Morocco. The dimensions and specifications of the prototype used in the experimentation are explained in Figure 2.
2.2. Instrumentation and measurements

The measurements mainly include temperature (T), relative humidity (RH), air quality index (AQI), and chickens weight.

Internal temperature and relative humidity are measured at two points: in the middle near to the roof of the house, and the chickens at a level of the 0.35m and 0.7m, respectively. Figure 3 indicates the locations of the sensors (sensors A and B). External temperature and humidity sensors have been placed on the outside roof of the house (sensor E). Additionally, a light intensity LDR module sensor (sensor C) has been mounted outside the house to automatically operate the electric lighting system, and a force-sensitive resistance (FSR) sensor is installed on the ground (sensor D) of the building to assess the average body weight of broilers. The air quality sensors were placed in the middle of the house with a level of 0.6 m (sensor F) to measure the ammonia and Carbone dioxide concentrations. Finally, a video camera system (OV5648 5 Mega-pixel) is fixed in the roof above the broilers to monitor the thermal comfort of the chickens inside the house (Figure 3).

The different sensors used in the system are tabulated in Table 1.

So as to completely operate the system, all the measured data from sensors were simultaneously set up and communicated to a computer through a central micro-controller (ATmega 2560) which is interfaced with the actuators as represented in Figure 4.
The monitoring system transfers the real data from the central micro-controller to the LabVIEW software through the serial port of the computer, and the required decisions are transmitted to the micro-controller. After, all the best operating conditions are given to the driver circuit pulse-width modulation PWM (Gradation-8 Transistors) to produce a variable voltage to operate the actuators at different levels. The variable signal is generated to the actuators through the PWM for the electronic switches.

It should be noted that supervisory control for the poultry house comprises three essential phases: collecting of data from the sensors, processing and comparing the measured input parameters to the desired command, and finally providing the best arrangement output signal to the actuators elements (Heater, Fan, Pad cooling and Windows).

2.3. SCADA system

A SCADA system is developed and implemented in LabVIEW Software (Figure 5). The platform interface contains features that can be easily intelligible and exploitable by the farmer’s side. These highlights
are exhibited in monitoring and controlling the system. The user can choose the control mode (MIMO Fuzzy-PID, Fuzzy, ON/OFF controllers), he can see the evolution of the sensed values (temperature, relative humidity, and air quality index), and can observe the age of broiler and the average weight of chickens (kg unit), also he can inspect the video in real-time and the recorded information. In the gadget director platform, the user can change and set the desired values depending on the recommended range. The fully automated poultry house system confirms to be a valuable stand-alone system for the farmer or the user who does not have enough specialized foundation in controlling and monitoring the system.

The quality gadget that appeared in Figure 5 is implemented to help the farmer to know the AQI levels from the colors used. The colors used are indicated as the air pollution levels. Figure 6 below defines the Air Quality Index scale used in our strategy of control. The air quality index (AQI) is calculated depending on the ammonia and the Carbon dioxide concentrations. The critical values are taken from the broiler breeding operations conditions. Higher AQI value represents the polluted air, and lower AQI value represents the clean air. For example, a value below 2000 ppm and 5 ppm for CO2 and NH3 concentration respectively is considered such a good quality of air, and it becomes dangerous when it exceeds 5000 ppm and 15 ppm for CO2 and NH3 concentration respectively.

2.4. MIMO Fuzzy-PID controller

Fuzzy logic control (FLC) is a method that commonly used to decompose a complex system into a few subsystems that do not need a detailed mathematical model [22]. The Fuzzy controller synthesis consists initially in defining the set input with the appropriate membership functions, secondly in dealing with the convenient rules, finally in transforming the results into exact values as it can be processed by other systems.

This proposed controller aims to combine a MIMO fuzzy with a self-tuning PID controller type adjusted by fuzzy rules, as illustrated in Figure 7.

The MIMO fuzzy-PID logic (MFLPID) is introduced here to improve the system response, get high precision, and reduce the computational time [23, 24].

