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UAV FLIGHT SAFETY SYSTEM BASED ON FUZZY LOGIC

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Abstract

The article proposes a method of deciding on the continuation or termination of the UAV flight on the basis of fuzzy logic to ensure its trouble-free flight, which will be used in the future to build an onboard monitoring system of the power supply of the unmanned aerial vehicle. The developed method of decision-making allows to determine the residual battery life on the basis of data on current voltage, battery temperature, temperature on board the UAV and the direction and strength of the wind, using which the computer system will make recommendations for continuing or terminating the UAV flight task. The method of decision-making using fuzzy logic involves the formation of linguistic variables, which are the input information parameters and the output decision, their linguistic terms and membership functions, as well as a system of rules for decision-making. The voltage at the output of the battery, its surface temperature and the wind direction on board the UAV were used as input variables, and the residual battery life was used as the output linguistic variable.

Keywords: LPAB, unmanned aircraft, fuzzy logic system, method of decision-making.

1. INTRODUCTION

Today, it is difficult to overestimate the popularity and importance of using unmanned aerial vehicles (UAVs). Every day humanity finds new applications for UAVs, thus making certain upgrades to flying assistants. Along with the need to perform flight tasks of the UAV, one of the important problems is to ensure the trouble-free flight of the UAV and the safe return of the aircraft to the base. On the vast majority of used UAVs with electric motors, control of the discharge of batteries (AB) is not carried out at all. The most widely used method is the time method of predicting the flight time of a UAV. It consists in planning the flight time of the UAV according to the manufacturer's specification with a conscious reduction of it in view of the possible change of air situation factors. And all these actions are justified, because the discharge of the battery below the allowable level means stopping the electric motors and, accordingly, can lead to the loss of the aircraft. The second common way to provide the required amount of electricity to perform a flight task is redundancy, ie the installation on board of several AB with automatic switching between them. The disadvantage of this method is the inevitable reduction in the payload of the UAV, which reduces its consumer performance [1].

The most widely used in UAVs are lithium-polymer batteries (LPBs), which have a number of advantages over other portable power sources. LPABs are characterized by high specific energy values, high voltage levels and low self-discharge. However, when using them, excessive charge or discharge currents, short circuits, overcharging of batteries above or below certain voltage levels, as well as exceeding the maximum allowable temperature of the batteries are not allowed. Failure to comply with these requirements may result in accidents and, in the worst case, loss of the UAV or the information and equipment contained therein [2].

To solve these problems will help intelligent systems that use methods of operational monitoring of the state of AB, based on the use of sample characteristics and parameters obtained in real time – without additional energy loss. This will allow you to assess the current state of the battery and predict the battery level.

Thus, forecasting the duration of the UAV flight and recommendations for the continuation of work or landing of the latter (to minimize the risk of loss of the aircraft or its data) is particularly relevant. This problem is solved by the proposed method of monitoring and forecasting.

The method of deciding on the possibility of stopping or continuing the UAV flight task is based on obtaining information about the current state of the voltage at the UAV output, its surface temperature and ambient temperature. Based on the experimental data and mathematical models of bit and temperature characteristics of the LPAB, the method of making the initial decision is constructed.

Decision-making takes place using a fuzzy logic system that allows you to make a final decision at interval values of input values. The optimal use of such system is due to the difficulty of predicting changes in influencing factors and the correlation between them.

The main input information for building a fuzzy logic system is the results of practical research [3]. The main method used to implement the proposed idea is computer simulation in the environment MathLab.

The decision-making system in the first approximation consists of two parts:

1. The first part – the block of preliminary processing of input data in which only classical (clear) logic is used.
2. The second part – the block of the fuzzy output system. Only a fuzzy logic device is used here.

The decision-making procedure using fuzzy logic consists of three stages: fasification, calculation of rules and defasification.

