AUTOMATION OF EXPERIMENTAL RESEARCH

APIARY MONITORING AND AUTOMATION IOT SYSTEM

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Abstract. A system of remote monitoring and automation apiary has been developed. This is a low-cost and scalable solution designed for deployment in distant rural areas. An unconventional solution is applying the industrial standard Modbus protocol to transfer data from the hives to a central server. This made it possible to reduce the cost of the system and standardize it. Monitoring the temperature and humidity inside the hives is important for analyzing the condition of bee colonies. The automation of the temperature and humidity control process is implemented based on a fuzzy model of the servo drive of the hive door.

Key words: internet of things, bee colony monitoring, automation of apiary, fuzzy logic.

1. Introduction

IoT (Internet of Things) technologies open up opportunities for the implementation of various solutions to solve advanced environmental problems. One of these problems is preserving the health and population of bees. IoT provides a solution to help beekeepers monitor and save their bee colonies. IoT can simultaneously help in a few different directions [1-4]:

– collection of accurate data for further analysis, monitoring, and prediction with a help of artificial intelligence technologies;

– automated microclimate control inside each hive;

– automation of the honey harvesting process.

In general, IoT technologies are often used for microclimate monitoring, where connected sensors collect data and provide information about the climate of specific areas. Temperature and humidity data, as well as data on other climate factors, can be collected and interpreted in real-time. Beekeepers apply this technology for remote monitoring of the activity of the apiary. Sensors installed inside the hives control humidity and temperature, which significantly affect the health of bees. When humidity or temperature approaches critical values, beekeepers can receive immediate notification and send a remote command to make the appropriate changes to normalize the microclimate in the hive [5-7].

2. Disadvantages

Currently, there are few solutions ready for the automation of an apiary based on IoT technologies, where various sensors, cloud technologies, and interconnectedness between devices are involved [1-2].

3. The Goal of the Work

The purpose of the current paper is to study and implement the IoT system for monitoring and automating the apiary system.

4. Apiary Monitoring and Automation System

To monitor the state of the hive, it is necessary to collect its basic parameters such as [8-13]: temperature, humidity, weight, and sound frequency as well as the state of the hive lid (open/close) and the temperature control door (open/close).

The controller, which is located in the hive, must transmit this data to the server with a frequency of at least 4 times per hour. Once critical values of temperature and humidity are received, the data should be sent immediately. Therefore, alarm notifications should be sent under the following conditions:

- the lid status was changed (opened/closed);
- the accelerometer detected the motion of the hive;
- the frequency of the beehive's sound signal reaches a critical level;
- there was a sudden change in the weight of the hive (decrease or increase);
- the temperature level in the hive reached the critical value.

There is the structural diagram of the IoT apiary automation system in Fig.1. We can highlight such functional components:

– server for collecting, aggregating, and storing data;

– communication protocol between the server and hive controller;

– microcontroller with sensors, which are installed inside each hive.

For apiaries, which in most cases are located in fields and rural areas, where the Internet signal is weak and the speed of cellular data transmission is low, it is more expedient to apply a local server with a SIM card installed in it. This makes it possible to report critical situations under any conditions.

To implement a local server, a Raspberry Pi 4 microcomputer with a processor clock frequency of 1.5

GHz was chosen. Its power is sufficient for processing and saving data, sending notifications, as well as executing the code of the graphical part (user web interface) [14]. Requirements for the server part are presented in Fig. 2

According to the above diagram, the beekeeper has access to monitoring of the real-time data, viewing statistical data on a graphical display, and the ability to receive notifications in case of emergencies. Another user is a researcher. Collected statistical data is available to scientists, which makes it easier and faster to study bee behavior and understand the problems of population decline. Since the server is located directly near the apiary, the optimal solution for implementing the client-server network is to apply wired communication. Cable communication is more reliable, because it is not affected by weather conditions and landscape, and has many standardized protocols.

One of the most common standards is Modbus. Modbus is a communication protocol for collecting data from sensors, controlling relays and controllers, monitoring, etc. All Modbus devices communicate following a master-slave model. Requests can only be initiated by the master device, and slave devices can only respond to requests and cannot independently initiate data transfer. The MODBUS RTU protocol and the RS-485 serial interface, which has the following characteristics, were chosen to implement communication at the physical level [15]:

- Up to 256 devices on one bus.
- The maximum length of data transmission is up to 1200 m.
- Maximum data transfer speeds up to 10 Mbit/s.
- Supports half-duplex and full-duplex data transmission.