As can be noticed in Figure 7, there are two main blocks: fuzzy tuner-PID (FT-PID) and MIMO-fuzzy logic controller (M-FLC).

The M-FLC aims to combine a MIMO fuzzy with a self-tuning PID controller type adjusted by fuzzy rules. All the inputs and outputs (e and \(e_0\), and Kp, Ki, Kd) of each FT-PID are respectively normalized in the limits [−1, 1] and [0, 1]. Also, five-membership functions have been considered with Gaussian shape that defines how each point in the input space is mapped to a membership value between 0 and 1. The rules are elaborated by the all-possible operating scenarios with 25 regulations that need to be considered in the FT. Five fuzzy adverbs are chosen such as: “NB: Negative Big, NS: Negative Small, ZE: Zero, PS: Positive Small and PB: Positive Big” of the two inputs (e and \(e_0\)), and five labels “OFF: No change, SV: Small value, MV: Medium value, LV: Large value and BV: Big value” for the three outputs (Kp, Ki, Kd). The universe of discourse of all values of the input and output membership functions of the FT-PID is illustrated in Figure 8. In this step of fuzzyification, the Min-Max Mamdani method was used.

The practical experiments performed on the process and the expert’s knowledge can give a precise idea about the crisp values and rule base of the FT. The rules bases formulated in Table 2 are elaborated based on two
essential conditions. It means that if the proportion of each measured error is large, actuators should reduce errors and if the error is small, the steady-error of the system should be eliminated.

All the detailed rules, guaranteeing the optimal operating are implemented in LabVIEW software using its fuzzy logic tools. In the tuning method, the parameters \([K_p, K_i, K_d]\) are updated continuously by the fuzzy tuner. The fuzzy gets the two inputs, it procedures to the fuzzy inference according to IF... THEN conditions and it assesses to the control rules of Table 2 and finally proceeds on the defuzzification step. The defuzzification process consist to analyze all the logical rules and then quantify and compute the final output value of the fuzzy-PID. It should be noted that the gravity center method is adopted for defuzzying the outcome values corresponding to each linguistic label. This method is chosen due to its clarity and appropriateness to be integrated into a study depends on the experiments.

The concept of self-tuning for the PID gains allows the poultry house parameters to reach the predetermined set point in the shortest time. Once the FT-PID controller results are computed, the M-FLC receives the corrected errors continuously according to the relationship considered in Eq. (1) with the four inputs, i.e. the four errors of the system which are the adjusted error of temperature \((U_1)\), relative humidity \((U_2)\), Carbon dioxide and ammonia concentrations \((U_3, U_4)\). Finally, the M-FLC

\begin{table}[h]
\centering
\caption{Formulation of rules for \(K_p\), \(K_i\), \(K_d\)}
\begin{tabular}{|c|c|c|c|c|c|}
\hline
\(e\) & \(de\) & NB & NS & ZE & PS & PB \\
\hline
\hline
NB & BV/BV/Off & BV/LV/Off & BV/MV/SV & LV/MV/SV & MV/MV/LV \\
NS & BV/BV/Off & BV/LV/Off & LV/LV/Off & LV/MV/Off & MV/SV/SV \\
ZE & LV/MV/Off & LV/SV/Off & MV/OE/OE & SV/OE/SV & SY/OE/LV \\
PS & MV/MV/SV & SV/MV/SV & SV/SV/OE & SV/OE/LV & SV/SV/SV \\
PB & SV/SV/OE & SV/OE/SV & OIE/OE/OE & OIE/OE/SV & OIE/OE/LV \\
\hline
\end{tabular}
\end{table}
actuates the five outputs, i.e., the electronic switches command signals to the actuators of the system.

\[ U_i(k) = K_{i1}e_i(k) + K_{i2} \sum_{j=1}^{4} e_i(j) + K_{i3}[e_i(k) - e_i(k-1)] \]  

(1)

where \( i = 1, \ldots, 4 \) related to the first, second, third and fourth corrected errors respectively.

