Decision-Making Automation for UAS Operators using Operative Meteorological Information

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Abstract

Nowadays, unmanned aircraft systems (UAS) can be successfully used to obtain real-time data at different stages of productive activity, thus, enhancing the automation of many processes. In this paper, we are focusing on UAS use for different industrial applications focusing on agriculture purposes. We developed the software for the automation of Decision-making for UAS operators. The developed automation for decision-making is based on weather risk analysis for the particular agricultural mission as well as for equipment (sensors, devices) that are used for different agricultural UAS operations. In the proposed software for decision-making automation, the improvements are achieved due to the operative obtaining and exchanging with real-time data on the current state of the atmosphere and atmospheric conditions. The computer simulation of decision-making under different weather conditions was done and the results of the simulation were analyzed. The computer modeling is based on the analysis of the general dangerous weather for UAS flights as well as weather hazards and limitations for particular agricultural activity. When weather-related hazards analysis, we considered also the influenced systems and equipment and possible final threats. It was indicated that the final results of the simulation depend on the properly defined mission and area of planned flight as well. The results of the study and simulation can be useful for UAS operators when planning and preparing for their mission realization. Also, we expect that the obtained results help to provide user-oriented services in the frame of IoT technologies, reduce the costs of data obtaining when using UAS for multipurpose tasks and create a basis for the automation of different industrial activities.

Keywords 1

UAS, industrial application, automation, meteorological limitations, weather hazards for UAS, weather hazards assessment, Decision-Making, agriculture application

1. Introduction

The progress in engineering and technologies in various areas of industry has become a driver to use the range of sensors and special software to obtain, process, and analyze huge volumes of data. This, in turn, allows to enhance the automation of many processes during the productive activity and services provision. The integration of different technologies, implementation Internet of Things (IoT) in different branches of industry, active utilization of cloud technologies, and looking towards artificial intelligence (AI) and machine learning in the operation of industrial facilities allows us to identify this period of transformation as Industry 4.0. This is used by analogy with the industrial revolutions that started in the 18th century [1]. On one side, the increased volume of information help to increase the efficiency of different operations, optimize the operations, and implement predictive maintenance. The vast, diverse information and operative information also help when decision-making. On the other side, the information should be properly processed and analyzed [2]. It should be relevant and contextualized as well. This, in turn, requires the development of the methods and algorithms to operate with this data

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for further use in decision support systems or in the systems of automated control of industrial operations.

One of the technologies that can be successfully used to obtain real-time data at different stages of productive activity is unmanned aircraft systems (UAS). Some advantages of using UAS for different industrial applications are:

- the ability to collect information from remote areas that can be hard or dangerous to reach;
- maneuverability;
- a rather low cost;
- possibility to operate at precise and accurate positions;
- reduce human factor errors.

At the same time, there can be distinguished some restrictions on drone operations. These restrictions are connected with the hazards and risks when UAS operations. The risk analysis should consider the nature of modern UAS as cyber and physical systems. The risks can be divided into natural and man-made and intentional and unintentional. An example of intentional man-made risks can be cyber risks. They can lead to the loss of control under the UAS and possible further malicious actions. The natural unintentional risks are often connected with meteorological hazards. This is because the operation of the physical and cyber parts of the UAS is dependent on weather.

Information about the meteorological situation and weather phenomena that can impact the UAS flight and operation is highly important for different industrial applications. One of the areas of application where drones have found their vast application nowadays is agriculture [3,4]. The challenges and opportunities of drone usage for this field of people activity is discussed in [5]. Some novel application for agriculture connected with the retrieval of data from remote field sensors using UAS is discussed in [6]. In Agriculture UASs can be used for the next tasks:

- crop monitoring and analysis (crop health, plants parameters, and growth, etc.) [7];
- making analysis of the soil and fields (water, nutrition, etc.) [8];
- planting seeds [9];
- spraying chemicals or distributing the trichograms [10,11];
- 3D mapping (audit and inventory of the agriculture areas, relief analysis [12];
- security-related tasks [13].

These UAS`s tasks for agriculture may require the realization of the next technologies: air photography (video and photo), thermal photography, laser scanning, 3D mapping, and spraying chemicals. A relatively new and rather experimental is the technology that is used for seed planting.

The assessment of the weather-related risks for different kinds of UAS activity for agriculture requires an understanding of the technologies and equipment operation that can be used for particular purposes. This is important as atmospheric conditions and weather phenomena complicate or make impossible some of the agricultural operations but can be quite favorable for others. Therefore, when mission planning and realization it should be taken into account the common weather restrictions for a particular type of UAS as well as restrictions for a particular mission or technological realization.

