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Intelligent Control System of Intra-Frame Beehive Heater

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Abstract

In this study, expert system software, proportional integrated derivative (PID) and fuzzy logic approach were tested on intra-frame beehive heater which was developed for beehives. With intra-frame beehive heater, it's aimed to prevent bee colonies from cold weather conditions and to allow them to turn into strong colonies rapidly. Today, using these three intelligent control method together ensures convenience to solve problems. Fuzzy logic approach which is the closest to human thought system gave the best result.

Keywords: Intelligent Control System, Fuzzy Logic, Expert System, PID Control, Heater Frame.

Introduction

Computers can solve very complex digital operations but they are inadequate at the point to realize and to use the information that is acquired by experiences. In an incident, the main property that makes human better is the ability to use information which is gained by neural sensors and relatively classified. Software that perform high cognitive functions or autonomous behavior such as sensing, learning, connecting multiple concepts, thinking, solving problem, communicating, making inferences and decisions are described as intelligent software.

Intelligent control approaches such as artificial neural networks and fuzzy logic don't need mathematical model and can be applied to nonlinear systems. Therefore, many researchers use intelligent control approaches in complex processes [1].In this study, PID, expert system and fuzzy logic approaches are used.

PID algorithm has a wide usage area in process control and motion control system applications because of its simplicity and trustworthiness. Expert system, basically, is a software that is operated by computer in order to perform human thoughts. While expert system is being developed, it's aimed to transfer to the computer expert's knowledge and experiences in a specific subject [2].

In these days, fuzzy logic has been frequently used in complex nonlinear control applications [3].Fuzzy logic works with fuzzy values between {0,1} boundaries[4].

In this study, it's aimed to control the intra-frame beehive heater that is developed for weak honeybees to keep in hive temperature value between suitable temperature ranges without harming the bees. Expert system, PID and fuzzy logic are used to adjust the suitable temperature in hive. These control methods were tested in the same conditions to determine which of them contributes to the growth of weak bee colonies at the appropriate temperature. Fuzzy logic approach gave the best results.

Materials and methods

In general, proposed system is composed of three basic units. These are photovoltaic panel, regulator and battery unit, heater frame and temperature sensors and RF (Radio Frequency) unit. Block diagram including these three basic units is indicated in the fig.1.

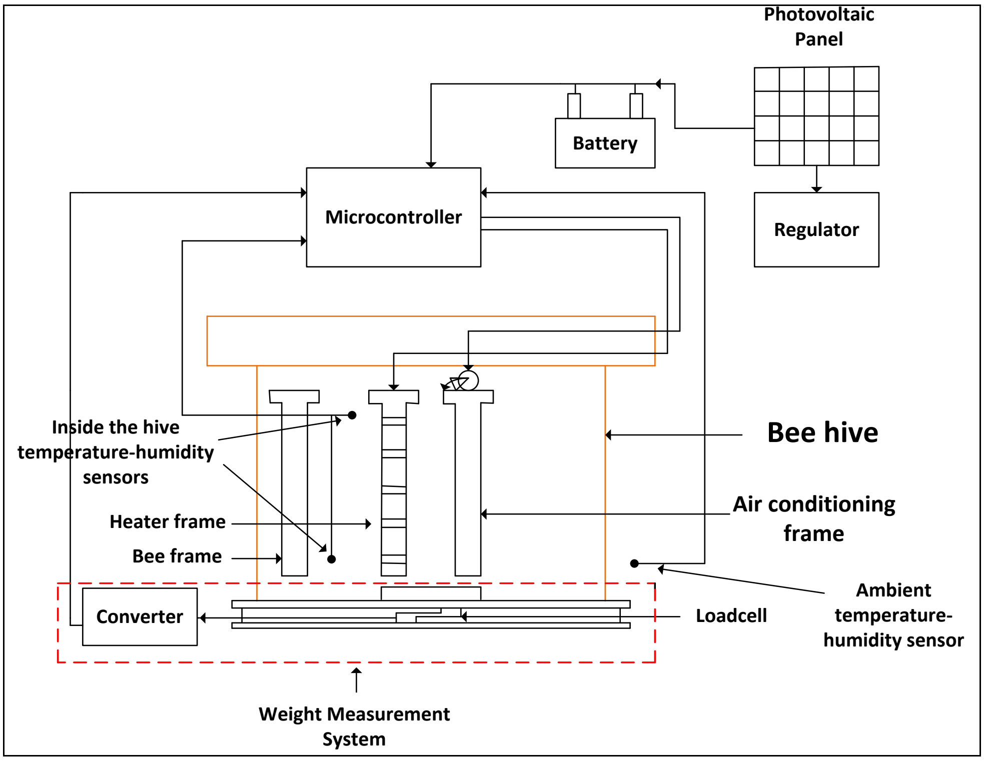


Fig.1. General diagram of the system which controls the in hive.

a) Temperature, humidity and weight measurement

Temperature, humidity and weight measurements were done in Turkey in the Sinop district from 1st July till 30st July, 2012. The sensors were installed in one colony. The hive had Caucasian queen bee and approximate 2000 worker bee. SHT11 temperature and humidity sensors were placed in hive. Also, one sensor was placed outside the hive. The beehive's weight was measured in order to observe the flow of honey. For this purpose, load cell was placed under the hive. The colonies weight increase was observed by measuring hive's weight constantly. Measurements were requested and recorded by computer using 1-Wire bus via RF communication. The sensors were connected with each other and the computer by cables. Measurements were done throughout the day and night, 15 times per minute thought out the experiment and transmitted to a remote computer via serial port.