2. THE ESSENCE OF THE STUDY

2.1. Research Significance

Fasification. The algorithm of operation of systems with fuzzy logic is based on the use of linguistic variables (LV). Therefore, to build a system with fuzzy logic, it is necessary at first identify the LV that affect the output of the system [3,4]. Such LV in our work are selected the voltage of the output of the battery ("voltage"), the surface temperature of the battery ("temp_ak") and an integrated indicator of wind direction, which characterizes the direction and strength of the wind ("wind") during the operation of LPB. Wind is chosen as one of the most important factors influencing the flight dynamics of UAVs [6]. After all, when the direction of the wind coincides with the direction of flight of the UAV – it prolongs the battery work and the aircraft is able to perform a longer flight task. In the case of a headwind, the flight duration of the UAV is significantly reduced.

The residual time of operation of LPAB under loading ("time") is used as an output LV.

Next, each LV should be divided into several linguistic terms (LT), which characterize the features of the state of the LV. Usually the LV consists of three to five LT. Each LT has one membership function (MF). This function characterizes the degree of reliability of the concept corresponding to LT, depending on the current value of the measured parameter.

The set of MF should cover the possible range of the measured value (Fig. 1 - 4). To implement the decision-making system, the following LTs were selected for the input voltage LV: high (12.55V-11.3 V), norm (11.5V-9.7 V), low (10.00V-9.25V). For the LV "temp_ak" LTs were used high (55°C - 25°C) and low (37°C - 0°C). LV "wind" is divided into two LT: talewind (1 - (- 0,4)) and headwind (0,4 - (-1)). The output LV "time" is characterized by LT: critical (0 min-5 min), enough (4 min-8 min) and spare (6.5 min-10 min).

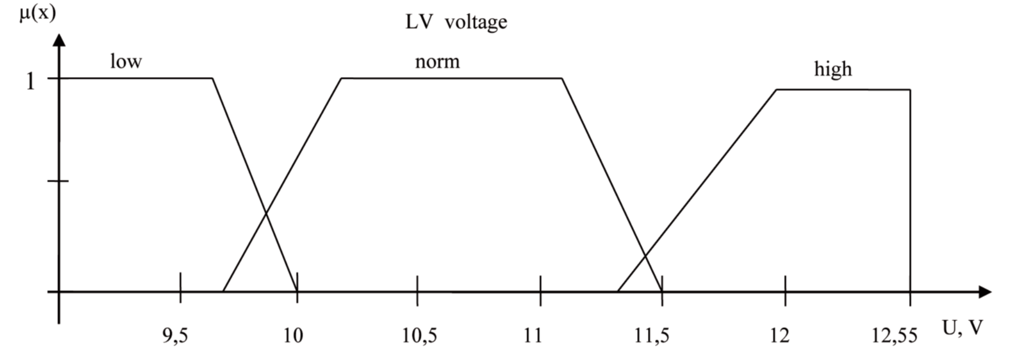

Fig. 1. Overlapping of LT of all range of LV "voltage".

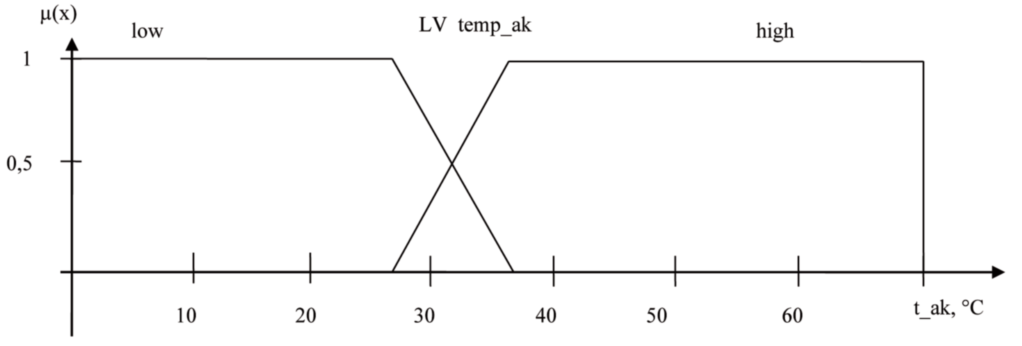

Fig. 2. Overlapping of LT of all range of LV " temp_ak".