In this paper, we are focusing on the application of UAS for agriculture purposes and the automation of Decision Support for UAS operators. The decision-making is based on weather-related risk analysis for the particular agricultural mission as well as for equipment (sensors, devices) that are used for agricultural UAS operations. In the proposed system, the decision-making improvements are achieved as well due to the operative obtaining and exchanging with real-time data on the current state of the atmosphere and atmospheric conditions. The software for a DSS to help UAS operators to perform particular tasks in agriculture drone activity was developed and analyzed.

2. Weather-related risks for UASs application in Agriculture Analysis

Nowadays there is a range of programs that are intended to provide support to pilots and air traffic controllers with information on current and prognostic weather conditions. At the same time, it is observed rather a lack of programs for meteorological support of UAS operators, especially for specialized tasks. The development of special applications is important as they take into account the hazards, threats, and risks of particular missions. The meteorological risks analysis and assessment are important for the development of risk-informed applications when decision-making supports of UAS operators and this follows safety management concepts and processes [14]. The Decision support systems (DSS) can be preferably used when there is a lack of proper information base for learning or the corresponding efforts are not reasonable [15].

The overview and analysis of the common meteorological hazards and risks can be found in [16 - 18]. Some constrains for UAS flights connected with weather are considered in [19,20]. The approach to weather risk quantification for small UAS safety risk management is made in [21].

The UAS`s flights for agricultural applications are made in the so-called boundary layer. The lower height of the flight is 50 meters. According to [22] the flight height when spraying chemicals should be a minimum of 2 meters above the plants and 10 meters above the trees. This boundary layer is characterized by the spatial variation of atmospheric characteristics depending on the type of underlying surface and diurnal variations of characteristics as well. Moreover, the weather can influence not only the UAS but equipment for special purposes as well.

Let us compose the list of meteorological hazards and connect them with a particular agricultural mission that can be later used in the decision-making support application. Also, we discussed and placed in Table 1 the possible threats to UAS and mission realization due to the indicated weather hazard.

There are also common hazards that complicate the UAS flight or make it impossible [22]. They can include:

- Wind-related phenomena: Strong wind, Windshear, Updraft/downdraft, spout, hurricane. These phenomena can influence UAS control, ground speed and flight path, and maneuverability;
- The high-density altitude. This can make an influence on the aircraft's performance;
- High humidity and precipitation except the mentioned above can influence the aerodynamic performance;
- Strong shower precipitation should be considered as a significant weather phenomenon that can highly influence the UAS flight;
- Icing. Affects the aerodynamic performance;
- Dust storm, Sandstorm;
- Temperature extremes. Except for the mentioned above, temperature influences [23] the battery and UAS airframe materials.

3. Algorithm and application for UAS Flight planning

In papers [24,25] there was developed the general decision-making algorithm for flight planning under different weather conditions. The algorithm can be adopted for a particular task in agriculture (Figure 1).

In Table 1 the weather-related hazards for each agricultural mission are indicated. These hazards were chosen as those that influence particular mission realization. Also, the developed algorithm considers the general weather-related threats that can influence the UAS flight operation. The weather influence on electronic sensors that are placed on the UAV platform to perform the task is also taken into account. The correction for weather limitation for particular UAS types and equipment on UAVs is made. The combination of the general and mission-related hazards is the basis for final recommendations.

The atmosphere is a highly dynamic medium. The variation of the atmospheric characteristics is provided by a range of factors including underlying surface type, relief of the land, rapid change in the synoptical situation (this can be connected with an active cold front approaching), and the presence of artificial objects. These factors can be the reason of formation local convection or wind-related hazards. For example, the presence of ravines in rural areas or artificial objects force wind to change its direction and speed. Then, areas of unexpected low-level turbulence can be formed. As it is possible to see from Table 1, convective weather, turbulence, and strong wind are the factors that influence many missions in agricultural activity. Therefore, real-time information about the possible formation of the potentially dangerous area is important. Taking into account this fact it is reasonable to use UAS additionally as the platform for the placement of the sensors for measuring atmospheric parameters. Then, using the communication link to collect real-time meteorological data. Then, the data is placed in the weather database in relation to the strict position of measurements. The GPS positioning that is used for UAS positioning can be used for this purpose. The database can be located in a cloud service for the convenient use of the interested authorized user. The information can be continuously exchanged between humans and machines and between machines and machines (C2M and M2M respectively) [26]. Also, we consider the possibility to use this real-time data for the operative forecast of low-level turbulence. At the current stage of the study, we have used the model presented in [27]. Such automation of the process allows using of the UAS not only as a tool to perform particular tasks but as a mobile platform to collect operative data to form individual user-oriented services. The characteristic of the individual user-oriented services allow to obtain (but are not restricted):

- information on demand,
- real-time information,
- information for interested area
- mission-oriented information.