In this block (M-FLC), min-max Mamdani and the center of gravity method has also been used for the fuzzy inference and defuzzification process, respectively.

Generally, all the inputs and outputs of the M-FLC were normalized in the interval [0,1] and configured with three levels conditions variables “L: Low, M: Medium, H: High” and covered utilizing triangular and trapezoidal membership function as represented in Figure 9.

The communication among the inputs and outputs is made through the aggregation of a set of 61 rules that needs to be considered in the M-FLC.

Table 3 represents some of the possible operating scenarios (rules) proposed in this study.

The x-axes of Figure 9 represents the universe of discourse of all possible inputs and outputs values corresponded respectively to the range of the corrected error \([U_{\text{min}}, U_{\text{max}}]\) and the range of the applicable level power \([DC_{\text{min}}, DC_{\text{max}}]\) of each electronic switches. The y-axes illustrate the membership degree of the fuzzy set. The fundamental idea is that an element that belongs to the fuzzy subset adverbs with a certain degree of membership will be taken as a real number in the standardized interval [0,1].

In this study, we explain, for example, the rule 2 reported in Table 3: with a medium value for the corrected error \(U_1\), \(U_1\) is associated to 0.5\(U_{\text{max}}\), and low values for the corrected \(U_2\), \(U_3\) and \(U_4\) are associated to \(U_{\text{min}}\) of each calculated corrected error. In this way, the fuzzy logic imposes that the value of the outputs will be assigned around the instant values: around 1, 0.5, 0, 0, and 0.5 for Fan 1, Fan 2, Electric Heater, Motors and Pump Water, respectively. With this reasoning, the levels of the commands signals of the electronic switches will be operated in the corresponding level power (DC Voltage) of each actuator, it means that the Fan1 will be operated around a high level, Fan2 and Pump Water around a medium level, Electric Heater and Motors around low levels.

As a result, the outcome signals fluctuates between 0 and 1 in agreement with the operating rules, and each output is converted to a duty cycle at its level percentage power using the PWM technique.

Lastly, each obtained output is injected into the electronic switches to activate the actuators of the system simultaneously: electric heating, ventilating systems, the inlet opening mechanism, the pad cooling system, and the electric lights.

3. Results and discussions

In order to demonstrate the performance and efficiency of the proposed control scheme, a series of experiments are illustrated in the present section. In particular, a supervisory control system is developed to organize and control the indoor microclimate in the poultry house with the proposed designed controller. In this experiment, we consider three different control schemes for comparison in the purpose of set-point response. These schemes are (a) MIMO fuzzy-PID controller, (b) Fuzzy controller, (c) ON/OFF controller.

3.1. Temperature and relative humidity response

Figures 10 and 11 show the response of temperature and relative humidity for the MFLPID, fuzzy, and ON/OFF controllers, respectively.

Results of Figures 10 and 11 indicate that the MFLPID controller provides a better response for temperature and humidity response with a very smooth variation in tracking the desired set points. In the fuzzy controller, the internal parameter smoothly followed the set point compared to the On/Off controller. Similar results in control for poultry house reported that the fuzzy control gives better performance compared to the On/Off controller in [19]. In other hands, it can be seen from the experiments of the On/Off controller that they are some response involved over the recommended range (upper/lower) in control of both humidity and temperature. These peaks can cause damage to some of the system components and relatively increase maintenance costs [25].

In fact, the MFLPID has the best response compared to the On/Off and fuzzy control. In another study, Kolokotsa et al [26] had concluded that the adaptive fuzzy-PD controller ensures sufficient satisfaction of the indoor air quality for buildings control.

For statistical analysis, the mean values of the following parameters were analyzed and compared using SPSS software: maximum positive and negative error from the set points, mean error (positive and negative) and the root mean squared error (RMSE). The results of comparison of the mean values by the controllers are illustrated in Table 4.