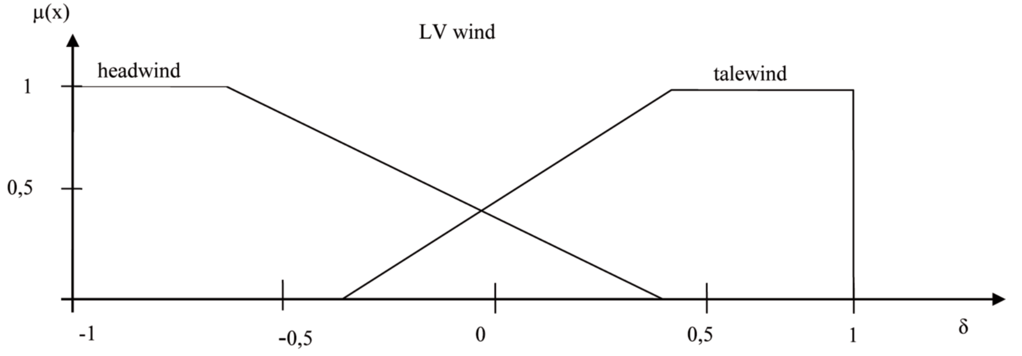

Fig. 3. Overlapping of LT of all range of LV "wind".

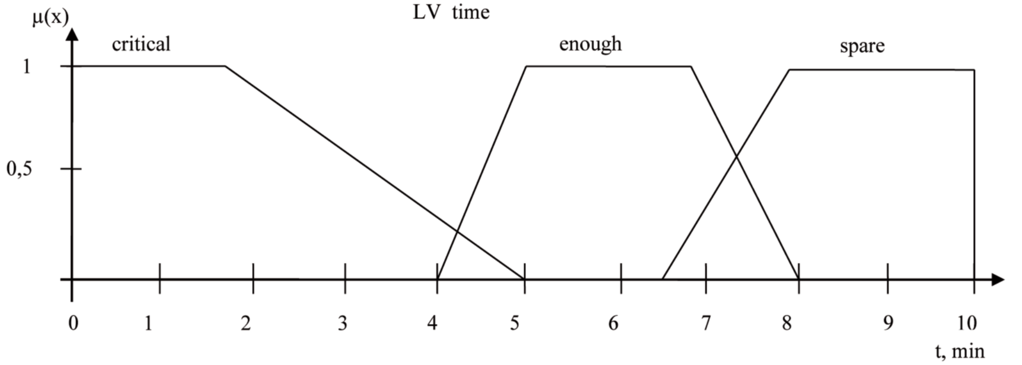

Fig. 4. Overlapping of LT of all range of LV "wind".

MFs can be arbitrary but in practice, especially for control tasks, often use MFs with trapezoidal or triangular shapes, as they are easier to implement and they are supported by most processors that have a special set of instructions for fuzzy logic, in including on-board UAV computers.

Thus, at the stage of fascification the input clear value for the system with fuzzy logic is received, as well as alternate reading from the knowledge base of all MFs related to this input value and the value of reliability (plausibility) of the measured value to each LT by their activity is established [5].

Calculation of rules. To calculate the rules, fuzzy inputs obtained from the fassification unit and the rules in the knowledge base are used. A system with fuzzy logic must have a base of rules, which, in essence, is the expert's empirical knowledge of the control mechanism. The rule is based on the following template:

IF [x is A1], then [output B1] or IF [x is A1] and… and [x is AN], THEN [output B1],…, [output Bk],where x is the input value, A1,…, AN - LT belonging to different input drugs, B1,…, Bk - LT which belongs to different output LV.