Table 1
Mission and weather hazards

Mission	Weather hazard	Influenced system, equipment	Threat
Crop monitoring and analysis	Visibility (phenomena reducing visibility), precipitation; Humidity	Reduce camera ability, Condensation on the camera lens Blocking vision-based sense-and-avoid technologies; Electrical components, electronics	Mission success Electrical components, and electronics wear out
Making an analysis of the soil and fields	Humidity; Precipitation	Influence on Electronics and electrical components	Electrical components, electronics wear out, errors
Planting seeds	Convective weather, Turbulence; strong wind	Influence the process of planting	Mission success
Spraying chemicals or distributing the trichograms	Convective weather, Turbulence; strong wind; Temperature	Influence the process of spraying and dropping	Mission success, Pollution of the nearby area
3D mapping	Humidity; Precipitation	Influence on Electronics	Electrical components, electronics wear out, errors
Security-related tasks	Visibility (phenomena reducing visibility), precipitation; Humidity	Influence on Electronics; Reduce camera ability	Electrical components electronics wear out, Mission success

In Table 1 it is shown also the components that can be influenced by particular weather hazards as well as the consequences of the hazard.

Therefore, the decision-making in the proposed algorithm considers:
type of aircraft,
installed apparatus, sensors, devices
mission,
characteristics and type of the planned area of flight,
general routine weather data and forecasted weather,
real-time weather information for the flight area

forecasted area of low-level turbulence based on real-time meteorological information.

These mentioned factors are included in the algorithm as Input data of the flight.

The block diagram of the proposed algorithm for automation of UAS operator`s decision-making is shown in Figure 1.

