Design and implementation of fuzzy control system for egg incubator based on IoT technology

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Abstract. Nowadays, automatic systems are using in more spheres of industry, and in this way, human intervention is avoided and used as minimally as possible. In the chicken poultry industry, the use of mother hens is transferring to automatic egg incubating systems. Such systems are helpful for the farmers to incubate the eggs automatically without the need for human intervention. These systems work by keeping the physical quantities, temperature and humidity, at the optimal level. In that way, the fetuses inside eggs are growing without the presence of the mother hen. The egg incubating systems not only improve poultry production considerably but also help in the regularity of income making, enabling the farmers to be able to get transition into possible rural entrepreneurship. This paper describes the design and implementation of a fuzzy control system for egg incubating based on IoT technology. The microcontroller is programmed to work as a fuzzy logic control system for controlling microclimate conditions in the egg incubator to keep the conditions for different eggs type optimal. Informations from the temperature and humidity sensors are sent wirelessly to the cloud. Also, the implemented egg incubating system enables automatic tracking of the remaining days until hatching chickens. In this way, remote monitoring, from any location, of microclimatic conditions inside the egg incubator is enabled. For the experimental work analysis of the implemented egg incubating system, the egg incubator is made. Based on the results of the experimental work analysis can be seen that the egg incubating system works well and that it helps with improving poultry production.

1. Introduction
The principles of artificial egg incubation were established centuries ago. Based on historical records, Paniago (2005) and van den Sluis (2011) mention that, in ancient Egypt, eggs were incubated in mud-brick buildings, called an "incubation house" [1]. In the upper part of the egg incubator were shelves for burning, straw, dung, or charcoal to provide heat. Vents in the roof allowed the smoke from the fires to leave and provided light. Humidity was controlled by placing moistened jute on eggs. The first mechanical incubator was built in 1749 (Reamur), and the first commercial incubator was built in 1881 (Hearson) [1]. In the last few years, artificial egg incubation systems have experienced a technological, economic, and social revolution [2]. In this paper is described the design and implementation of an egg incubator based on artificial intelligence and IoT technology. The fuzzy controller has been designed to regulate the temperature inside the incubator, which must be constant regardless of any disturbances that may occur. Also, all important microclimatic conditions inside the incubator are sent to the cloud (ThingSpeak platform) further to the Android application for a 24-hour insight into the proper operation of the incubator.
2. Required microclimate conditions for egg incubator

Different types of poultry require different egg incubation conditions as well as the duration of incubation. This is given in Table 1 [3].

| Species     | Incubation period/days | Temperature in ℃ | Humidity in % |
|-------------|------------------------|-------------------|---------------|
| Chicken     | 21                     | 37.5-37.7         | 90            |
| Turkey      | 28                     | 37.2              | 90            |
| Duck        | 28                     | 37.2              | 90            |
| Goose       | 23-28                  | 37.2              | 90            |
| Pheasant    | 23-28                  | 37.7              | 92            |
| Peafowl     | 28-30                  | 37.2              | 90            |

By the time the eggs hatch, the humidity is around 35%, and when they hatch, the humidity increases to about 90%, or vinegar is added to soften the eggshell.

2.1. Temperature

Eggs have four types of heat transfer: conduction, radiation, convection and evaporation [2]. Temperature control in the egg incubator is very important for successful incubation. Large temperature fluctuations in the egg incubator lead to a reduction in the number of hatched chicks. The transfer function in egg incubators is assumed to be:

\[ \frac{\theta_1(s)}{\theta_2} = \frac{1}{\tau s + 1} \]  

Where:  
\[ \theta_1 \] - max temperature in egg incubator (in our case 37.5 ℃)  
\[ \theta_2 \] - start temperature in egg incubator before turning on system  
\[ \tau \] - time needed for temperature rise to max in egg incubator

2.2. Humidity and air ventilation

During incubation, egg water content is absorbed by the embryo and fetus from embryonic annexes, where a small portion is lost to the external environment [3]. In addition, metabolic water is also produced inside the eggs by embryo lipid metabolism, and particularly by fetal lipid metabolism during the last week of incubation, accounting for 8 to 13% of the fetal water content [4]. Low air relative humidity during incubation may cause excessive egg water loss, resulting in embryo dehydration and death or the hatching of small and dehydrated chicks. If the air relative humidity is too high, the incubation period is shortened [5]. There is a consensus among studies that egg water loss should be approximately 12-14% of the initial egg weight [6].

2.3. Egg position and egg turning

The effects of egg turning and changing egg position influence on gas exchange and heat transfer between the eggs and the external environment, egg water loss, adhesion of the embryo and nutrient availability. The egg turning process is most important during the first week of incubation because of the long distance between the embryo and the eggshell. The position of the eggs in the egg incubator is critical for the formation of the air chamber inside eggs. If the eggs are in wrong position in the egg incubator results are embryonal oxygen deficit and delayed metabolism. Wrong positioning of the eggs may be related to slightly more rounded shape of the eggs, impairing the formation of the air chamber, and consequently, internal pipping [7] [9]. Figure 1 shows the candling method of chicken eggs. In Figure 1 can be seen the difference between healthy fertilized egg and unfertilized egg.
3. Design and implementation of fuzzy control system for egg incubator based on IoT technology

In this part of the paper, design and implementation of fuzzy control system for egg incubator based on IoT technology is described. The functional block diagram of the egg incubator system is shown in Figure 2.