In the first part of the conditions of the rules, possible descriptions of the situation at the input of the system are taken over, and in the second part of the rules it is indicated which LT of the output LV in this case describes the correct reaction of the system.

For our case, the system of rules is as follows:

– if (voltage is high) and (temp.ak is low) then (time is spare);
– if (voltage is high) and (temp.ak is high) then (time is enough);
– if (voltage is norm) and (temp.ak is high) then (time is enough);
– if (voltage is norm) and (temp.ak is low) and (wind is headwind) then (time is critical);
– if (voltage is norm) and (temp.ak is low) and (wind is talewind) then (time is enough);
– if (voltage is low) and (temp.ak is low) and (wind is talewind) then (time is enough);
– if (voltage is low) and (temp.ak is low) and (wind is headwind) then (time is critical);
– if (voltage is high) and (temp.ak is high) and (wind is headwind) then (time is enough);
– if (voltage is high) and (temp.ak is high) and (wind is talewind) then (time is spare).

Currently, a large number of strategies have been developed to calculate an array of fuzzy inferences, but the most common of them are the Mamdami method (or MIN-MAX method) (Fig. 5), the Sugeno method, and the Tsukamoto method. The paper uses Mamdam's method as the most optimal.

Defasification. The final step in the fuzzy logic algorithm is defasification, is the transformation of fuzzy information contained in the form of values of the reliability of linguistic terms into a clearly defined meaning. Defasification is carried out according to the figure obtained by adding all the MF terms of the output LV, and from the MF is taken only the lower part (to the calculated value of its reliability).

Currently, many defasification algorithms have been developed, but the most commonly used methods are method of the center of gravity, the methods of the left and right maximum, the method of the center of the region.

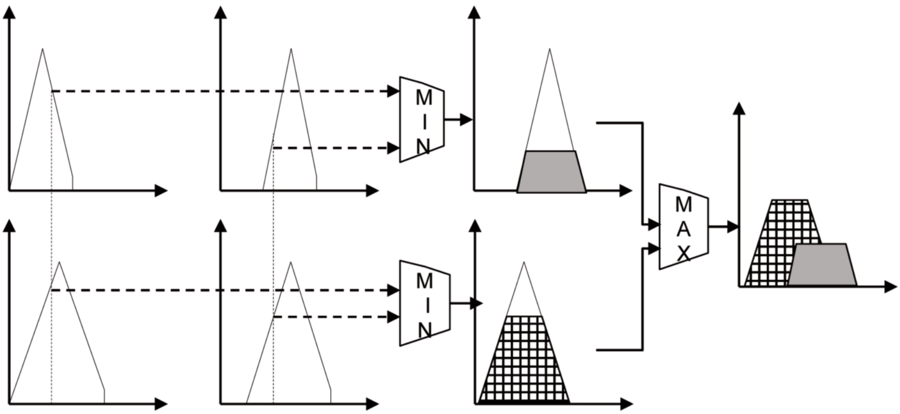

Fig. 5. Strategy for calculating an array of fuzzy conclusions by the Mamdam method.

2.2. Experimental Investigation

The developed system model was implemented in the MathLab software package, namely in the Fuzzy Logic application and allows to determine the residual battery life using which the computer system will generate based on data on current voltage, battery temperature, UAV temperature and wind direction and strength. recommendations for continuation or termination of the UAV flight mission [7].

The simulated system has three input LVs, the voltage at the output of the battery ("voltage"), the surface temperature of the battery ("temp_ak") and an integrated indicator of wind direction, which characterizes the direction and strength of the wind ("wind") during operation (Fig. 6).