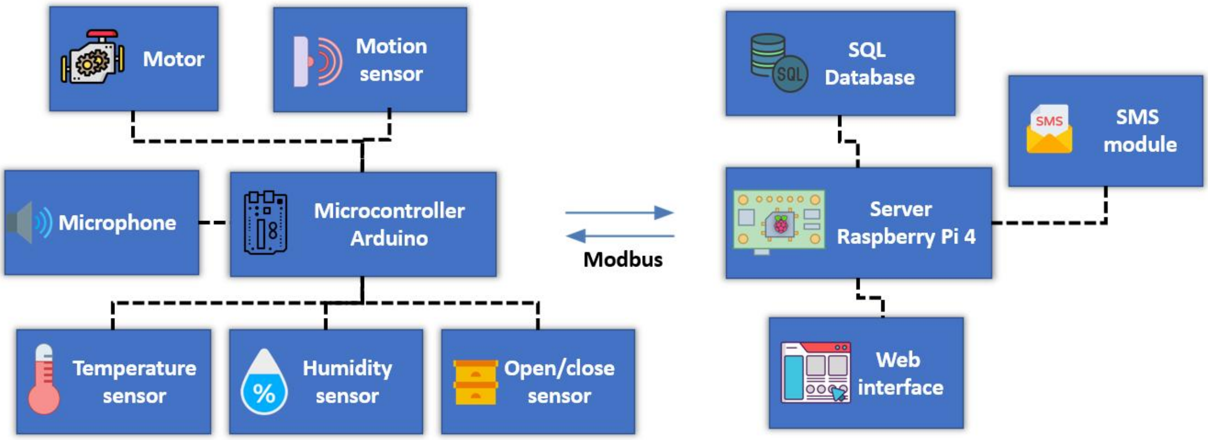


Fig.1. Structural diagram of the IoT apiary automation system

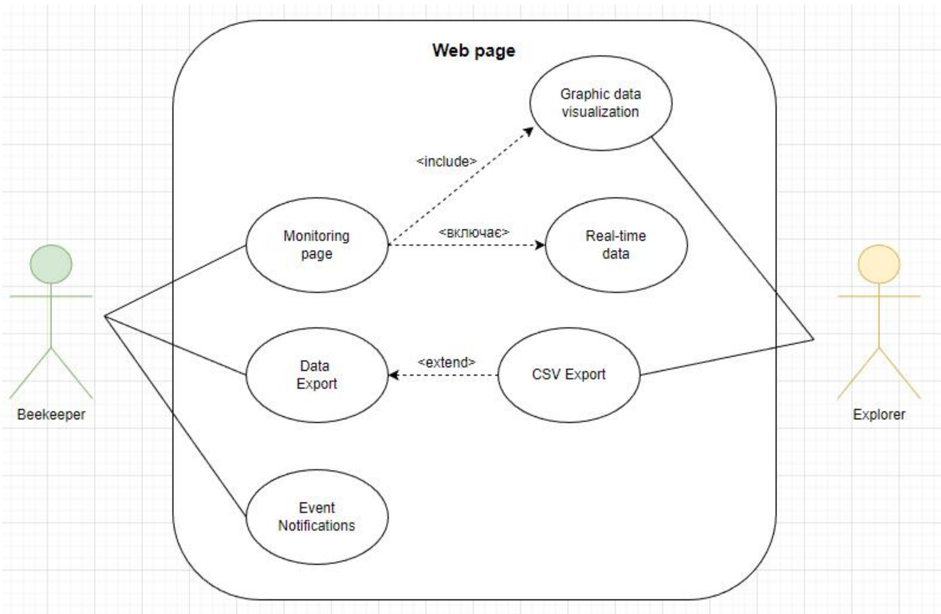


Fig.2. UML diagram of user interaction with the system

Arduino Pro Mini 5V is chosen as the controller for collecting data from sensors and sending data to the server. The board is equipped with an ATmega328 microcontroller and has 14 digital I/O ports [16]. The dimensions of the board are 1.8 cm x 3.3 cm. Connecting the RS-485 interface to Arduino is implemented based on the MAX485 TTL to the RS485 module [17]. The received data is stored on the server using the relational database management system SQLite using the constructed structural and logical diagrams of the database, which are presented in Fig. 3.