According to Table 4, the MFLPID control system has the smallest maximum positive error (1.87 °C, 3% for temperature and relative humidity, respectively) and it has the least maximum negative error (-2.8 °C, -4% for temperature and relative humidity, respectively) compared to the fuzzy and On/Off controller system. While, the corresponding results created in On/Off controller showed a higher maximum positive and negative error estimated in (4.2 °C, -5 °C for temperature) and (8%, -9.5% for relative humidity). Likewise, there was no noteworthy difference noticed between MFLPID and fuzzy in their maximum negative error on control of relative humidity. Also, the mean values of positive errors for MFLPID controller (1.0958% and 0.5 °C) were essentially lower than that of the fuzzy controller (1.6% and 0.72 °C) and that of On/Off controller (2.3% and 1.559 °C) for relative humidity and temperature, respectively. In others hands, the mean value of negative errors for On/Off controller (-2.008 °C and -2.7259%) was fundamentally higher than that of the fuzzy controller (-1.0663 °C and -1.4158%) and that of MFLPID (-0.6221 °C and -1.0041%). Additively, the high error produced in the experiments of the On/Off controller increases the time required to reach the predetermined value and relatively increase the energy consumption by the actuators.

The internal temperature and relative humidity measured during the breeding period concurred accurately with the recommended range by the MFLPID controller, the RMSE generated by the proposed controller has the lower values (0.8028 °C and 1.35 %) compared to that of fuzzy (1.1618 °C and 1.8637 %) and that of On/Off controller (2.0914 °C and 3.0873 %) for the temperature and relative humidity, respectively.

Figure 9. Membership functions for the MIMO-FLC: a) Inputs (corrected error) and b) Outputs (Duty cycle command signals).
Table 3. MIMO FLC rules bases.

| Rules | Inputs | Outputs: electronic switches |
|-------|--------|-------------------------------|
|       | $U_1$  | $U_2$ | $U_3$ | $U_4$ | Fan 1 | Fan 2 | Electric heater | Motors | Pump water |
| 1     | L      | L     | L     | L     | H     | H     | L               | L      | H         |
| 2     | M      | L     | L     | L     | H     | M     | L               | L      | M         |
|       |        |       |       |       | :     | :     | :               | :      | :         |
| 81    | H      | H     | H     | H     | H     | H     | L               | H      | L         |

Figure 10. Comparison of MFLPID, FLC and ON/OFF controllers in temperature response.

Figure 11. Comparison of MFLPID, FLC and ON/OFF controllers in relative humidity response.

Table 4. Comparison of the mean values of the parameters.

|        | P.err$_{max}$ | N.err$_{max}$ | Mean P.err | Mean N.err | RMSE  |
|--------|----------------|---------------|------------|------------|-------|
| T      | MFLPID         | 1.87          | -2.8       | 0.5        | -0.6221 | 0.8028 |
|        | FLC            | 2.1           | -4         | 0.72       | -1.0663 | 1.1618 |
|        | On/Off         | 4.2           | -5         | 1.559      | -2.008  | 2.0914 |
| RH     | MFLPID         | 3             | -4         | 1.0958     | -1.0041 | 1.3478 |
|        | FLC            | 5.5           | -4         | 1.6        | -1.4158 | 1.8637 |
|        | On/Off         | 8             | -9.5       | 2.3        | -2.7259 | 3.0873 |
Depend upon all these results, it can be remarked that the MFLPID controller has the least mean error, littiest root mean square error, and the smallest maximum positive and negative errors.

A box-plot was represented in Figure 12 in order to illustrate the estimations of the corresponding sample standard deviations (Std) deduced from the internal climate parameters of temperature and relative humidity in each experimentation.

Results obtained from Figure 12 were derived by considering the Std of temperature and relative humidity for the sample experimental data from three random days in July.

It can be shown that the MFLPID controlling system has the lowest band pass, least value excluding outliers, and the low maximum upper quartile by comparing to the fuzzy and On/Off controlling system. Besides, it can be observed that there is a higher variability in the data set range with the On/Off controller compared to the others. So, it can be concluded with 95% confidence that the correct median of the distribution data generated by the MFLPID is so close to the desired point for both temperature and relative humidity.