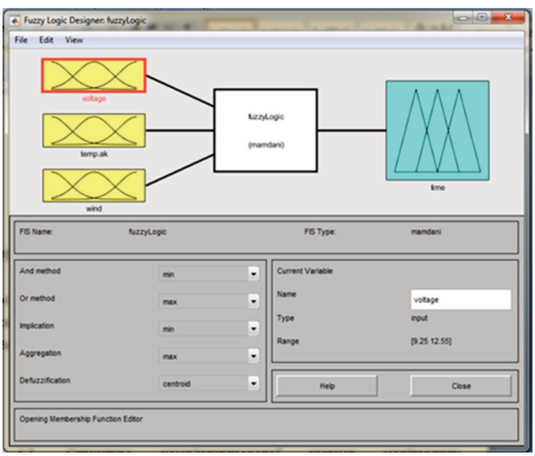

Fig. 6. Decision making system in MatLab Fuzzy Logic.

The distribution of linguistic terms within the linguistic variables is shown in Fig. 7-10. The boundaries of the LVs are selected based on the results of real experiments and the characteristics of the studied type of batteries. The boundaries of LTs are determined experimentally, namely the absence of disputes in the decision rules and the adequacy of the results.

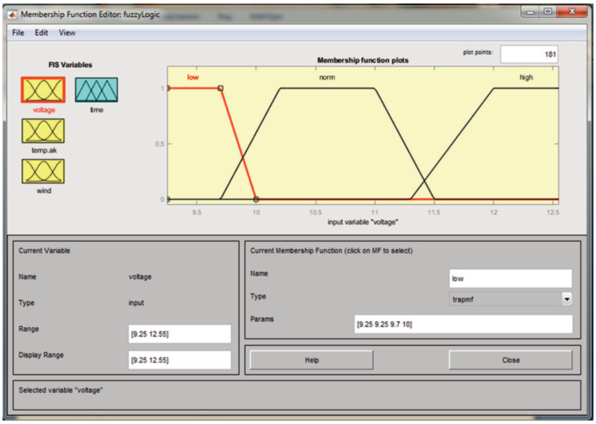

Fig. 7. LTs belonging to the input LVs of output voltage of the battery.

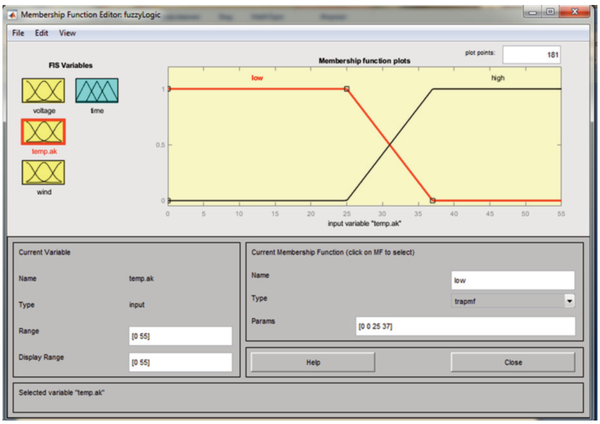

Fig. 8. LTs belonging to the input surface temperature LV of the battery.

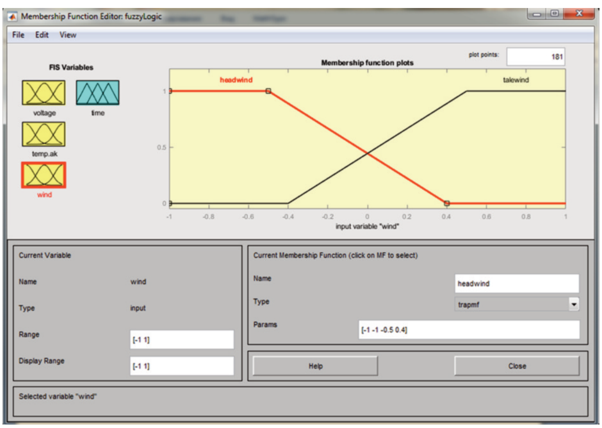

Fig. 9. LTs belonging to the input LV of integrated wind indicator.