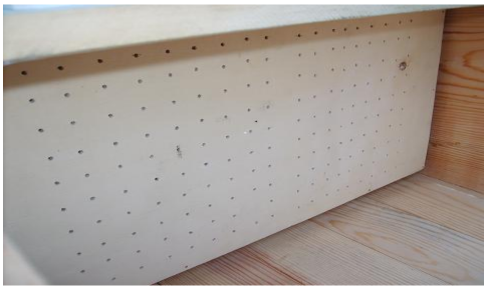
b) Intra frame beehive heater design

Honeybees have a division of labor mechanism. While young bees take part in adjusting the appropriate temperature and humidity values in hive and hive cleaning, bigger ones take part in collecting food from outside. 32ºC-36ºC temperature range which is necessary for growth of offspring is adjusted easier and colony growth is faster [5].

Temperature and humidity values are the most effective factors that affect honeybees except diseases and pests. Actually, when appropriate temperature and humidity values catched, possibility of diseases and pests also decreases. Honey production increases. Because of decreased humidity rate in honey, quality of honey increases. It is easier to adjust the temperature when the number of bees in the hive is more [6]. Honeybees satisfy the needs of energy which is necessary to adjust the in hive temperature to appropriate values by consuming the sherbet and honey. When the ambient temperature decreases to 19°C, metabolic rate ratio of bee colony increases from 7 watt/kg to 19 watt/kg [7]. The generated temperature was estimated for each bee, the equation in eq 1 was found [5].

$$The\ each\ per\ honey\ bee\ temp\ (t)\ = \frac{(brood\ weight\ tempT(t) - ambient\ tempT(t).NlarvalCell}{N\ heating\ bees(t)} \quad (1)$$

Number of worker bees takes a big part of distribution of the temperature in the hive. Weak bee colonies can't adjust the appropriate temperature in the hive and can't satisfy necessary nutritional needs, because they are not sufficient numerically, therefore, they die down soon. Bee colony that is used in this study consists of 2000 worker bee. This colony can't adjust the temperature in the hive, so intra-frame beehive heater was designed to give vital support to bees. Fig 2. Shows the shape of the heater frame.



Heaterframe

Internal structure of the heater frame

Fig. 2. Intra-frame beehive heater.

Intra-frame beehive heater works with 12V. 36W heater does not spread any vibration or noise. It consists of horizontally aligned 9 row wire resistance. Temperature spreads into the hive through the holes that on the outer surface of the heater frame. The holes are smaller than 2,5 mm, so bees can't get into resistance. Resistance was isolated from wooden material by using porcelain stones. The wire that is used as resistance has 1,09Ω/mm2 resistance at 20C°. Intra-frame heater is given at Fig 3.

Fig. 3. The heater in the placement of beehives.

To get information from hive to the computer such as temperature, humidity and weight, a microcontroller based system has been developed. 18f452 microcontroller that produced by MicroChip Company was used for this purpose. Microcontroller sends the data to the remote computer via radio frequency communication moduls. Block diagram of the system is given at Fig 4.

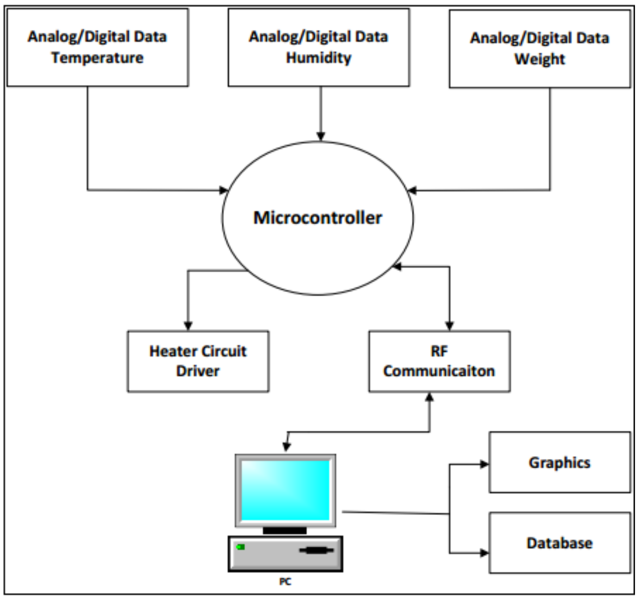


Fig. 4. Block Diagram.

Computer both visualizes and saves the parameters read from serial port instantly on the database. During the tests of heater frame to heat the hive, information related to test was also saved. Developed software were embedded into microcontroller. Software were written in mikroC.

So many researches have been made about honeybees. To ensure temperature isolation in the hive top of the hive was covered with polythene (PE) and a microclimate was developed[8]. Meitalovs J. and his friends designed a hive observation system to get images from inside of hive and to observe ambient conditions. It is estimated 6 days in advance when the hive will give swarm by analyzing the sounds of bees in the hive [9]. The experimental carried beehives is given at Fig 5.

Fig. 5. Experimental hive.

