UAS Flight Trajectory Optimization Algorithm Based on Operative Meteorological Information

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Abstract

This paper deals with the UAS trajectory planning and optimization using the operative meteorological data. The algorithm and software for UAS operators when preparation to UAS flight and for possible UAS flight correction during the mission realization were developed and studied. The detailed explanation of the algorithm operation was done. The interface of the developed software was analyzed from the position of the convenience to percept information. The simulation of the application operation was done and the results of simulation shows the correspondence of the current conditions and decision proposed by the DSS software

Keywords 1

Flight trajectory optimization, algorithm, DSS, meteorological hazards, UAS, sensors, software

1. Introduction

The integration of Unmanned aircraft systems (UAS) into the National and Global Airspace, increasing number of UAS flights and operational tasks require the researches to overcome barriers connected with safety and economy of UAS flights [1,2]. It is possible to distinguish some general barriers and challenges [2,3] that refer to

- technical issues;
- economic issues;
- rules and regulations and coordination;
- procedures, training and personnel;
- transversal issues that include social, legal and environmental barriers.

Environmental barriers include also factors connected with reduction of aviation's environmental impact such as weather influence of UAS flight operation or influence of global warming on weather-related hazards frequency of appearance. It is indicated also that the training and personnel preparation is inevitably important for safety and efficiency of UAS operations.

The environmental and personnel and training barriers can be intersected in the next points and demand research in the field of:

- understanding the hazards connected with weather for UAS flight and mission realization;
- UAS operators' preparation and further training to identify the hazards and know the avoidance techniques;
- development and study the decision support systems (DSS) for UAS flight and mission planning and weather-related hazards avoidance when UAS flight.

In this paper we are focusing on the development of procedure DSS algorithm and software for UAS operators when preparation to UAS flight and for possible UAS flight correction during the mission realization. As it is indicated in [4,5], this can be important for productivity improvements, enhancing the use of the airspace, increasing human performance.

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2. Literature Review

Manned and unmanned flights are still significantly dependent on weather and weather phenomena [6]. In papers [7-10] the overview of the weather-related hazards is done. Papers [11,12] devoted to the study of climate change due to anthropogenic factors all over the globe. The simulation that was done that paper reveals a significant increase in the events of clear air turbulence in the future. The aim of a paper [13] is the study of the impact of extreme temperatures observed in different airports on aviation. It was indicated in the paper that temperature extremes are the result of climate change, that, in turn, also increases the number of turbulence events. The variability of UAS characteristics on weather conditions is discussed in [14]. Paper [15] considers UAS as the tool for meteorological studies. In papers [16,17] some requirements to the accuracy of measurement and observation by the sensors located on moving platforms are discussed. This shows the possibility to use UAS not only the user of meteorological information, but as one of the elements of distributed network of meteorological observations.

The survey on the task of mission planning and characteristics of the mathematical programming method and algorithms is made in paper [18]. The aircraft trajectory planning methods are proposed and demonstrated in [19-22]. In paper [19] the proposed method is based on optimization algorithms that can be used for unmanned and manned aircraft. Paper [20] is devoted to the design of robust wind optimal flight trajectory. In paper [21] an algorithm that calculates wind-optimal trajectories for cruising aircraft with ability to avoid the regions with contrails formation is developed and analyzed. In the paper the optimal trajectories are calculated by solving a non-linear optimal control problem with path constraints. In paper [20] the operative flight trajectory correction is made using the operative meteorological information from onboard sensors focusing on meteorological radar data [23,24]. The analysis of the paper shows the necessity of study and comparison of efficiency of existing and proposed algorithms as well as telepolling the algorithms for online flight correction to avoid areas of potential weather-related hazards. Also, there is a task to help UAS operators to choose the decision from the many possible. This can help to decrease overloads of the operators and overcome the constrains connected with procedures, training and personnel. In paper [25,26] the multi-criteria decision support system for multi-UAV mission planning was proposed and tested. A prototype of a DSS for UAVs fleet-mission planning in a manner that they are suitable to be sent to Air Traffic Control for flight approval is developed in [27].