The necessary hive data is stored in the *hive* table. The *statistics* table stores the data received from the sensors and the timestamp. In the future, the data from the *statistical* tables can be analyzed and researched to improve the productivity of the apiary. Since one user can have several hives as well as apiaries, there is a table *apiary_has_hive* for grouping hives, for which a many-to-many relationship is implemented. It makes it possible to bind a hive to an apiary. Two tables *alert* and *alerts_log* are applied for sending notifications and viewing their history. The *alert* table is responsible for storing various notification templates, and *alerts_log* is for displaying the history of sent notifications.

The web interface is implemented based on the Flask microframework and the Python programming language. The framework provides the ability to template HTML pages and handle HTTPS requests. The web interface, in contrast to mobile applications, is more flexible and allows one to connect with various devices, including mobile phones and computers [18]. Implemented web interface (Fig. 4) gives the possibility to view real-time data as well as averaged data from previous days.

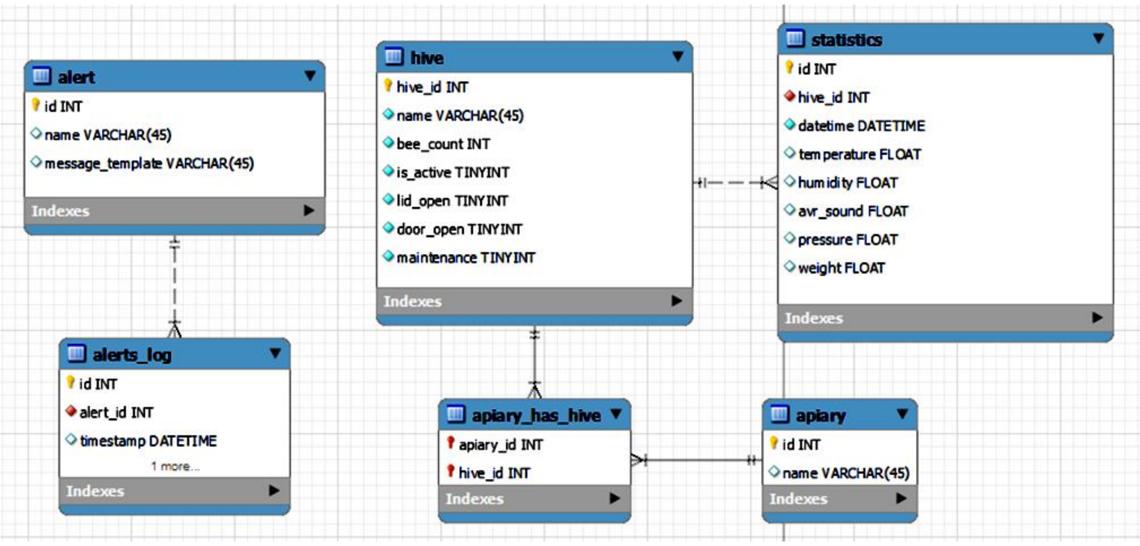


Fig.3. Data warehouse class diagram

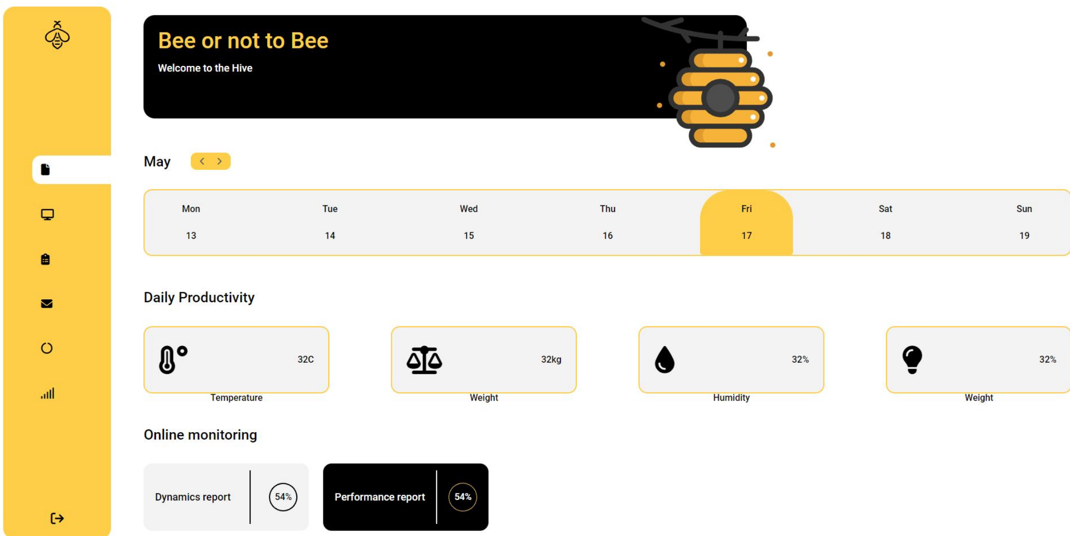


Fig.4. The IoT web interface of the apiary monitoring and automation system

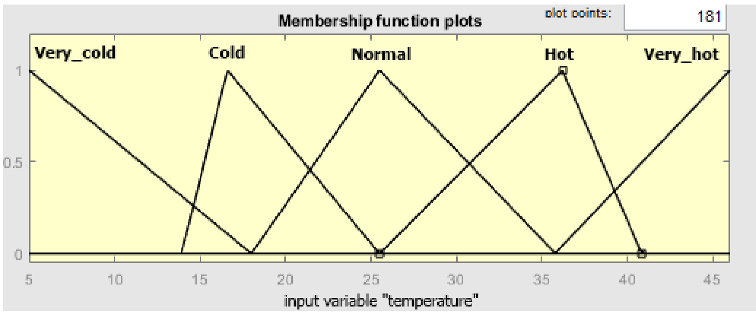
5. Development of a Model for a Fuzzy Logic Controller