Optimization algorithms was developed by examining the food collecting and social behaviors of bees. Researchers investigated which factors affect the bees while they create temperature and they found that air circulation is one of the most important reasons [10]. To determine Varroa mites in the hive, electronic observation was realized [11].

c) Control Methods

PID is a control method. PID parameters (P: Proportional, I: integral, D: derivative) do not change during the control process. Therefore, its hard to get a good control performance from PID algorithm when system status or parameters change. PID algorithm does not guarantee a qualified control [12]. For PID algorithm, function that shows the relationship between input and output given at eq (2).

$$u(t) = Kp\left[e(t) + \frac{1}{\tau i}\int_0^t e(t)dt + \tau d\,\frac{de(t)}{dt}\right] \quad (2)$$

u(t) refers to control output, e(t) refers to error as the input of controller, *kp* refers to proportional gain, *ti* refers to integral time and *Td* refers to derivative time[13]. PID algorithm was used to design an internal-combustion engine by [14]. Also, intelligent PID algorithm is being used in many applications including water level [15] and water pressure control systems [15].

Expert system is an intelligent computer software that solves the real world problems by using human's knowledge and reasoning skills [16]. Expert system uses artificial intelligence principles. The heart of an expert system is knowledge base. Knowledge base is a database which consists of intuitive and real data. Expert system consists of a knowledge base that holds information about the problem to be solved and a decision mechanism that infers by using these information. Inference rules are constituted with simple *IF* rules. The block diagram of an expert system is given at fig 6.

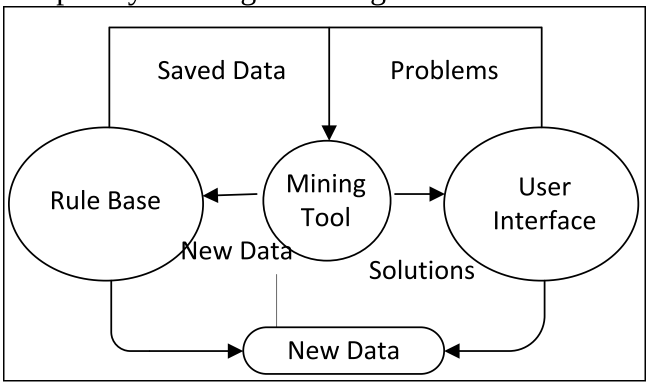


Fig. 6. The block diagram of an expert system.

Expert system can be used in assessment of proficiency [16] and stages of recruitment. Expert system used in agricultural applications to detect and control diseases on plants [17]. Sun Xianglin used artificial neural network-based expert system in design of high-voltage circuit breaker [18]. Wang Jiangping used artificial neural network-based expert system in fault detection of drilling operations [15], Li Zhigang also used artificial neural network-based expert system in water-saving irrigation systems[19]. Zhang Weigong used expert system as an early-warning system [20]. In adjusting the oven temperature [21] and many other applications, expert system is successfully applied. Expert system is also applied successfully with neural Networks in geographical information systems and remote search of plant disease and pests [22].

Fuzzy control is a control method based on fuzzy logic. It is possible to develop the verbal formulation of system model by using linguistic expressions. The accuracy of this formulation can be detected by observing it during the test or actual operation of system. Faults could be prevented using the differences between situations of variables [23]. A fuzzy controller consists of fuzzification, inference, knowledge base and defuzzification units. A fuzzy logic mechanism has been given at Fig 7.

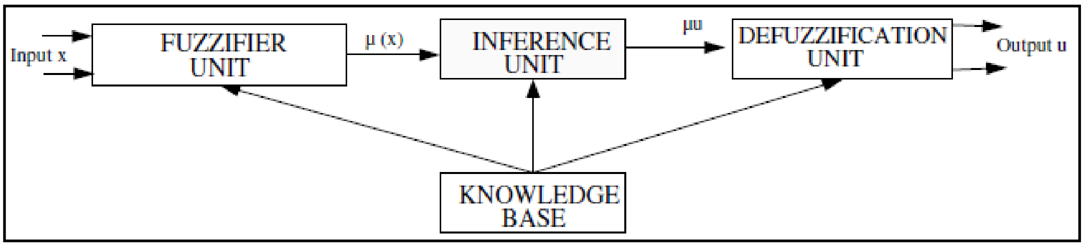


Fig. 7.Fuzzy logic controller.

In a fuzzy logic controller; x is the input value, $\mu(x)$ is the fuzzified value, $\mu(u)$is the inference result and u is the output value. Fuzzification unit converts the input data to linguistic variables. Knowledge base contains two basic data. These are database and rule base. Database contains definitions for each system variable while rule base covers control rules necessary to get the actual output. Inference unit constitutes fuzzy inferences according to rules. Inference unit performs operations similar to human's way of thinking. Defuzzification unit allow us to get digital data that is usable in real world from fuzzy values [24].

Fuzzy logic is being successfully applied in many areas such as an agriculture robot[25] and detection of various diseases in the field of health[26]. As an example, a fuzzy logic controller has been used to adjust the level of sugar in the blood[27]. A static compensator control has been established by using the mamdani method in fuzzy logic controller[28]. To detect the blows to head, fuzzy logic was used in the neurosurgical intensive care unit[29]. In robotic applications adaptive fuzzy logic controller is used to follow the trajectory[30]. In cities, fuzzy logic is used to control traffic lights for more efficient traffic transportation[31]. To get maximum energy from solar panels fuzzy logic approach is used[32]. Small intelligent vehicle designs are made using the fuzzy logic[33]. Fuzzy logic is used to increase energy efficiency in embedded fuel cells[34].

Experimental Study

To determine the situation of the weak bee colony and to understand which parameters need to be controlled during the control experiments, in hive temperature and humidity, out of hive temperature and humidity, hive weight was measured and saved for 10 days. Measurement dates are between 05/07/2012-14/07/2012.

