Algorithm of wind-related hazards prediction for UAS flight and urban operations based on meteorological data fusion

Yuliya Averyanova[1,*,†], Maksym Zaliskyi[1,†], Oleksandr Solomentsev[1,†], Oleksii Holubnychyi[1,†], Ivan Ostroumov[1,†], Olha Sushchenko[1,†], Yurii Bezkorovainyi[1,†], Kostiantyn Cherednichenko[1,†], Olena Sokolova[1,†], Viktoriia Ivannikova[2,†], Roman Voliansky[3,†], Borys Kuznetsov[4,†], Ihor Bovdui[4,†] and Tatyana Nikitina[5,†]

[1] *National Aviation University, Liubomyra Huzara Ave., 1, Kyiv, 03058, Ukraine*

[2] *Dublin City University, DCU Glasnevin Campus, 9, Dublin, Ireland*

[3] *National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Polytechnichna Str., 37, Kyiv, 03056, Ukraine*

[4] *Anatolii Pidhornyi Institute of Mechanical Engineering Problems of the National Academy of Sciences of Ukraine, Pozharskogo, 2/10, Kharkiv, 61046, Ukraine*

[5] *Educational scientific professional pedagogical Institute Ukrainian Engineering Pedagogical Academy, Universytetska st. 16, Kharkiv, 61003, Ukraine*

Abstract

Nowadays unmanned aircraft systems (UASs) are planned to be used in many branches of people's activity and fulfill different tasks. It is also considered one of the prospective technologies for realization of the concepts of Industry 4.0. and Society 5.0. Many of the tasks in the frame of prospective concepts including cargo delivery, photo and filmmaking, future transportation, monitoring, different security applications, and others are, obviously the subject of urban flying. It is obvious that to provide safe, secure, efficient UAS operations the operators and corresponding services should be aware of possible hazards during the flight and mission realization. The paper considers the possibilities of modern and prospective technologies to collect, fuse, and process diverse weather data including real-time data focusing on meteorological information. An algorithm that is based on statistical meteorological data analysis for machine learning to indicate and forecast potentially hazardous areas for unmanned aircraft flight was proposed. The concept of common information space for the exchange of operative information and study components of the common information space for advanced weather service of aviation was presented and discussed. The data exchange pattern in the advanced system for weather service of aviation was also considered and characteristics that should be taken into account were discussed. The simulation was done to demonstrate the benefits of the proposed approach.

Keywords

air navigation, data processing, aviation, data fusion, meteorology, UAS, urban flying, algorithm

ADP'24: International Workshop on Algorithms of Data Processing, November 5, 2024, Kyiv, Ukraine

* Corresponding author.

† These authors contributed equally.

ayua@nau.edu.ua (Y. Averyanova); maximus2812@ukr.net (M. Zaliskyi); avsolomentsev@ukr.net (O. Solomentsev); oleksii.holubnychyi@npp.nau.edu.ua (O. Holubnychyi); vany@nau.edu.ua (I. Ostroumov); sushoa@ukr.net (O. Sushchenko); yurii.bezkor@gmail.com (Y. Bezkorovainyi); cherednichenko.kostya@gmail.com (K. Cherednichenko); sokolovaelena89@gmail.com (O. Sokolova); viktoriia.ivannikova@dcu.ie (V. Ivannikova); volianskyi.roman@lll.kpi.ua (R. Voliansky); kuznetsov.boris.i@gmail.com (B. Kuznetsov); ibovduj@gmail.com (I. Bovdui); tatjana55555@gmail.com (T. Nikitina)

0000-0002-9677-0805 (Y. Averyanova); 0000-0002-1535-4384 (M. Zaliskyi); 0000-0002-3214-6384 (O. Solomentsev); 0000-0001-5101-3862 (O. Holubnychyi); 0000-0003-2510-9312 (I. Ostroumov); 0000-0002-8837-1521 (O. Sushchenko); 0000-0001-5970-5150 (Y. Bezkorovainyi); 0000-0002-9388-3521 (K. Cherednichenko); 0000-0001-6341-0195 (O. Sokolova); 0000-0001-7967-4769 (V. Ivannikova); 0000-0001-5674-7646 (R. Voliansky); 0000-0002-1100-095X (B. Kuznetsov); 0000-0003-3508-9781 (I. Bovdui); 0000-0002-9826-1123 (T. Nikitina)

1. Introduction

Technological development, digitalization of many physical aspects of human activity, and automation of industrial processes are the markers of a new stage of industry and society development that is known as Industry 4.0 [1, 2] and Society 5.0 [3] or Smart society. One of the markers of Society 4.0 is the fast access to information. Combined with automation this allows to optimization of many industrial processes and creates fundamentals for growth of quality of human life based on nature-friendly technologies. In turn, this is the basis for the concept of a super smart society that aims to be a human-centered society minding the safety and security of individuals when living in a super-intelligent ecosystem. In turn, the development of society 5.0 is based on the information lifecycle. These include the data collection, processing, analysis, dissemination to the right customer, and use for substantiated decision-making. One of the technological solutions that is aimed to support the Society 5.0 development is unmanned aircraft systems (UAS). The UAS can play an important role in the frame of the Industry 4.0 and Society 5.0 Concepts as they can be successfully used in different branches of people activity and assist in the implementation of the Internet of Things (IoT) and everything [4, 5].