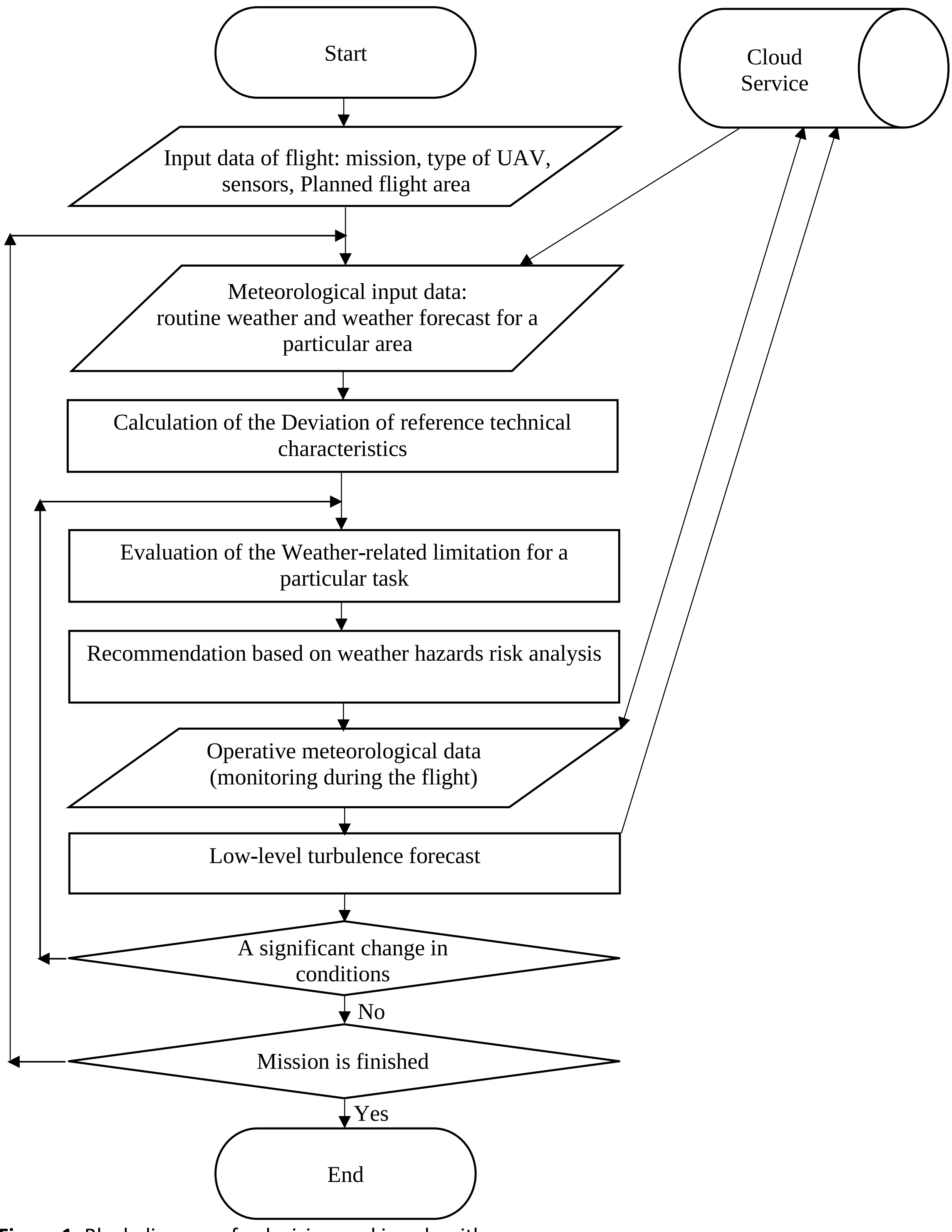

Figure 1: Block diagram of a decision-making algorithm

In additionally, to the general input data, the meteorological data are introduced for further processing. At this stage, the meteorological data can be collected from the available resources including specialized and general internet resources, and official meteorological databases. Then, the calculation of UAS characteristics for current weather conditions is made.

The next step is the comparison of UAS, sensors, mission, and area weather limitations with present meteorological conditions is made. After comparison and evaluation of the possible weather-related risks on the base of a risk-oriented approach, the recommendations to perform the flight and fulfill the planned mission are issued. The recommendations are given according to [14] and considered intolerable, tolerable, and accepted risks. In case of intolerable risk, the flight or mission realization is forbidden. Tolerable risk requires additional consideration of the possibility to perform the flight. The accepted level of risk means that flight and mission can be performed.

The key thing of the algorithm is that after the beginning of the flight, the UAS is used a mobile platform to obtain real-time meteorological data. This data from one side is transferred to the cloud serves from which it can be used by other participants of flight on-demand, and to form the data set of real-time data for operative use.

And from another side, it is used for operative correction of initial meteorological data and for forecast of the boundary layer turbulence

The next step is a comparison of the operative data with initial meteorological information. If significant deviations or turbulence presence, then go to the reevaluation of the limitations. In this case, the new recommendations can be given. If no significant change in conditions, then update in 15 seconds until obtaining new operative data. After finishing the flight, the algorithm stops operation.

On the basis of the proposed algorithm and weather-related hazards analysis, we developed the software for the automation of UAS operator`s decision-making. The general interface of the decision support application is shown in Figure 4.

The main or first window of the developed software is shown in Figure 2 and specifies the information about the fields of activity (in this paper we focus on agricultural works).

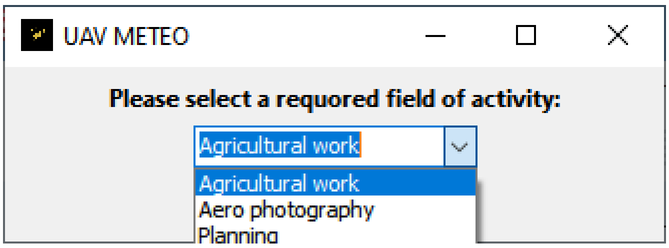

Figure 2: The window to choose the mission on the interface of the developed software

The option “mission” (Figure 3) determines the particular agricultural mission. Different missions have their own weather limitations. The general analysis of the missions and corresponding hazards are presented in Table 1. Thus, the final proposed decision considers the weather limitations and weather-related hazards connected with the peculiarities of a particular mission.

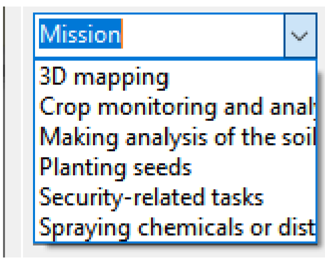

Figure 3: The part of the interface that determines the agricultural missions

This information about the type and characteristics of UAS is required to correlate the current weather condition with the ability to perform flight using the particular UAS.