3.2. Air quality response

Figures 13 and 14 illustrate the evolution of CO2 and NH3 concentrations, respectively, for the MFLPID, fuzzy, and ON/OFF controllers.

Based on Figures 13 and 14, the MFLPID control system can smoothly reduce the Carbone dioxide concentration better than the fuzzy and On/Off controllers. According to the air quality index defined in Figure 6, there is no dangerous or unhealthy concentration recorded during the data collection, even if the CO2 concentration is higher than the 5000 ppm, the N H3 concentration still lower (<5 ppm).

The results show that the highest value of CO2 concentration was found with On/Off controller, it increases up to 8010 ppm, and these concentrations often exceed the harmful limits of 5000 ppm. These high values will occur so much energy consumption, especially within the ventilation system. Alaa Kiwan et al. [27] have been reported that the ventilation mechanism is required for evacuating harmful gases to guarantee indoor air quality and to meet the needs of both animals and humans.

On other sides, the mean value of CO2 concentration with MFLPID, fuzzy, and On/Off controller was 2461 ppm, 3294 ppm, and 3624 ppm respectively. It means that with the MFLPID control, the occurrence of finding a good AQI value (green color) is greater than that of the fuzzy and On/Off controller.

The maximum positive error for relative humidity and temperature for MFLPID is lower than that of the On/Off and fuzzy controller. It implies that the ventilation and inlet systems frequently work to decrease the excessive level of temperature and relative humidity. Additively the inlet system has proven its advantage in reducing the noxious gases (CO2, NH3).

The geometry of the building, the location of the actuators, and the algorithm implemented in fuzzy conditions had influenced the excellent control of the hygro-thermal parameters, and the concentration of noxious gases.

3.3. Performance of the broilers

Figure 15 shows the growth of the birds for 4 weeks.

As can be seen in Figure 15, there was a little deviation in the average body weight of the chickens between 10 and 17 days when the conventional controller On/Off is used.

However, we observed a significant correlation between the average weight of the birds and their reference weight especially during the first period (1–9 days) when the proposed controller is applied. The highest average daily weight was found in the first experiment (MFLPID controller) with an RMSE of 32.86g. This could be explained by the higher activity of birds, during this period, they eat more feed and are more active because thermal comfort is achieved. Similar studies have been announced [28] that the motivation of birds for feed influences the growth rates of the body weight of chickens.

In the second period, we noticed the littlest weight gained with an RMSE of 65.8g. This is due to the fluctuations of the hygro-thermal and air quality responses that could generate an inappropriate optimum level. In the third experiment, a higher average daily weight was again found with an RMSE 40.5g when the fuzzy logic controller is tested. Therefore, there is no significant difference between the daily weight of the MFLPID and FLC.

The authors declare that the hygro-thermal parameters and concentration ofnoxious gases influence the increase of the cumulative weight.

Consequently, the weight efficiency is evaluated at about 97% for MFLPID, Fuzzy and On/Off controller, respectively.

3.4. Performance of the actuators

Table 5 and Figure 16 illustrate a sample of the mean values of energy consumption by the actuators per day and their operation percentage.

As per Table 5, the total energy consumption of actuators on fuzzy controlling is less than that of On/Off controller system. The results demonstrated that the most extreme energy consumption is for the ventilating system in all cases of experiments, moreover, no critical distinction between the power consumption of the evaporative cooling system for the three controllers. In addition, minimum energy consumption is for heating, so this lowest energy item is identified to the hot conditions required during the breeding period.

On the other hand, the total mean value of energy consumption by actuators for the On/Off controller is (1798 Wh), for the fuzzy controller is (1190 Wh), and for the MFLPID is (1024 Wh). As a consequence, the energy savings reported by the MFLPID and fuzzy systems are estimated respectively around 43% and 34% compared to the On/Off controller. Related outcomes have been accounted in [19], they had presumed that energy reserve by fuzzy was 42% lower than that on/off in poultry house system for the winter season including ventilation, humidifier, and heater. Other results in [29], they had detailed that total energy savings by fuzzy were 36.8% lower than that of On/Off controller for buildings including cooling, lighting, and heating.