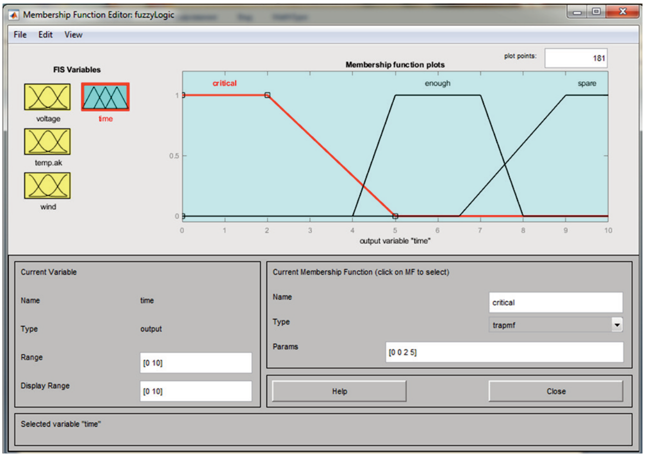

Fig. 10. LTs belonging to the output LV of residual battery life.

The system of decision rules in the environment of MathLab Fuzzy Logic is built on the general theoretical bases of construction of decision rules in the system of fuzzy logic (Fig. 11).

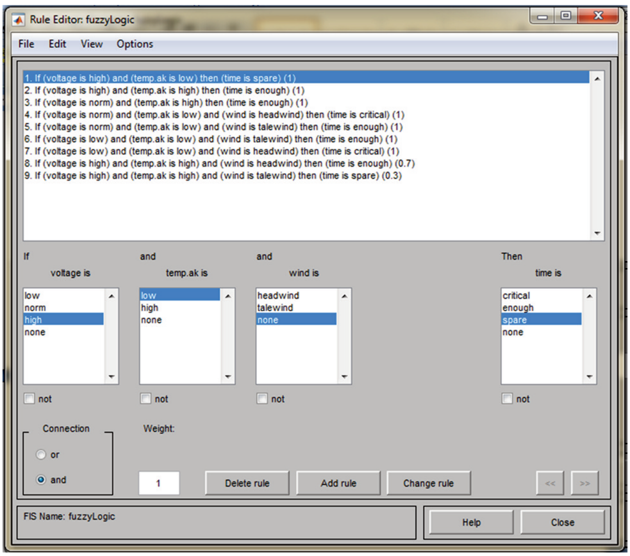

Fig. 11. Decisive rules in fuzzy logic in MatLab Fuzzy Logic.

The results of system modeling are shown in Fig. 12. At an output voltage of 11.9V, a battery temperature of 41.4°C and headwinds, the remaining battery life is 5.99 min (Fig. 12 (a)), and at the same values of input voltage and surface temperature, but in the presence of associated wind, the system will give values of 6 min (Fig. 12 (b)), the difference in which will be 1% of the total possible operating time of the hospital with the selected parameters.

At an output voltage of 9.75 V, a battery temperature of 12.3°C and a headwind, the remaining battery life is 2.99 min (Fig. 12 (c)), and in the absence of wind - 3.86 min (Fig.12 (d)).