The right panel contains information about the current weather (menu option "Weather operative"). The button "Get recommendations" allows to obtain the decision made by the developed software. Figure 5-8 demonstrate the simulation results of decision-making support software for different meteorological situations and agricultural missions. The shown results are for the different missions but for the same meteorological situation.

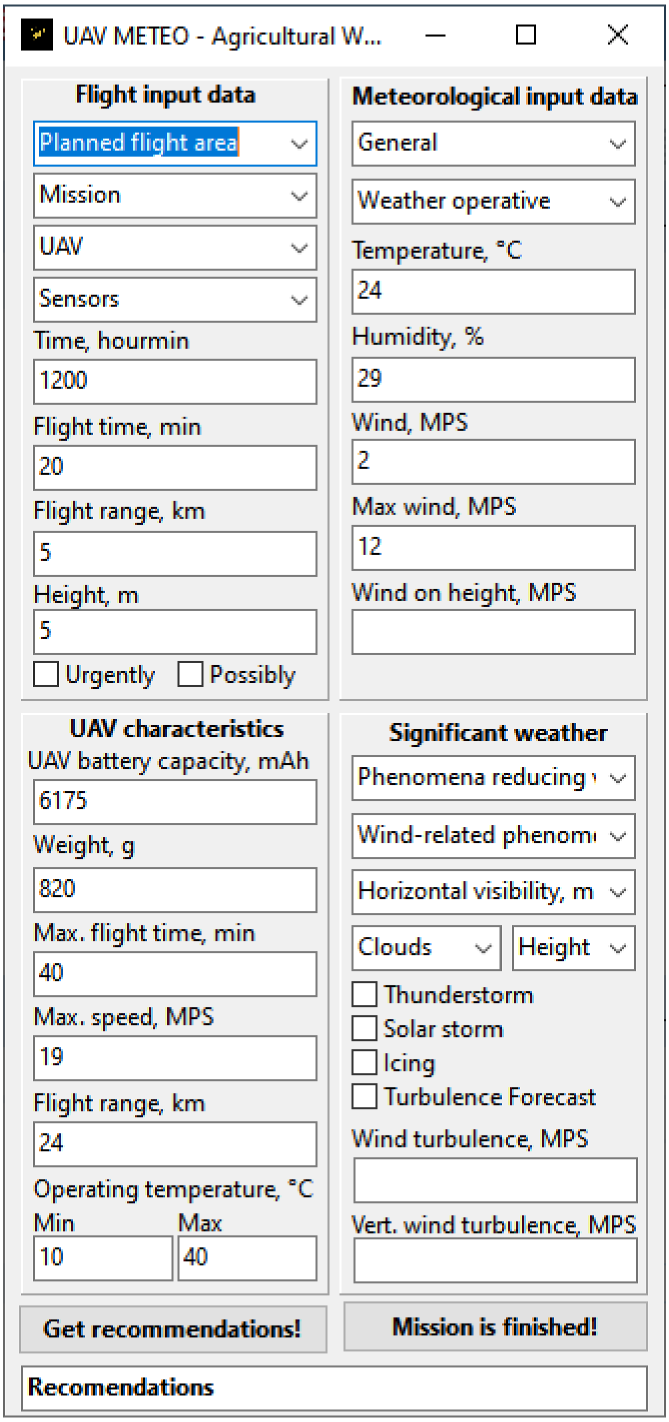

Figure 4: The general interface of the decision support application

In Figure 5 the simulation result for the 3D mapping is shown. We can see that the parameters of the Atmosphere (temperature, wind, humidity) and weather phenomena (rather a clear sky (FEW) and absence of other weather-related hazards) are above the weather limitations for general flights and planned missions.