3. Algorithm for flight trajectory optimization based on meteorological information

The block-diagram of the developed algorithm for UAS flight trajectory correction based on meteorological information is shown in Figure 1.

The operation of the proposed algorithm is based on the next general operational steps:

1. Collecting weather information

The first stage of the algorithm is the input data collection. It includes: UAS type and characteristics, weather information, characteristics of planned area, mission peculiarities, etc. For this purpose, the general aviation information as well as general regional information is accumulated and processing.

The rest of the input data can include:

- Weight and size: The weight and size of a drone can vary depending on its purpose and functionality. It is important to consider the weight and size restrictions that can be used in certain locations or for certain types of missions.
- Communication range: Communication range is the maximum distance a drone can communicate with an operator or base. To ensure flight safety, it is important that the drone is able to maintain stable communication throughout the flight.

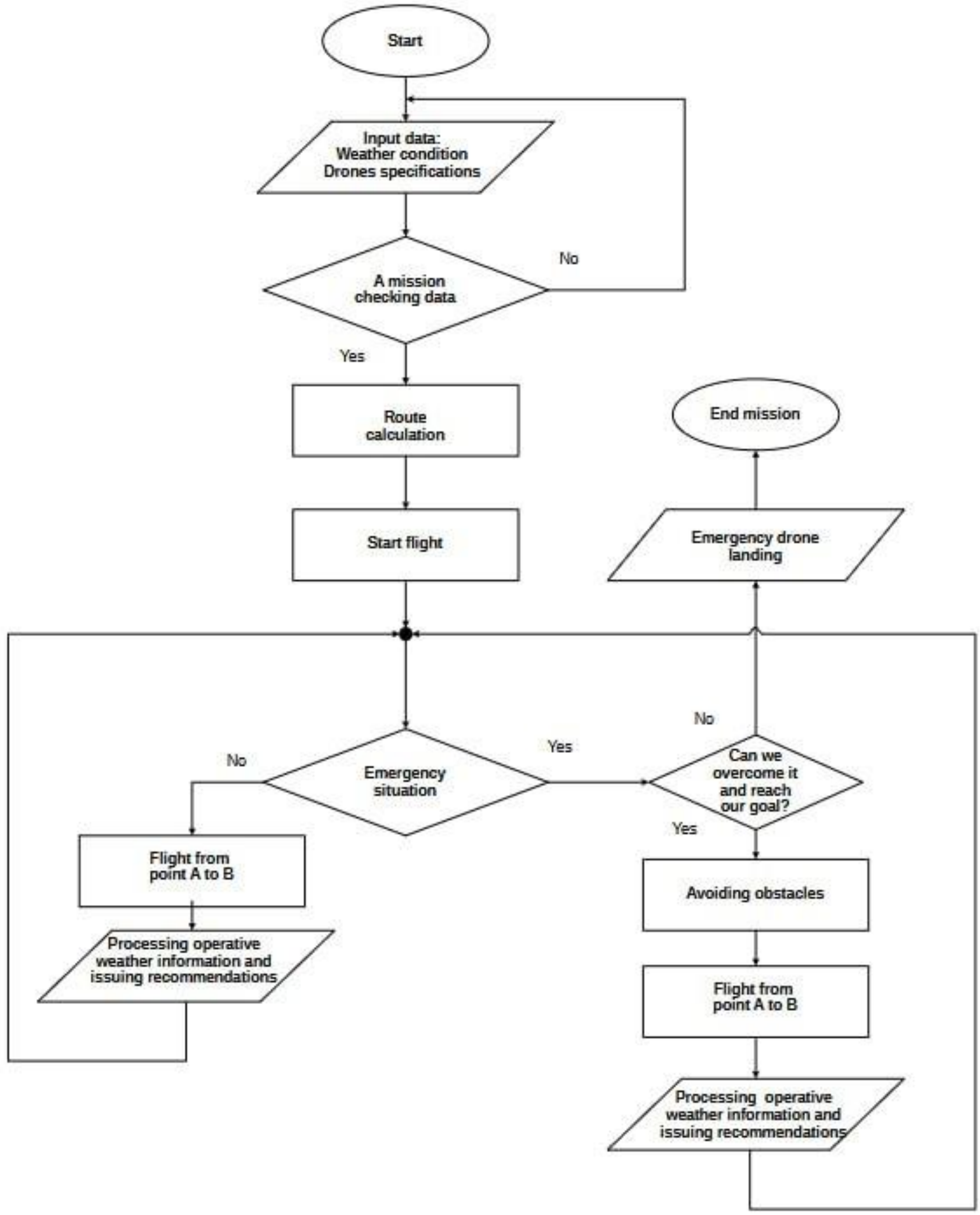

Figure 1: The block-diagram of the developed algorithm for UAS flight trajectory correction based on meteorological information

- Speed and maximum altitude: Speed and maximum altitude are parameters that define the maximum speed and altitude a drone can fly. It is important to consider these parameters when planning your flight route and staying safe.
- Autonomous flight time: The battery life is the time a drone can fly without recharging or replacing the battery. For long-duration missions such as environmental monitoring, it is important to have a drone with a high battery life.
- Availability of cameras and other sensors: Cameras and other sensors, such as GPS or pressure sensors, can help a drone collect data and images from the air for various missions. It's important to consider the availability and quality of these sensors to ensure quality and accurate data.

2. Data processing

The initial data including weather information is processed and optimal flight trajectory is calculated. In our case, the flight trajectory was calculated using the Bellman-Ford algorithm.

In this case, will use the Bellman-Ford algorithm to optimize the movement of the UAV.

The equation (1) will solve the task of the shortest path, which depends on time t.

$$v_i(t+1) = min_{k(i,k)\in A} |c_{ik} + v_k(t)|, \tag{1}$$

where $i = 1, ..., n\text{-}1$ - number of repetitions;

c_{ik} - is the value of a possible route that can be taken;

$v_k(t)$ - this is the length of the old route, where we indicate its value to know it for using the new route.