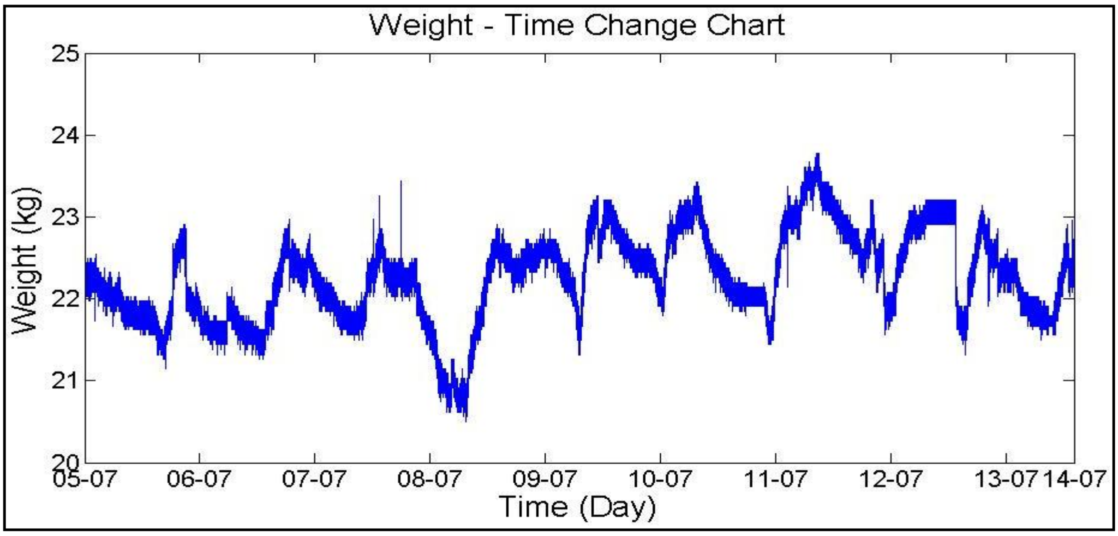


Fig. 8.Weight of the hive.

Fig 8 shows the hive weight graphic. At the beginning of the experiment weight of the bees in the hive was 1,5 kg. Values shown in the graphic are total weight of the hive. After 10 days of observation, bee weight 0,1 kg increased. It is clear that obtained increment which in 10 summer day is not enough for weak bee colony to spend the winter.Temperature values that were taken during 10 daysare given at Fig 9.

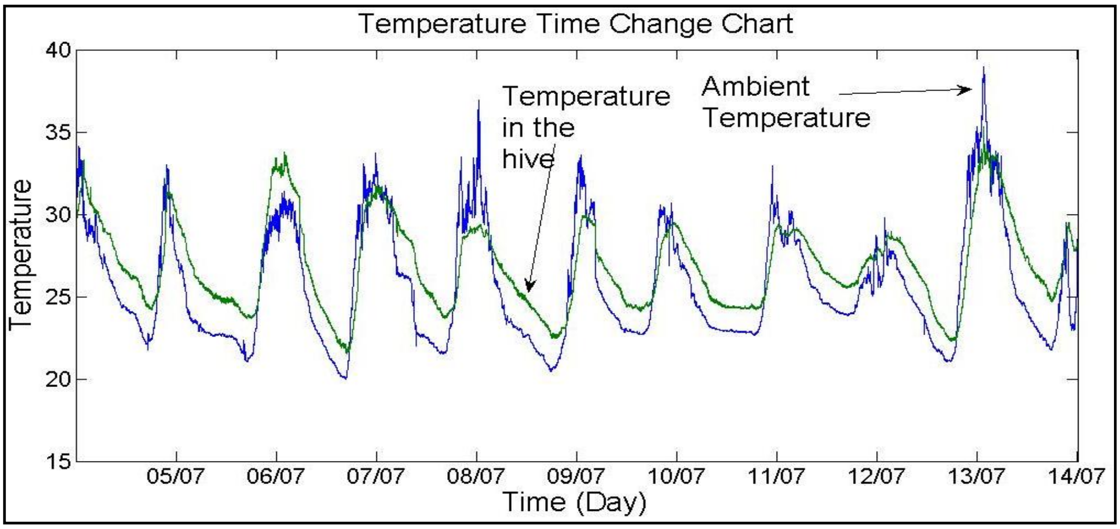


Fig. 9. Temperature values of the hive and ambient.

When ambient temperature drops to 19°C, inside temperature of the hive that holds the weak bee colony drops to 21°C.Weak bee colony doesn't have the ability to heat enough inside the hive. It is hard for weak bee colony to turn into a normal colony at this temperature. Especially in winter, it is not possible for this weak bee colony to survive. Humidity rates that were measured during the observation are given at Fig 10.