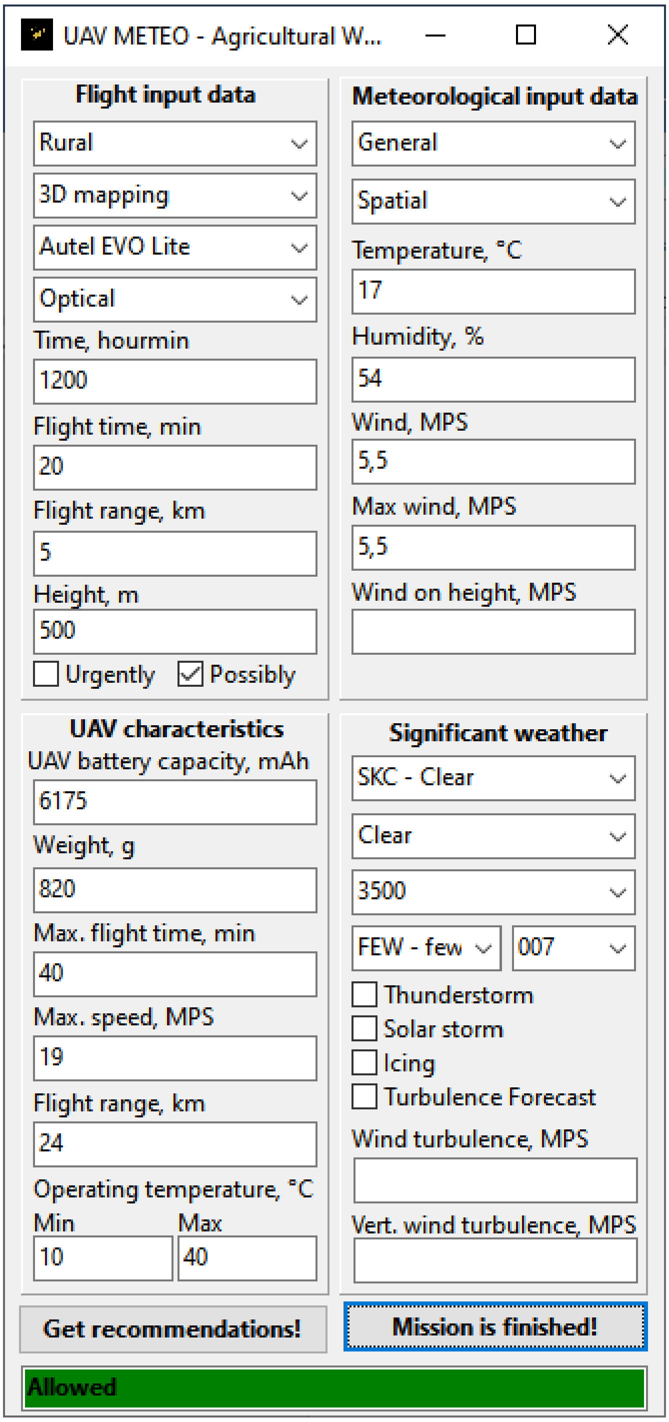

Figure 5: The simulation results. Mission 3D mapping

In Figure 6 the simulation result for crop monitoring is shown. Again, the state of the Atmosphere for general flights, and planned missions is quite favorable.

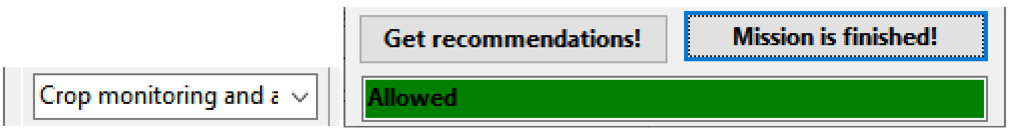

Figure 6: The simulation results. The mission is crop monitoring

In Figure 7 the simulation result for spaying chemicals is shown. This type of activity can be performed when wind speed is above 4 meters per second and absence of any convective movements [22]. So, the average wind 5 meters per second is below the required minimum for the given mission.

Figure 7: The simulation results. Spraying chemicals

In Figure 8 the simulation result for planting seeds is shown. Nowadays this agricultural mission is not of wide application. But it was interesting for us to consider the prospective UAS missions and analyze the possible meteorological hazards for them. Again, the decision is flight forbidden because of the mission limitation – the wind that can cause the seeds to drop out from the intentional planting area.

Figure 8: The simulation results. Planting seeds.

4. Conclusions and discussion

In this paper, we have developed decision-making support software for the automation of UAS operators' activity to avoid meteorological hazards. It is expected that the developed and demonstrated software allow to decrease the overload of operators when working with a big volume of information and decrease human-related errors. At the same time, it allows to process and to take into account the data that can be crucially important for a particular industrial application in a particular area. We have been focusing on the missions connected with agricultural work. The developed DSS utilizes the weather forecast, routine aviation information as well as operative meteorological data in the area of flight for operative correction during the decision-making process. The application takes into account not only meteorological limitations for particular UAVs but also the limitation for different missions and sensors that are used for mission realization. The developed software allows using the general information from internet resources, and official meteorological databases as well as to form the data set of real-time data for operative use. Also, we studied how the information of different kinds that are required for mission planning is gathered and processed for decision-making support.