The principle of this algorithm is that it indicates nodes that may have a negative value, and when using a flight, the value of the flight will be taken into account (taking into account weather conditions and other reasons).

If you add all these routes together, it will not reduce the length of the total route (2):

$$v_i(t) = v_i\,(t-1). \tag{2}$$

3. Route selection

Next, the UAS operator choose the best route, taking into account the weather conditions and technical characteristics of the drone and mission. We realize the Bellman-Ford algorithm for flight route calculation in the developed software.

4. Tracking the drone's movement

During the flight of the UAS, its movement should be tracked and this information should be sent to the control center. This will allow drone operators to monitor the flight in real time and respond to possible dangers in a timely manner.

The sensors located on the drone allow to collect weather information along the flight route. In particular, it can be a thermometer, barometer, hygrometer, wind speed sensor, etc. The collected weather information will be used to warn the drone of possible dangers during the flight. Also, based on this data, a weather forecast can be issued for some time in the future. In the proposed algorithm we have introduced the turbulence forecast based on operative measurements of atmospheric characteristics.

5. Optimize the UAS movement

Drone motion optimization is aimed to increase efficiency in the term of safety, reducing energy consumption and decreasing flight time. For this purpose, UAS operator can make the next choices:

- Selecting the optimal speed: The speed of the drone should be optimal to reduce energy consumption and increase flight time. The optimal speed can be selected based on the drone's specifications and flight conditions.
- Relay the particular sensors: The use of additional sensors, such as GPS, can help the drone navigate through space and determine its position. This can help the drone optimize its path and reduce the number of stops.
- Calculating battery capacity: The battery capacity of the drone should be sufficient to complete the entire route. Artificial intelligence algorithms can be used to calculate the battery capacity, which can take into account the flight conditions and determine the optimal battery capacity.

The dependence of the drone battery capacity on the ambient temperature can be described by the following formula (3) [28]:

$$\mathrm{C}(t) = \mathrm{C}_0\,(1 + \alpha\,(t - t_0)). \tag{3}$$

Where:

- $\mathrm{C}(t)$ is the battery capacity at temperature t,
- C_0 is the initial battery capacity at the optimum temperature t_0,
- α is the temperature dependence coefficient,
- t is the current ambient temperature,
- t_0 is the optimum temperature (usually 25°C).