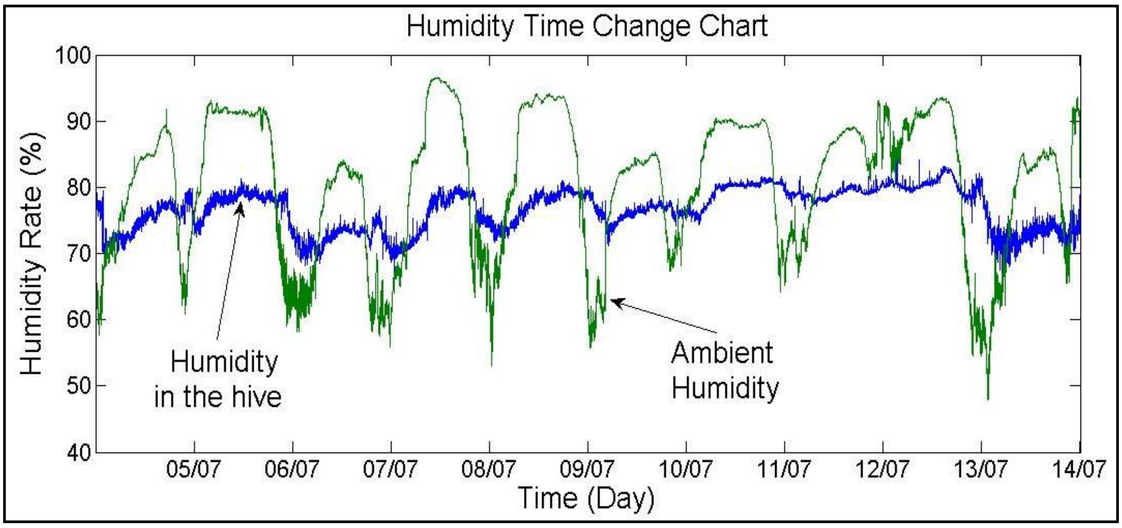


Fig. 10. Humidity rates of hive and outer ambient.

As can be seen from the graph, when humidity rate of the outer ambient exceed 90%, humidity rate of the hive rises to 80%. Because weak bee colony can't make enough air-conditioning in the hive. Humidity levels greater than 80% in the hive causes slowdown in the vital activity of bees and it can cause bee deaths if takes longer.

a) Expert system experiment

As a result of the observation experiment, it can be seen that temperature and humidity values are not appropriate for bees. Also, weight increment of the hive is not as expected. In cold climate conditions hive must be heated for growth and transformation of weak bee colony to a healthy colony by considering that weak bee colony can't heat the hive enough.

The control of the beehive was established with expert system to give vital support to weak bee colony and to allow them to transform into a strong colony. In expert system, knowledge base consists of cluster of inference rules of in hive appropriate temperature and humidity. These rules were created by analyzing the results of observation experiment. Fig11 shows the temperature values that were measured during the expert system experiment.

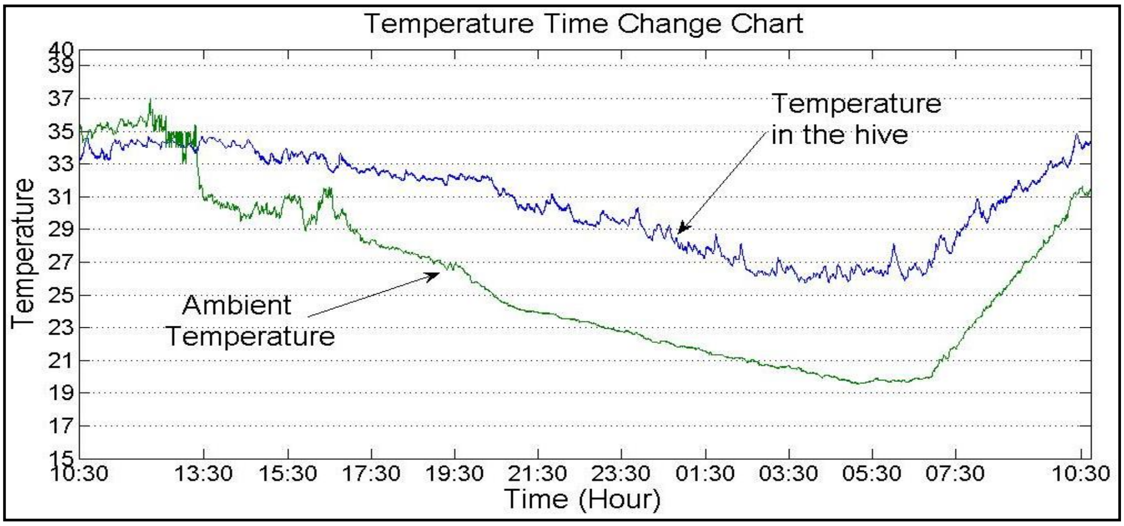


Fig. 11.Temperature values of inside and outer side of the hive.

In hive, temperature increased 4°C with expert system. Humidity level kept constant at 60%.Therefore, appropriate temperature and humidity values for weak bee colony was ensured in the hive. Humidity level graph is given at Fig 12.

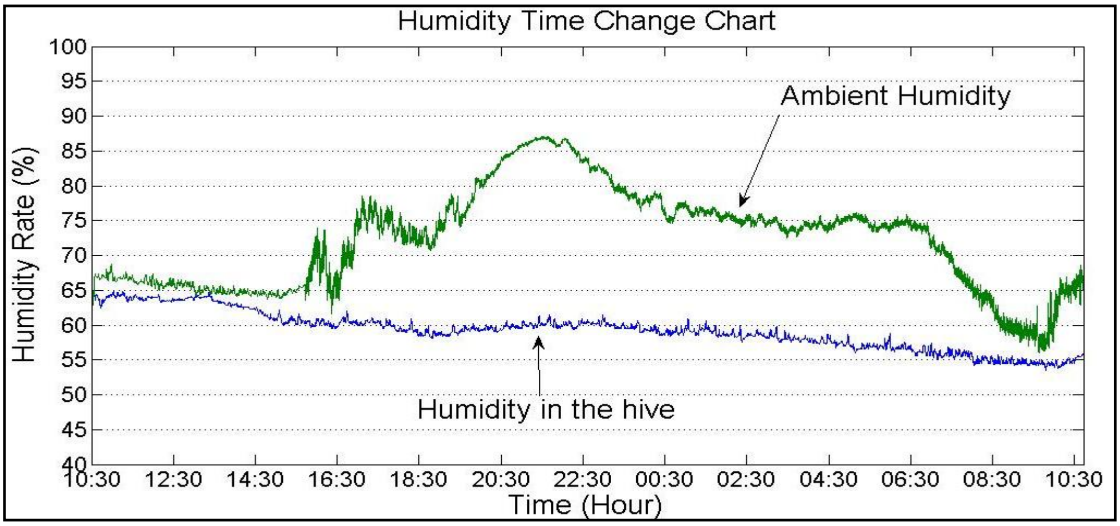


Fig. 12.Humidity rates of inside and outer side of the hive.