We expect to continue the research and add the function of automatic collection and exchange of information about current weather for fully automated flights. The function of the real-time set of meteorological data formation is based on the operative information from the UASs that make flights in the nearby area or at the same area but earlier [28]. For this purpose, the UAS can be considered a mobile platform to place the sensors for weather observation. The information from the sensors can be used inside their own network or can be used as a component of the global observing system of the Atmosphere [29, 30]. The considered approach allows us to provide user-oriented services in the frame of IoT technologies, reduce the costs of data obtaining when using UAS for multipurpose tasks and create a basis for the automation of different industrial activities. It also can be the basis for self-optimization and autonomous decision-making for automated UAS flight trajectory correction when mission realization.

5. References

[1] F. Yang, S. Gu, Industry 4.0, a revolution that requires technology and national strategies. Complex Intell. Syst. 7, 2021, 1311–1325. https://doi.org/10.1007/s40747-020-00267-9.

[2] M. Mamad, Challenges and Benefits of Industry 4.0: an overview. International Journal of Supply and Operations Management. # 5(3), 2018, pp.256-265. 10.22034/2018.3.7.

[3] C. Yinka-Banjo, O. Ajayi, Sky-Farmers: Applications of Unmanned Aerial Vehicles (UAV) in Agriculture, Autonomous Vehicles. London, United Kingdom: IntechOpen, 2019. URL: https://www.intechopen.com/chapters/70496.

[4] A. Rejeb, A. Abdollahi, K. Rejeb, Y. Treiblmaier, Drones in agriculture: A review and bibliometric analysis. Computers and Electronics in Agriculture, Volume 198, 2022, 107017. doi:10.1016/j.compag.2022.107017.

[5] M. Bacco, A. Berton, E. Ferro, C. Gennaro, A. Gotta, S. Matteoli, F. Paonessa, M. Ruggeri, G. Virone, A. Zanella, Smart farming: Opportunities, challenges and technology enablers. 2018 IoT Vertical and Topical Summit on Agriculture, Tuscany (IOT Tuscany), 2018, pp. 1-6.

[6] M. Merz, D. Pedro, V. Skliros, C. Bergenhem, M. Himanka, T. Houge, J.P. Matos-Carvalho, H. Lundkvist, B. Cürüklü, R. Hamrén, A.E. Ameri, C. Ahlberg, G. Johansen, Autonomous UAS-Based Agriculture Applications: General Overview and Relevant European Case Studies. Drones, 2022, 6, 128. doi:10.3390/drones6050128.

[7] FJ. Mesas-Carrascosa, UAS-Remote Sensing Methods for Mapping, Monitoring and Modeling Crops. Remote Sensing. 12(23), 3873, 2020. doi:10.3390/rs12233873.

[8] A.-J.Emilien, H. Goswi, A. Macdonald, B. Wesemael, K. Oost, UAS-based soil carbon mapping using VIS-NIR (480–1000nm) multi-spectral imaging: Potential and limitations. Geoderma, Volume 275, 2016, pp. 55-66. doi:10.1016/j.geoderma.2016.04.012.

[9] M. Lysych, L. Bukhtoyarov, D. Druchinin, Design and Research Sowing Devices for Aerial Sowing of Forest Seeds with UAVs. Inventions 6(4):83, 2021. doi:10.3390/inventions6040083.

[10] D. Giles, R. Billing, Deployment and Performance of a UAV for Crop Spraying, Chemical Engineering Transactions. 44 (2015) 307-312. doi:10.3303/CET1544052.

[11] S. Ji, J. Gong, K. Cui, Y. Zhang, K. Mostafa, Performance Test and Parameter Optimization of Trichogramma Delivery System. Micromachines 13(11):1996, 2022. doi:10.3390/mi13111996.

[12] W. Budiharto, E. Irwansyah, J.S. Suroso, et al, Mapping and 3D modelling using quadrotor drone and GIS software. J Big Data 8, 48, 2021, pp.1-12.

[13] G. Ononiwu, J. Onojo, N. Chukwuchekwa, O. Isu, UAV Design for Security Monitoring. International Journal of Emerging Technology & Research. 2 (2015) 16-24.

[14] Safety Management Manual, ICAO Doc 9859. URL: https://www.icao.int/.