Fuzzy logic was applied to implement the microclimate control and management algorithm of the hive. The application of this method of artificial intelligence in this system makes it possible to control the rotation angle of the servo drive to close or open the hive lid to regulate the temperature and humidity. The practical implementation of the fuzzy control task of the hive microclimate parameters was carried out based on the fuzzy FIS-editor inference systems from the Fuzzy Logic Toolbox, which is part of the MatLab R2021b mathematical modeling application package [19].

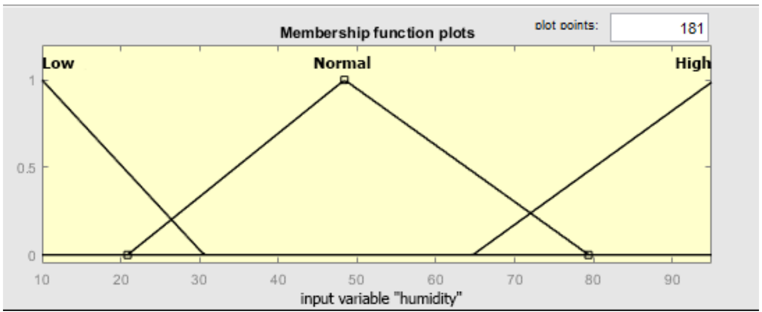
Temperature and humidity are selected as input parameters. The output parameter is the angle of rotation of the servo drive, which controls the beehive door mechanism. A triangular function was chosen as a function of dependency of the input and output variables. Based on the analysis of microclimate requirements in hives at different times of the year and existing recommendations for temperature and humidity [20], optimal conditions and their intervals are determined. The output variable is represented by five ranges that correspond to the angle of the servo, where 180° is fully open, 0° is fully closed. Graphs of membership functions of input and output variables are presented in Fig. 5.

To implement the system of fuzzy control of temperature and humidity, 15 rules of fuzzy inference were developed, which are presented in Fig. 6.