b) PID experiment

Temperature control was realized inside the hive using PID. Because it is understood from observation experiment that weak bee colony can't heat the hive enough in winter. While the temperature rises in the hive owing to PID control there was no sudden increase in temperature (It could be harmful on bees)and set point of temperature(32°C) was reached in time.

```
start:
  error = setpoint-actual_position
  integral = integral + (error * dt)
  derivative = (error-previous_error) / dt
  output = (Kp * error) + (Ki * integral) + (Kd * derivate)
  previous_error = error
  wait(dt)
goto start
```

Values of *Kp, Ki, Kd* and *dt* parameters changed until appropriate graphical results were obtained using Ziegler Nichols method. Optimum parameter values were found by this way. *Ki* = 0,8; *Kp* = 0,45; *dt* =

2; *Kd* = 0 and desired temperature value was set to 32°C. The reason of the 0 value of the *Kd* parameter is that bees give reaction to sudden temperature changes. Temperature graph is shown at Fig 13.

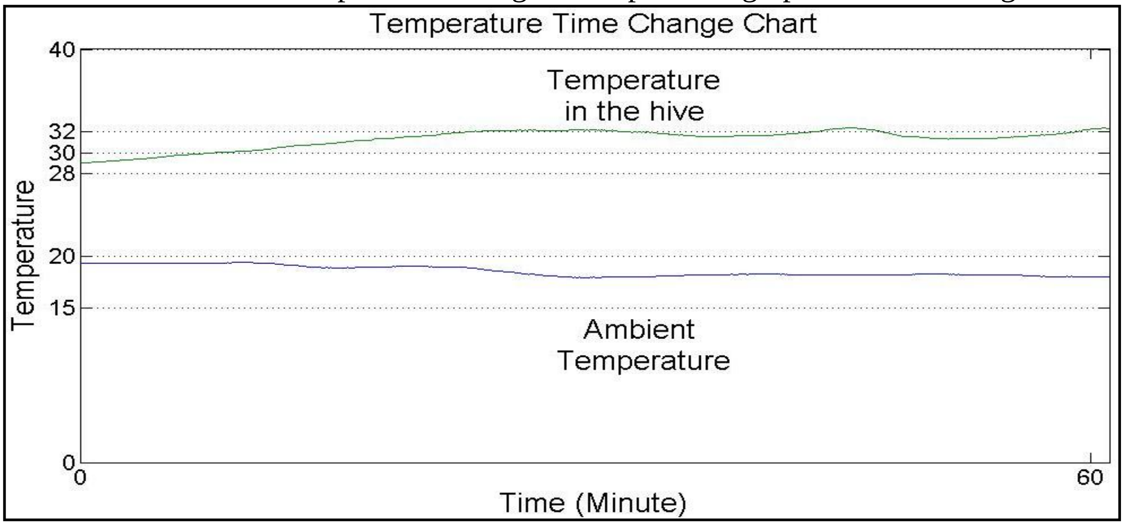


Fig. 13.Temperature values of inside and outside of the hive.

Inside and outside of the hive humidity values that were measured during the PID experiment are shown in Fig 14.

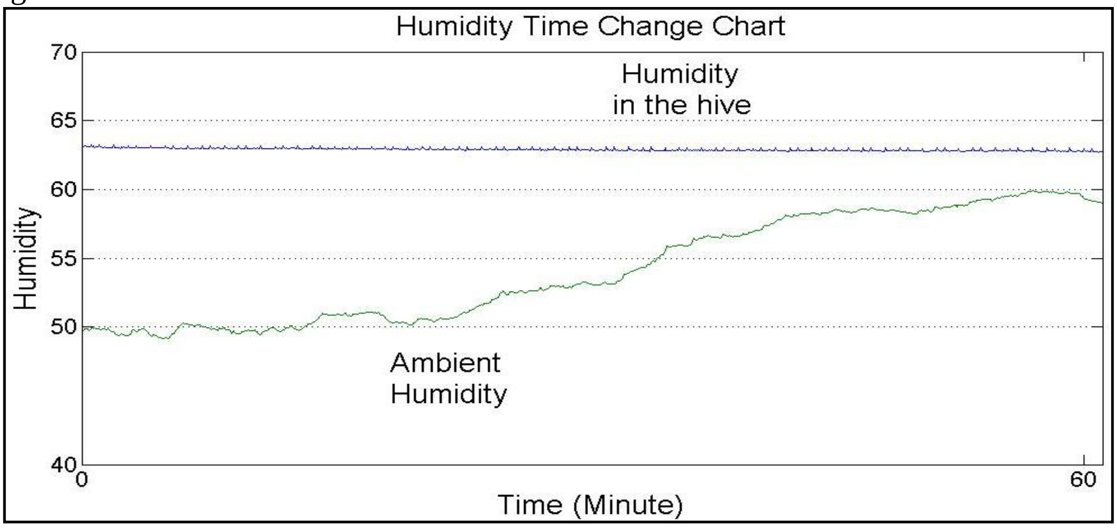
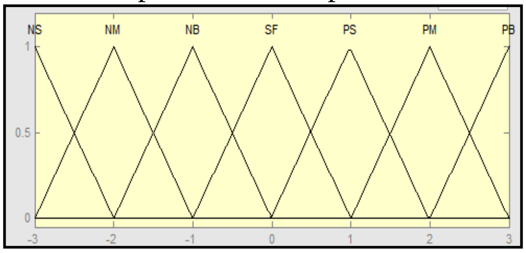