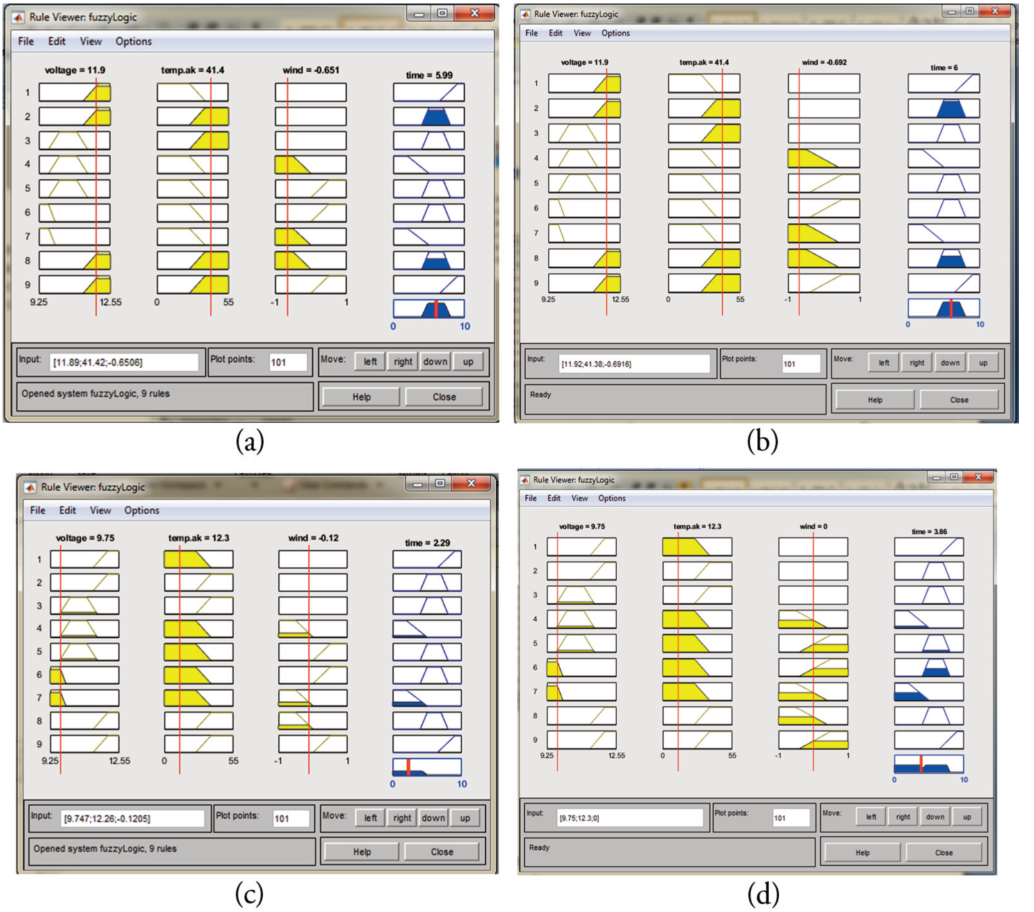

Fig. 12. Simulation of the decision-making system Matlab Fuzzy Logic.

The decision-making surface is depicted in the form of three three-dimensional graphs, each of which records one input parameter: Fig. 13 (a) – the dependence of the residual operating time of the LPAB on the voltage and internal temperature of the LPAB, Fig. 13 (b) from the voltage and wind direction, Fig. 13 (c) – the dependence of the residual operating time of the LPAB on the internal temperature of the battery and the wind direction.

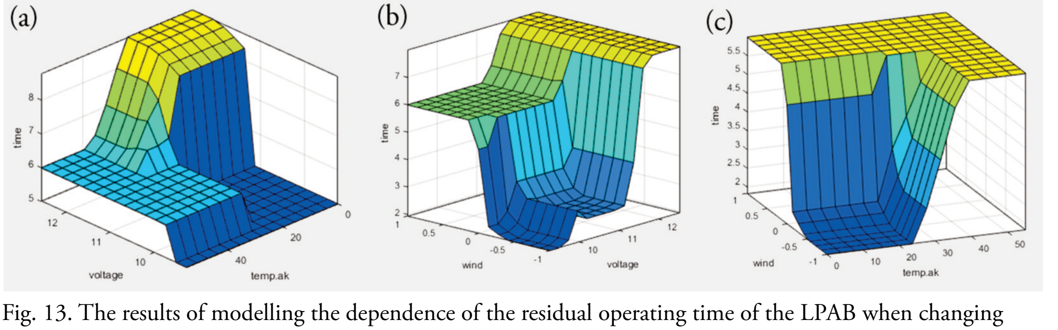

Fig. 13. The results of modelling the dependence of the residual operating time of the LPAB when changing the input parameters.