As a result, a surface visualization of the dependence of the servo motor rotation angle on temperature and humidity was obtained, presented in Fig. 7.



a



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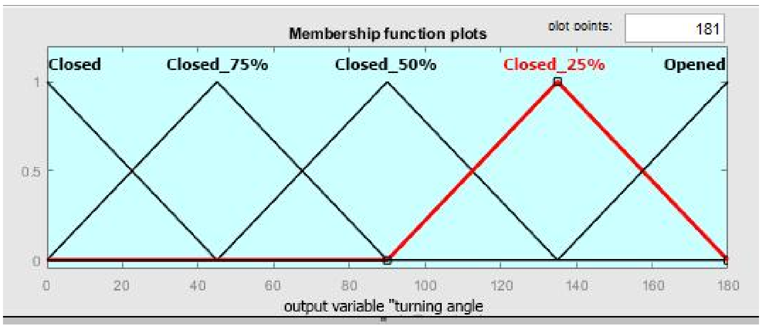

c

Fig.5. Graphs of dependency functions
a) temperature, b) humidity, and c) angle of rotation of the servo drive

1. If (temperature is Very_cold) and (humidity is Low) then (turning_angle is Closed) (1)
2. If (temperature is Very_cold) and (humidity is Normal) then (turning_angle is Closed) (1)
3. If (temperature is Very_cold) and (humidity is High) then (turning_angle is Closed_75%) (0.3)
4. If (temperature is Cold) and (humidity is Low) then (turning_angle is Closed) (0.2)
5. If (temperature is Cold) and (humidity is Normal) then (turning_angle is Closed_75%) (1)
6. If (temperature is Cold) and (humidity is High) then (turning_angle is Closed_50%) (0.3)
7. If (temperature is Normal) and (humidity is Low) then (turning_angle is Closed_75%) (0.2)
8. If (temperature is Normal) and (humidity is Normal) then (turning_angle is Closed_50%) (1)
9. If (temperature is Normal) and (humidity is High) then (turning_angle is Closed_25%) (0.3)
10. If (temperature is Hot) and (humidity is Low) then (turning_angle is Closed_50%)) (0.2)
11. If (temperature is Hot) and (humidity is Normal) then (turning_angle is Closed_25%)) (1)
12. If (temperature is Hot) and (humidity is High) then (turning_angle is Opened) (0.3)
13. If (temperature is Very_hot) and (humidity is Low) then (turning_angle is Closed_25%)) (0.3)
14. If (temperature is Very_ hot) and (humidity is Normal) then (turning_angle is Opened) (1)
15. If (temperature is Very_ hot) and (humidity is High) then (turning_angle is Opened) (1)

Fig.6. Rules of fuzzy inference

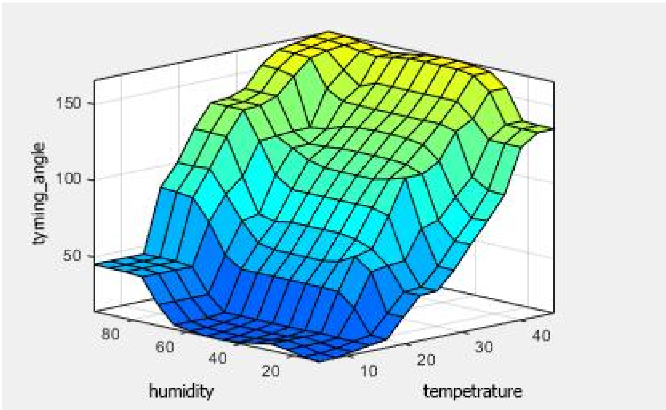

Fig.7. The surface of the dependence of the angle of rotation of the servo drive on temperature and humidity

Practically, the fuzzy logic system was implemented in the Python language based on Raspberry Pi 4. The obtained value of the angle of rotation is transmitted via the wire protocol to the Arduino Pro Mini 5V controller located in the hive.

6. Conclusions

The application of IoT and artificial intelligence technologies in the apiary monitoring and automation system provides an opportunity to obtain a cost-effective solution. A reliable hive monitoring system based on the wire protocol Modbus has been developed to measure hive temperature, relative humidity, and weight remotely in real time. The monitoring system performs synchronized data collection from all hives of the apiary, which is the basis for further data analysis and their comparison between different hives. The peculiarity of the monitoring system is the control of temperature and humidity parameters based on fuzzy control. Becomes possible to partially automate the monitoring and managing of the parameters of both an individual beehive and the whole apiary. The developed system is scalable according to the number of nodes and parameters of physical measurements. Its implementation permits to access the data via a local database server.

7. Gratitude

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8. Conflict of Interest

The authors state that there are no financial or other potential conflicts regarding this work.

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