The temperature dependence coefficient α determines how quickly the battery capacity changes with temperature. Typically, for lithium-ion batteries, α is about 0.1% per degree Celsius.

This formula shows that as the ambient temperature increases, the battery capacity decreases, and as the temperature decreases, the capacity increases.

Calculation of the battery capacity on temperature according to formula (3) is shown in Figure 2: Dependence of the battery capacity on temperature for the Autel Evo Lite quadcopter.

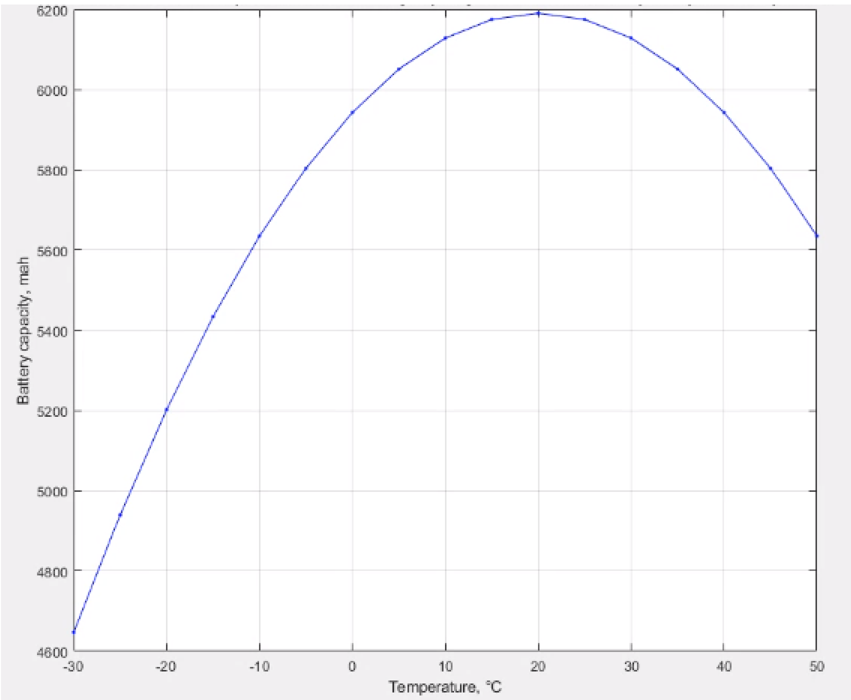

Figure 2: Dependence of the battery capacity on temperature for the Autel Evo Lite quadcopter

6. Weather-related hazards warnings Avoiding weather-related hazards

During flight, your drone may encounter hazards such as obstacles, weather, other aircraft and drones, animals, and people. To prevent these hazards, the drone must have a hazard warning system. This system can include obstacle sensors, radars, cameras, and other devices that help the drone detect and avoid hazards in time.

Additional protection can be achieved using the devices such as raincoats that protect against rain, snow, and other atmospheric phenomena. You can also use protective caps on the propellers to protect them from snow, rain, and other weather conditions.

Recommendations:

In the case of turbulence or other weather conditions, our algorithm can offer several solutions:

- Reduce the drone's flight speed. This can help reduce the impact of turbulence on the drone and make it more stable.
- Increase the altitude of the drone. Higher altitude can help avoid lower layers of the atmosphere where turbulence can be more severe.
- Use automatic flight stabilization and control systems. These systems can help keep your drone stable during turbulence and reduce the impact of weather conditions on your flight.
- Consider the weather forecast and plan your flights accordingly. Before flying, pay attention to the weather forecast and plan your flights accordingly.
- Be aware of drones and other aircraft that may be in the air near you. Follow safety rules and avoid obstacles and other hazards.

During the flight the constant control of the UAS state, position and sensor data is monitored. This information is included in the further stages 8-10.

8. Meteorological data collection in progress

To perform the tasks successfully, the UAS must obtain up-to-date meteorological information about local weather conditions. To collect this information, you can use sensors that measure temperature, humidity, atmospheric pressure, and other indicators. This information can be useful for determining the best time to fly, determining the optimal speed and route, and warning of possible hazards.