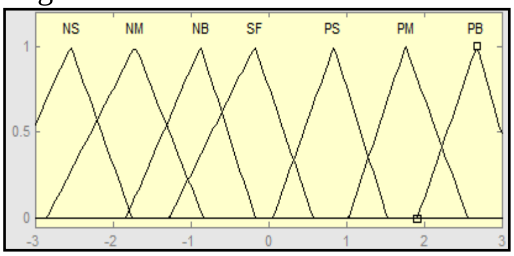
Fig. 14.Humidity values of inside and outside of the hive.

c) Fuzzy logic experiment

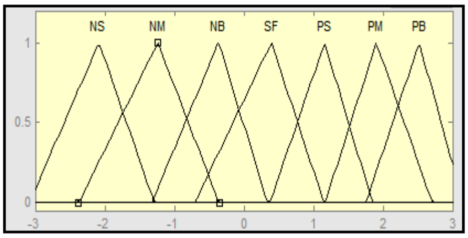
Temperature in the hive that is one of the most effective factors on vital activities of honeybees have been controlled with fuzzy logic at appropriate intervals. Fuzzy logic consists of two input function as error *(e)* and error change (*e(t)*). Output function is the input value of heater via Pulse Width Modulation (PWM) that ranges between 0-255. There are 7 input-output function and 49 rules. Error function, the error change function and the output membership function are shown in Fig 15.



I. The error input membership function



II. The error change input membership function



III. The output membership function

Fig. 15. Error input membership function, the error change input membership function and the output membership function.

Membership function's linguistic expressions were determined as NB, NM, NS, SF, PS, PM and PB (Negative Big, Negative Medium, Negative Small, Zero, Positive Small, Positive Medium, Positive Big). Error data that was obtained by subtracting the temperature value from set point were applied to error input function which contains 7 membership functions. Error change was estimated by subtracting the current measured error from previous.

Error change was applied as an input to error change membership function. Input values were converted to fuzzy values by using fuzzy logic software. Fuzzy values and membership function names that are on the intersecting points are saved for inference and defuzzification operations.

Mamdani method was chosen as fuzzy inference method. Determination of output membership functions was made according to rules. Before defuzzification the names and values of output membership function were estimated. Weight average method was chosen as defuzzification method. The average weight was calculated by computing the center of gravity of membership functions that affects the output. Table 1 shows the rule base.

Table1. Rule base.

e / e(t)	NB	NM	NS	SF	PS	PM	PB
NB	NB	NB	NB	NM	NM	NS	NS
NM	NB	NB	NB	NM	NM	NS	NS
NS	NM	NM	NS	NS	SF	PS	PM
SF	NS	NS	NS	SF	SF	SF	PS
PS	NS	SF	PS	PM	PM	PB	PB
PM	PS	PS	PS	PM	PM	PB	PB
PB	PB	PB	PB	PB	PB	PB	PB

While controlling the temperature of the hive, the most important factor to be considered is that bees are disturbed from sudden temperature changes. The rule base was developed by the way suitable for this purpose. Inside and outside temperature and humidity values of the hive and output membership function's values were saved during the experiment. The temperature graph is given in Fig 16.Fuzzy logic and PID experiments drove along 60".

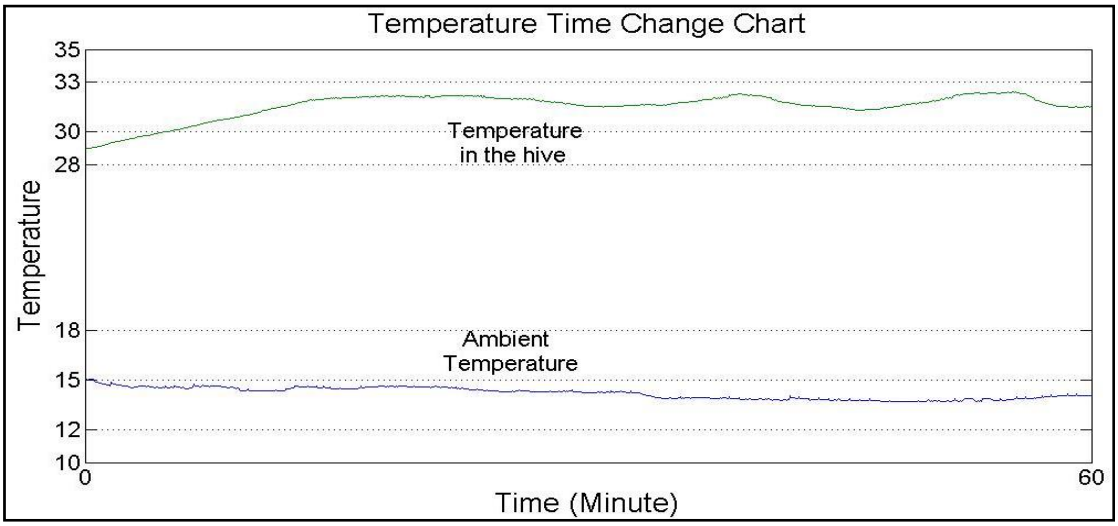


Fig.16.Temperature values of inside and outside of the hive.