This system consists of the sensors for collecting input information, the control system based on the ATmega 328 microcontroller, the actuators for maintaining micro climatic conditions inside the egg incubator and the nodemcu esp8266 module for sending and receiving the desired information to/from the cloud and android application [8]. Two thermistors with a value of 10 kΩ are used to measure the temperature, and sensor DHT22 is used to measure the humidity. The sensor manufacturer guarantees the accuracy of the sensor within the defined limits in datasheets. Providing enough humidity can be done in two ways. The first way is to place a container of water inside the egg incubator and due to the
higher temperature (37.7 °C) water will evaporate and the humidity will increase. Another way is to place additional heater for the water and thus increase the humidity. In this paper is used the first way. If the humidity inside egg incubator is higher than the desired humidity set by the user, the cooling fan is turn on, and in this way the humidity will stay in desired range. The cooling fan also is turn on to periodically ventilate the egg incubator. The ventilate period is chosen to be every 30 minutes. If the humidity exceeds 35%, the cooling fan is turned on until the humidity value returns in limits, i.e. 35%. Ventilation is periodically turned on every 30 minutes for air renewal and stays on for 3 minutes after which is automatically turn off. The Figure 2 shows that for cloud, the ThingSpeak IoT platform is used. Also, for easier access to data, an android application is designed. The temperature and the humidity read from the sensors and the desired temperature and humidity set form user are sending to the cloud. For the temperature control the fuzzy controller is projected. In the next part of the paper is described the designed of fuzzy logic controller for controlling the temperature inside egg incubator based on experiential knowledge.

3.1. Designing the fuzzy logic controller

The input data in the fuzzy controller is: an error between the desired temperature, i.e. the value of the temperature received from the user and the real temperature, and the error rate change. Those values are crisp and need to be converted to fuzzy values i.e. perform fuzzification. That is shown in Figure 3. Trapezoidal and triangular functions were used for fuzzification of input variables, and triangular functions were used for output variable. In Figure 3, abbreviations were used, the meaning of which is given in Table 2.

| Table 2. The membership functions. |
|-----------------------------------|
| Name | Meaning     |
|------|-------------|
| NH   | Negative High |
| NL   | Negative Low  |
| Z    | Zero         |
| PL   | Positive Low |
| PH   | Positive High |
| N    | Negative     |
| P    | Positive     |
| VL   | Very Low     |
| LOW  | Low          |
| MED  | Medium       |
| HIGH | High         |
| VH   | Very High    |
After creating the membership functions, the rules for Mamdani type fuzzy logic controller are created based on experience. These rules are listed in Table 3.

**Table 3.** The rules for fuzzy controller.

| ΔError | Error | PH     | PL     | Z      | NL     | NH     |
|--------|-------|--------|--------|--------|--------|--------|
| P      | HIGH  | MED    | MED    | LOW    | VL     |
| ZE     | VH    | HIGH   | MED    | LOW    | VL     |
| N      | VH    | HIGH   | MED    | MED    | LOW    |

After defining the rules need to choose the method of defuzzification. In our case, was selected centroid method of defuzzification because it gave the best results. These processes are graphically shown in the Figure 4.

**Figure 3.** The membership functions and range for input and output variables

After creating the membership functions, the rules for Mamdani type fuzzy logic controller are created based on experience. These rules are listed in Table 3.
It is now necessary to apply the designed fuzzy controller to control the temperature inside the egg incubator. In Figure 5 is shown block diagram system for control temperature using designed fuzzy controller.

In Figure 5, desired temperature is temperature received from user using android application. The temperature read from the temperature sensor returns from the output. The desired temperature and the real temperature are compared and their difference is sent in the fuzzy controller. Also, the error rise / decrease rate is sent to the fuzzy controller as a second input. From the fuzzy controller the output crisp value is send as a PWM signal to the MOSFET transistor which is used as an amplifier. The amplified PWM signal is send to four 10-watt tungsten bulbs.

Values $\text{Error}$ and $\Delta \text{Error}$ are:

$$\text{Error}(i) = T_{\text{des}}(i) - T_{\text{real}}(i)$$

$$\Delta \text{Error}(i) = \frac{\text{Error}(i) - \text{Error}(i-1)}{t_i - t_{i-1}}$$

Where is: $T_{\text{des}}(i)$ - the desired temperature in the i-th step,
$T_{\text{real}}(i)$ - the real temperature in the i-th step,
$\text{Error}(i)$ - temperature difference in the i-th step,
$\text{Error}(i - 1)$ - temperature difference in the (i-1)-th step
$t_i$ - current time i-th step,
$t_{i-1}$ - time in (i-1)-th step.
If the $T_{\text{real}}$ is lower than $T_{\text{des}}$ then $\text{Error}$ is the positive value. Else if $T_{\text{real}}$ is higher than $T_{\text{des}}$ then $\text{Error}$ is the negative value. If temperature rises then $\Delta\text{Error}$ is positive, else if temperature decreases then $\Delta\text{Error}$ is negative.