9. Processing and transmission of meteorological information

The received meteorological information must be processed and transmitted to the ground for further analysis.

10. Battery status monitoring

The state of the drone's battery is an important parameter that needs to be monitored throughout the flight. The drone should have a battery health monitoring system that will monitor the battery level and report low battery levels. If the battery level becomes very low, the drone should automatically return to the base station or runway to replace the battery or recharge.

11. Performing tasks

After preliminary preparation and adjustment of the drone, it can be sent to perform tasks. To do this, the drone must be programmatically configured to perform certain actions, including data collection and processing, video and photo capture, sending data to the ground, and other actions. While performing tasks, the drone must be under the constant control of a ground-based operator who can remotely control the drone and make decisions on performing additional tasks or reprogramming the drone

In addition to the software required to perform the tasks, the drone may be equipped with additional devices, such as location sensors that allow the drone to determine its location in real time, autonomous control systems that allow the drone to perform tasks independently, and other devices.

12. Data processing and analysis

After completing tasks, the drone must collect and transmit data to the ground for further processing and analysis. Data processing may include object recognition, coordinate determination, and other procedures. Data analysis can help draw conclusions and make decisions based on the data.

13. Returning to the base station

At the end of the mission, the drone must return to the base station or runway. The return of the drone should be ensured by an optimal route that takes into account safety and energy consumption. Upon returning to the base station, the drone must be inspected and repaired, if necessary, before the next mission.

4. Simulation on the Base of proposed Algorithm

The software was developed to simulate the operation proposed algorithm. It was developed as DSS system to help UAS operators when flight along the preliminary planned trajectory. The Interface of the software is shown in Figure 3.

Application according to the proposed algorithm operates according to next stages.

The first stage of the algorithm is to collect information and prepare the drone for the task. This means entering the model of the drone and its technical characteristics, charge capacity, and the presence of sensors that will collect information about the flight during the mission in our program.

After all this is entered into the protocol and the program, we check whether all this data is correct for the route in question. If there is an error, it means that the mission should not be started yet.

The second stage of the algorithm is route planning and calculation, taking into account weather conditions and the area where the mission will take place. To start the flight, the initial conditions are entered in real time as it is shown in Figure 4. and updated every 15 seconds to ensure a quick response when controlling the drone. If the weather conditions do not allow us to start the mission, we either wait for the weather conditions to improve or cancel the flight altogether.

The third stage of the algorithm is choosing the optimal route of flight taking into account the terrain (houses, hills, rivers, etc.) and prohibited flight zones (factories, military facilities, etc.). This also includes prompt processing of weather conditions as it is shown in Figure 5 and Figure 6. Then, a report on the operation of the drone's elements (battery capacity, damage, if any, and the integrity of the luggage (if it is a mission to transport something)) and sending the data to the operator's database, where he can further use all this data for future flights.

When planning the route in point 2, we can change it if there is a need and purpose to avoid obstacles and weather hazards on the way. There is also a condition here that the drone operator can make an emergency landing, where the device will be safe until the precipitation or strong winds and turbulence stop. The program, which will receive information directly from the sensors located on the drone, give recommendations to the operator. It is crucial that the final decision is made by operator.