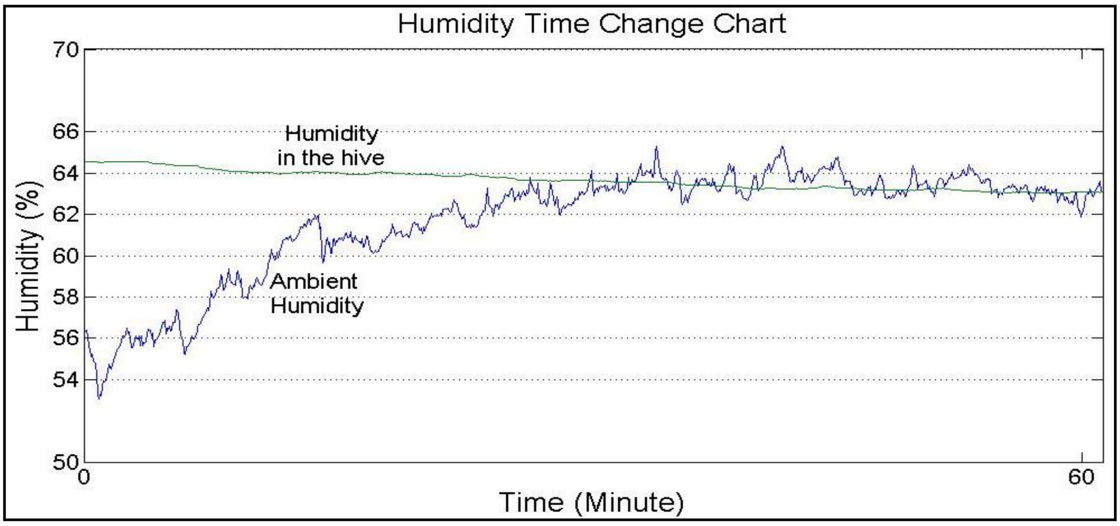


Fig. 17.Humidity rates of inside and outside of the hive.

As given in Fig17, while adjusting the appropriate temperature values, humidity values were also adjusted. Expert system software was operated for a day. With this system some duties such as heating the hive and removing the excess moisture from the hive fulfilled automatically which is normally fulfilled by bees. This situation leads the bees to other duties. It is observed that the number of flies is more because of the appropriate values in the hive. This increment is reflected to the amount of produced honey. Bees were engaged in air conditioning and heating business less.

Conclusion

The appropriate temperature and humidity values which are necessary for weak bee colony to grow up and to transform into a healthy colony, were adjusted with expert system. In developed system; temperature of the hive was fixed to 26°C in the hive control with expert system software experiment. Outer ambient temperature drops to 19°C during the experiment. It is ensured that there is 4°C increment in temperature of the hive. Humidity rate in the hive adjusted to 65%. Humidity rate of the outer ambient is around 80%. These values show that developed hive design and expert system software is successful and applicable.

Beekeepers, in winter, recover weak bees by combining or leave them to their fate. In winter, temperature drops excessively and bees die. Because they can’t heat the hive enough. To learn whether the heater that was developed for this study could heat enough the hive or not, usability of PID and fuzzy logic software were determined. In this study, experiments started when the temperature of the hive was 29°C and it is desired to fix the temperature to 32°C.Test time was determined as 1 hour. Fig 18 shows the comparison of the experiment results.

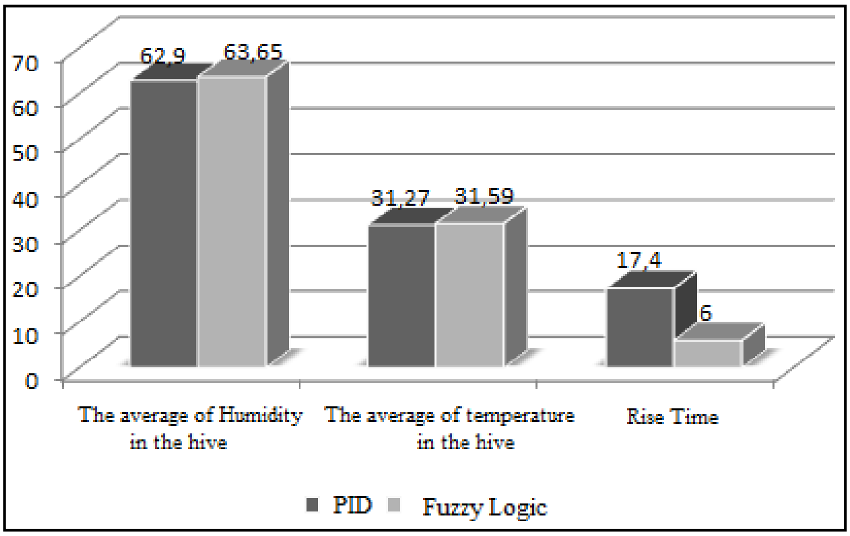


Fig. 18.The comparison of the PID and fuzzy logic experiment results.

As can be seen from experiment results, temperature of the hive can be controlled with PID and fuzzy logic. Figure 16 shows that fuzzy logic gives better results than PID. Fuzzy logic reaches more rapidly to set point of the temperature. Also average temperature of the hive is higher.

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