[15] O. Havrylenko, K. Dergachov, V. Pavlikov, Z. Simeon, O. Shmatko, N. Ruzhentsev, Decision Support System Based on the ELECTRE Method. In: Shukla, S., Gao, XZ., Kureethara, J.V., Mishra, D. (eds) Data Science and Security. Lecture Notes in Networks and Systems, vol 462. Springer, Singapore, 2022, pp. 295-304. doi:10.1007/978-981-19-2211-4_26.

[16] Yu. Averyanova, E. Znakovskaja, Weather Hazards Analysis for small UASs Durability Enhancement. In: Proceedings of the 6-th International Conference on Actual Problems of Unmanned Air Vehicles Developments (APUAVD), IEEE, Ukraine, 2021, pp. 41-44. doi:10.1109/APUAVD53804.2021.9615440.

[17] E. Ranquist, M. Steiner, B. Argrow, Exploring the range of weather impacts on UAS operations. In: Proceedings of the 18th Conference on Aviation, Range and Aerospace Meteorology Proceedings, AMS, United States, 2018, pp. 1-11.

[18] N. Ruzhentsev, Z. Simeon, V. Pavlikov, V. Volosyuk, E. Tserne, A. Popov, Radio-Heat Contrasts of UAVs and Their Weather Variability at 12 GHz, 20 GHz, 34 GHz, and 94 GHz Frequencies. In: ECTI Transactions on Electrical Engineering, Electronics, and Communications, 20(2) (2022) 163-173. doi:10.37936/ecti-eec.2022202.246878.

[19] M. Gao, C. H. Hugenholtz, T. A. Fox, et al., Weather constraints on global drone flyability. Sci Rep 11, 12092 (2021). doi:10.1038/s41598-021-91325-w.

[20] Yu. Averyanova, V. Larin, N. Kuzmenko, I. Ostroumov, M, Zaliskyi, O. Solomentsev, Turbulence detection and classification algorithm using data from AWR. In: Proceedings of the 2022 IEEE 2nd Ukrainian Microwave Week (UkrMW), 2022, pp.518-522. doi:10.1109/UkrMW58013.2022.10037172.
[21] C. A. Roseman., B. M. Argrow, Weather hazard risk quantification for sUAS safety risk management. J. Atmos. Oceanic Tech. 37(7) (2020) 1251–1268.
[22] On the approval of the Rules of organization and performing aviation works in rural areas and forestry, Order #1179 of Ministry of Infrastructure (Ukraine) (in Ukrainian).
[23] V. Larin O. Solomentsev, M. Zaliskyi, A. Shcherban, I. Ostroumov, N. Kuzmenko, Prediction of the Final Discharge of the UAV Battery Based on Fuzzy Logic Estimation of Information and Influencing Parameters. In: Proceedings of the 3rd KhPI Week on Advanced Technology, KhPI Week, IEEE, Ukraine, 2022, pp. 44-49. doi:10.1109/KhPIWeek57572.2022.9916490.
[24] Yu. Averyanova, Y. Znakovska, The spatial relationships of meteorological data for Unmanned Aerial System Decision-Making Support. In: Ortiz-Rodríguez, F., Tiwari, S., Sicilia, MA., Nikiforova, A. (eds) Electronic Governance with Emerging Technologies. EGETC 2022. Communications in Computer and Information Science, vol 1666, pp. 64-80. Springer, Cham. doi:10.1007/978-3-031-22950-3_6.
[25] Y. A. Averyanova, Y. A. Znakovska, Simulation of UAS operator's decision-making under different weather conditions. In: Proceedings of the 4th International Conference on Modern Electrical and Energy System, MEES, IEEE, Kremenchuk, Ukraine, 2022, pp. 1-4. doi:10.1109/MEES58014.2022.10005627.
[26] V. Roblek, M. Meško, A. Krapež, A complexity view of Industry 4.0. SAGE Open. 6. (2016). doi: 10.1177/2158244016653987.
[27] Fast Eddy Model https://github.com/NCAR/FastEddy-model
[28] Yu. A. Averyanova, A.N. Rudiakova, F.J. Yanovsky, Aircraft Trajectories Correction using Operative Meteorological Radar Information. In: Proceedings of the International Radar Symposium, IRS, IEEE, Poland, 2020, pp. 256-259.
[29] Global observing system. World Meteorological Organization. URL: https://public.wmo.int/en/programmes/global-observing-system.
[30] WMO Global Climate observing system. URL: https://climate-adapt.eea.europa.eu/en/metadata/portals/wmo-global-climate-observing-system-gcos-global-observing-systems-information-center-gosic.