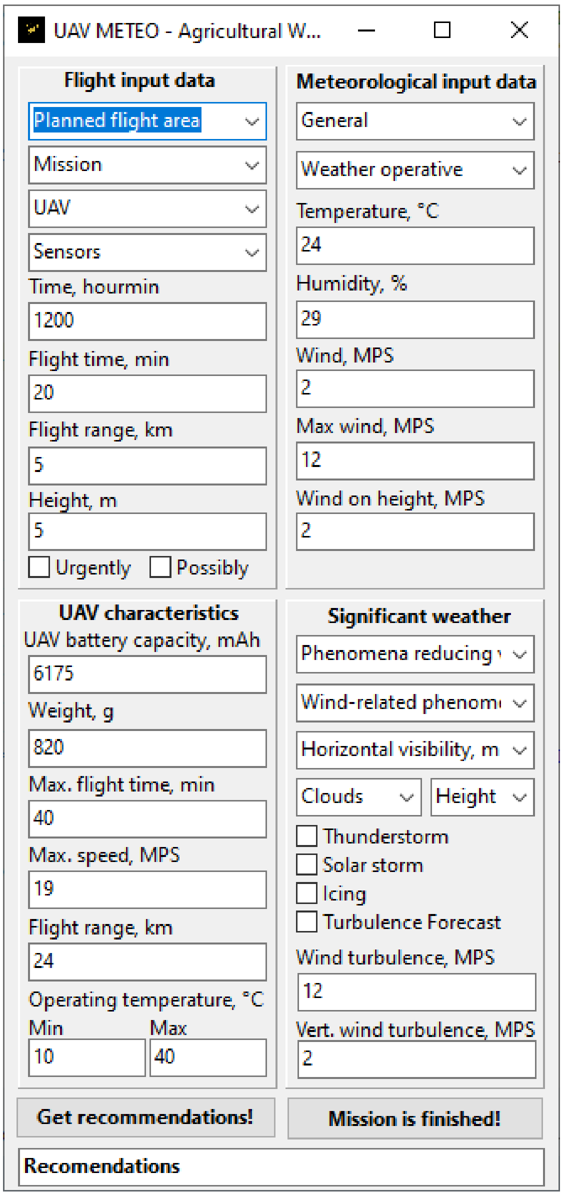

Figure 3: Interface of the software

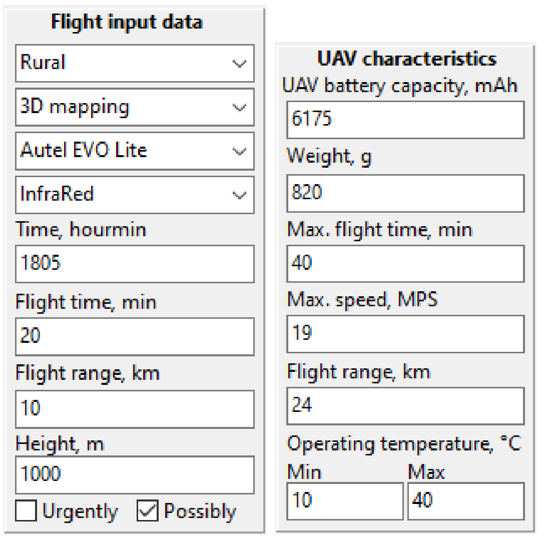

Figure 4: Flight input and characteristics of the unmanned aerial vehicle

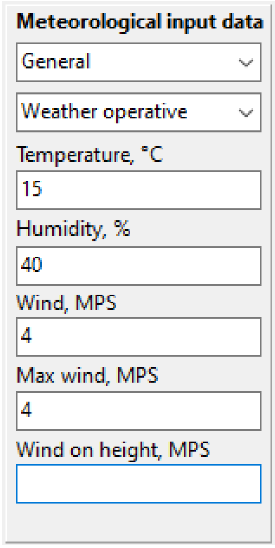

Figure 5: Initial input real time meteorological conditions

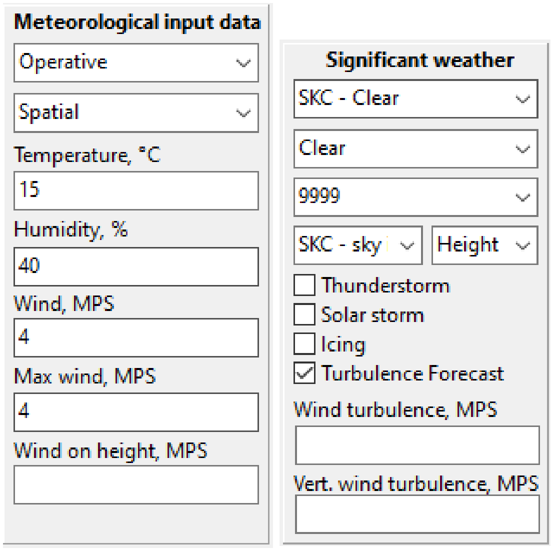

Figure 6: Operative weather data and weather updates with turbulence forecast

The fourth stage is landing the UAS and processing all the data collected during the mission. The landing should be performed on a flat surface, in compliance with safety regulations. At the end of the mission, you need to check that everything is intact and that there are no water drops on the outside. After that, we can remove the battery and the flash drive (as a backup memory disk) and analyze it all for further missions.