Figure 16 indicates that the frequency of closing and opening of actuators on the MFLPID controller is essentially lower than that On/Off control system. In addition, it very well may be seen from the
Figure 13. Results of MFLPID, FLC and On/Off performance on CO2 concentration.

Figure 14. Results of MFLPID, FLC and On/Off performance on NH3 concentration.

Figure 15. Comparison of the growth control of a group of chickens by applying the MFLPID, FLC and On/Off controllers.
performance percentage of actuators of On/Off system that use the maximum operation range (100%) compared to the MFLPID (89%) and the fuzzy (95%).

Finally, it tends to be concluded that the MFLPID structure controlling can be extensively decreased the energy consumption of system. A few results have affirmed the benefit of the fuzzy controller in reducing the power consumption [30, 31, 32].

4. Conclusion

In this work, a powerful technique for monitoring and supervising the microclimate of chickens has been designed and successfully implemented. Three controllers have been developed and tested to control the indoor climate of the poultry house system. It was noticed via the comparison between the recommended and experimental data that the MFLPID structure satisfies the comfort requirements of broilers with high efficiency and accuracy.

Generally, all controllers were able to control the poultry house and are applicable in any livestock buildings, but the proposed designed controller can achieve the optimal level of environment and growth factors inside the poultry house. A control system was designed and programmed to control the gathering data. Besides, the automation poultry house has been utilized as a platform where the last users can easily monitor and change the set points parameters.

Results from the statistical analysis of the hygro-thermal parameters confirm that the proposed controller had a lower deviation from the desired point and a little fluctuation. Moreover, the ventilation and inlet systems have demonstrated their benefits in reducing the CO2 and NH3 concentrations.

The experimental results from the actuator's performance demonstrate that the energy consumption can be saved to 43% with MFLPID compared to the conventional On/Off controller. In addition, the average body weight of the chickens during the growing period was well efficient with an amount of 97%.

It is worth pointing out that our proposal control scheme offers several benefits, which can be summarized as follows:

- The supervision and control can both be directed remotely, as it does not need the full-time presence of the livestock farmers;
- The developed controller ensures the system stability in the desired range with a less oscillation, and thus is ideally suitable for better production of broiler housing;
- The proposed method tends to provide optimum conditions for ammonia and Carbone dioxide concentrations (NH3, CO2), which reflected on behavior chickens during the growth time;
- Excellent dynamic and steady-state performance, due to the combined effect of PID and MIMO fuzzy controllers;
- The method has the capability to be energy-efficient and low-noise micro-climate for birds;
- The control design can be effortlessly programmed and implemented in a commercial broiler house, since that the fuzzy controller does not require a mathematical model about the system to configure the design of a working controller: it just employs the plant information sources, which are typically accessible through sensors on line.

It is also remarking that the method could be inappropriate if the decision-making and the knowledge base used are incompletely defined to decide the precise control action, as the fuzzy rules are the heart engine of our proposal.

In conclusion, the enhanced approach turns out to be more advantageous since the obtained results approve the superiority of the implementation of the MFLPID controller in the poultry processes.

Declarations

Author contribution statement

Ilyas Lahlouh: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.
Fathallah Rerhrhaye: Performed the experiments; Contributed reagents, materials, analysis tools or data.
Ahmed Elakkary: Performed the experiments.
Nacer Sehmani: Contributed reagents, materials, analysis tools or data.

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Table 5. Energy consumption of the actuators (Wh).

| Controller | Ventilation | Heater | Evaporative | Total |
|------------|-------------|--------|-------------|-------|
| MFLPID     | 472         | 248    | 304         | 1024  |
| FLC        | 530.56      | 305    | 353.9       | 1190  |
| On/Off     | 744         | 496    | 558         | 1798  |
Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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