The obtained surfaces prove that the study selected the optimal number of informative parameters for making an adequate decision about the battery.

In practice, the developed decision-making system can be "stitched" in the onboard microcomputer of the UAV and monitor the current values of the voltage at the output of the UAV, its surface temperature and wind direction and strength to obtain a conclusion about the residual duration of the UAV under load in the current mode of the UAV [8]. Moreover, it should be noted that for different values of air temperature on board the UAV, the decision-making system will differ, due to the difference in the coefficients of mathematical models of discharge and temperature characteristics of LPAB, and accordingly the placement of LT on the respective LVs [9, 10].

The information obtained about the residual operating time of the UAV during the flight of the UAV is then used to decide whether to continue or terminate the flight mission [11].

After receiving information about the remaining battery time, the monitoring system decides on the possibility of continuing the flight task (t_{vest} – residual flight time, t_{ret} – return time):

- If $t_{vest} > 0,5t_{ret}$ – then the flight continues without problems;
- If $t_{vest} = 0,4t_{ret}.....0,5t_{ret}$ – then, if necessary, return the UAV to the launch point, a decision is made to terminate the flight mission and return;
- If $t_{vest} < 0,4t_{ret}$ – then the UAV continues to perform the flight task until the moment of landing, which is set before the flight depending on the scope of the UAV and the specifics of its flight task.

Based on the developed method of monitoring the condition of the UAV during the flight of the UAV and the decision-making system, a fully autonomous monitoring system of the unmanned aerial vehicle can be developed.

3. CONCLUSION

The article proposes a method of decision making based on fuzzy logic. It allows, based on current voltage, battery temperature, UAV temperature, and wind direction and strength, to determine the remaining battery life, using which the onboard microcomputer system makes recommendations for continuing or terminating the UAV's flight mission.

This method solves one of the main problems associated with the use of UAVs – the problem of monitoring the state of power supply and battery life of the UAV during the flight to ensure the trouble-free flight of the drone.

Based on the developed method of monitoring and decision making the condition of the UAV during the flight of the UAV, it is possible to design systems for monitoring the power supply of the unmanned aerial vehicle. This structure will be completely autonomous, is placed on board the UAV and will not require the intervention of the ground operator in the flight, which in turn will minimize the loss of the UAV in the absence of communication with the ground control point.

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SYSTEM BEZPIECZEŃSTWA LOTÓW UAV OPARTY NA METODACH LOGIKI ROZMYTEJ

Abstrakt

W artykule zaproponowano sposób podejmowania decyzji o kontynuacji lub zakończeniu lotu UAV w oparciu o logikę rozmytą zapewniający jego bezproblemowy lot, który posłuży w przyszłości do budowy pokładowego systemu monitoringu zasilania bezzałogowego pojazdu powietrznego. Opracowana metoda podejmowania decyzji pozwala określić resztkową żywotność baterii na podstawie danych o aktualnym napięciu, temperaturze baterii, temperaturze na pokładzie UAV oraz kierunku i sile wiatru, na podstawie których system komputerowy będzie zalecał kontynuację lub zakończenie zadania UAV. Metoda podejmowania decyzji z wykorzystaniem logiki rozmytej polega na tworzeniu zmiennych lingwistycznych, którymi są parametry informacji wejściowej i decyzja wyjściowa, ich terminy językowe i funkcje przynależności, a także system reguł podejmowania decyzji. Napięcie na wyjściu akumulatora, jego temperatura powierzchni i kierunek wiatru zostały wykorzystane jako zmienne wejściowe, a pozostała żywotność akumulatora została wykorzystana jako wyjściowa zmienna językowa.

Słowa kluczowe: UAV, bezzałogowy statek powietrzny, metody logiki rozmytej, podejmowanie decyzji.