All the information that was obtained during the mission can be taken into account for the flight route optimization of other UAS mission operation. This can be done at the time when the mission is in progress or when the next mission is planned.

In Figure 7 the simulation of the decision-making support according to the proposed algorithm is done.

As we can see from the interface panel of the developed software, the current meteorological conditions correspond to the restrictions of UAS specification, mission and planned area of flight. The forecasted wind components of the turbulence calculated on the base of operative meteorological data also in the allowed limits. The recommendation given by the developed software is flight allowed and it fully corresponds to the current situation, UAS model and planned task.

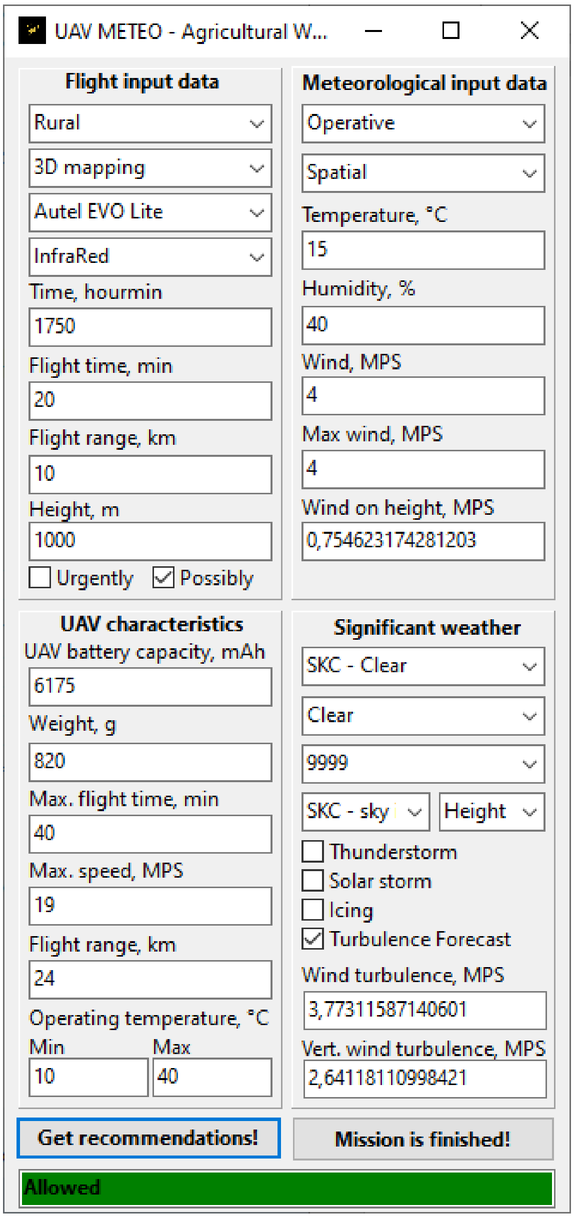

Figure 7: Processing operative weather conditions and issuing recommendations on flight (continuing the flight or flight rout optimization)

5. Conclusions and Discussions

In this paper the algorithm for flight trajectory optimization based on operative meteorological data was proposed. The DSS software to help UAS operators to take decisions during the UAS control and mission realization under the changing meteorological conditions was developed. The simulation of the application operation was done and the results of simulation shows the correspondence of the current conditions and decision proposed by the DSS software.

Taking into account the development of the new technologies including artificial intelligence algorithms it is reasonable to consider the realization of such technologies for automated flight path correction and optimization. The use of artificial intelligence algorithms can help the drone choose the most optimal route and reduce the number of stops, which increases flight efficiency.

This is planned to be the next step in our researches aimed to increase the efficiency of UAS application for various industries, such as agriculture, construction, energy, and others.

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