3.2. Implementation of fuzzy control system for egg incubator based on IoT technology

After designing the fuzzy controller, it is necessary to connect all system components based on Figure 2. After connecting all the components, the system shown in Figure 6 is obtained. The power supply to the system is 12 V. This supply voltage value is selected so that the system could operate smoothly in the case of a 220 V mains supply failure. NodeMCU ESP8266 is connected used serial communication with an ATMega 328 microcontroller and connected to 5 V power supply. In our case, an IRFZ44 MOSFET transistor with an additional heatsink is used. A voltage regulator 7805 is used to obtain a stabilized voltage of 5 V required for the working the ATMega328 microcontroller and ESP8266. After connecting all the components, the ATMega328 microcontroller is programmed to perform the function of a fuzzy controller and the ESP8266 microcontroller to send / receive data to / from the cloud using wireless communication.

Figure 6. Appearance of system for maintaining microclimatic conditions inside the egg incubator

For the implementation of the system, egg incubator size 26 x 36 x 20 cm is made of wood. Inside the egg incubator are placed four 10-watt tungsten bulbs as heater, LED strip, cooling fan, water container and stand for maximum 12 eggs. On the right side of egg incubator is placed display on which is showing temperature and humidity in real time. On the back side of egg incubator is placed hardware part of the system shown in Figure 6. In Figure 7 is shown appearance of the finished egg incubator system.
3.3. Designing android application

The design of the android application is done using the MIT App Inventor. Using free online software MIT App Inventor enables creating applications by dragging and dropping components into a design view and using a visual language blocks to program application behaviour [10].

3.4. ACloud

The designed android application sends the desired data (temperature and humidity) from user to cloud. This data are forwarding from the cloud to the created system for controlling the microclimate conditions in the egg incubator. From created system for control microclimatic conditions inside egg incubator, real temperature and humidity are sending to cloud and forwarded to android application. This is shown in Figure 9. As cloud is used ThingSpeak platform. ThingsSpeak is a free platform used to collect, visualize and analyze data in the cloud.
4. Results of experimental work analysis

After turning on the egg incubator system, the temperature inside the egg incubator rise very quickly to the desired temperature send from designed android application. After that temperature stay in the desired limits as well as the humidity. In our case sending data from the egg incubator system to the cloud is every 90 s, which is enough for such systems. The microcontroller reads from the sensor every 2 seconds, which is quite enough for the correct operation of this system. The power supply of the egg incubator system is $V_B=12$ V. The total electricity consumption of the designed egg incubator system from putting eggs to hatching of chickens is:

$$E = P \times t \approx 40.48 \text{ W} \times 21 \text{ day} = 40.48 \text{ W} \times 504 \text{ h} = 20402 \text{ Wh} = 20.402 \text{ kWh}.$$ 

The ventilator with a DC motor is used for ventilation and to reduce the humidity in case it increase above limits. For LCD display on egg incubator is used another termistor. This LCD display is using to visually confirm the temperature inside the egg incubator. In this way, the possibility of incorrect temperature reading via the main sensor is avoided. The ThingSpeak platform (cloud) is using to store, analysing and monitoring data. The android application is designed to access this data. The ThingSpeak channel and the designed android application is shown in Figure 10.

In Figure 10 (a) is shown the created ThingSpeak channel where in Field1 is Temperature read from the sensor, in Field2 is Humidity read from the sensor, in Field3 is Desired temperature and in Field4 is Desired humidity. In Figure 8 (b) is shown designed android application where at the top are...
text boxes for user to enter desired temperature and desired humidity values for the egg incubator system. Below those values in android application are shown read values the temperature and humidity from sensors. After analyze the data collected in ThingSpeak channel, is obtained that the average value of the humidity is 34.878 %, and the average value of the temperature in the egg incubator is 37.4568 ºC at set desired values humidity 35 %, and temperature 37.5 ºC. The average values for humidity and temperature are obtained on 2000 samples of received data. Time needed to collect 2000 samples on ThingSpeak cloud was 3 000 minutes or 50 hours. Based on results obtained from performed experimental analyze can be conclude that the designed fuzzy controller works very well and maintains the temperature within the desired limits. In our case under ±0.1 ºC. Humidity is maintained within the desired limit, in our case below 35 %.

5. Conclusion
In this paper, the fuzzy controller is proposed to control the temperature inside the egg incubator. The IoT system is designed to collect data from the egg incubator system and set the desired values. The android application is designed for easier access and assignment of data by users. An experimental work analysis of the designed system is performed, based on which it can be concluded that the designed system works properly.

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