Nowadays the UAS is also considered as the component of the future aviation transport system. The development of future aviation transport system is connected with the combined use of aircraft of different types that can perform their tasks in different segments of air space as well as an increase in the number of flights and diversity of fulfilled missions [6]. One of the components of the future aviation transport system is unmanned aircraft. It includes remotely piloted and autonomous aircraft [7]. According vision of the future of aviation presented in [8], mobility for social connections and service access with safety and sustainability in mind is a key task of an efficient future transportation system.

UAS is the fast-developing segment of the aviation transport system in the frame of the concept of air mobility including the urban air mobility (UAM) [9]. At the same time to provide safe operations in the frame of prospective concepts, it is crucial to understand, analyze, and assess the possible risks to UAS operations, especially in urban environments. Among the range of risks that include, but are not limited the system errors and cyber, technical, and human factor risks, it is possible to distinguish the weather-related risks. In the Report [10] that was presented in 2019, it was shown that weather-related factors as highly dynamics and changes in weather conditions were the main reasons for drone accidents. The analysis of the paper [11] proves that urban microclimates are very complex and it is difficult to understand. The urban microclimate can be fast-changeable due to the marked difference in the underlying surface and the presence of the system that increases heating and convection. The buildings deform the wind velocity and can be the source of the appearance of rapid and strong wind-related phenomena that influence drone flight and operation. Therefore, the prediction of hazardous weather conditions requires the development of models that can match the vast specifics of the modern and prospective urban weather and diversity of aircraft. The development of technologies also should be taken into account. In [8] it is mentioned that Artificial intelligence (AI) and Big Data are fruitful technologies to solve tasks to increase the safety, sustainability, and efficiency of future transport systems. The impact of Big Data and AI is accelerated by the development of smart cities and Internet of Things (IoT) technologies. In the frame of urban air mobility, the smart buildings, that use a wide range of IoT devices and sensors can be considered as the additional source of information about current local meteorological conditions. The information exchange and data fusion between such sensors with fixed positions and information for flight planning could be beneficial for both: UAS operations in the frame of UAM concepts and for UAS-based smart city applications. Further data integration into a forecast system or decision-making support system promises to assist the deep analysis of the possible situations and predict and alert about potential hazards.

This was our motivation to consider possibilities of modern and prospective technologies to collect, fuse, and process diverse weather data including real-time data, and develop an algorithm that is based on statistical meteorological data analysis for machine learning to indicate and forecast potentially hazardous areas for unmanned aircraft flight when their use for different applications.

Also, we consider the concept of common information space for exchange with operative information and study the components of the common information space for advanced weather service of aviation and implementation of Industry 4.0 and Society 5.0

2. Analysis of the latest research

The analysis of adverse weather that influences unmanned aircraft operations can be found in the range of works including [12–15]. The weather guidance for unmanned aircraft flight is given in [16]. Some research is aimed at developing algorithms to forecast the state of atmospheric parameters. Paper [17] focuses on visibility prediction based on a combined approach: statistical and numerical predictions. The method to predict the danger for flight areas that is based on a deep neural network is proposed in [18]. In the paper [18] the wind environment was simulated based on weather research and forecasting model of the large eddy simulation. A novel approach to estimating wind-related phenomena including turbulence is presented in [19, 20]. The deviation from the planned path is chosen as the criterion to evaluate the danger to flight.

In the paper [21] the evaluation of wind influence on flight trajectory was made. For this purpose, the simulation of flight path correction was done using the Bellman-Fort algorithm. The benefit of real-time information can be demonstrated in the diagram shown in Figure 1. This is based on the simulated data of trajectory correction when flying in potentially hazardous areas. The three bars show the distance of flight and fuel consumption for three flying scenarios. The first one corresponds to the planned trajectory with absence of the weather hazards. It is like "the perfect situation" of flying along the shortest path. The second bar corresponds to the situation of weather hazards avoidance using real-time data about hazards, position, distribution, and possibility to identify relatively safe zones close to the intentional flight path. The third bar corresponds to the situation when flight path correction is based on the routine and forecasted information obtained during the pre-flight stage of flight planning.

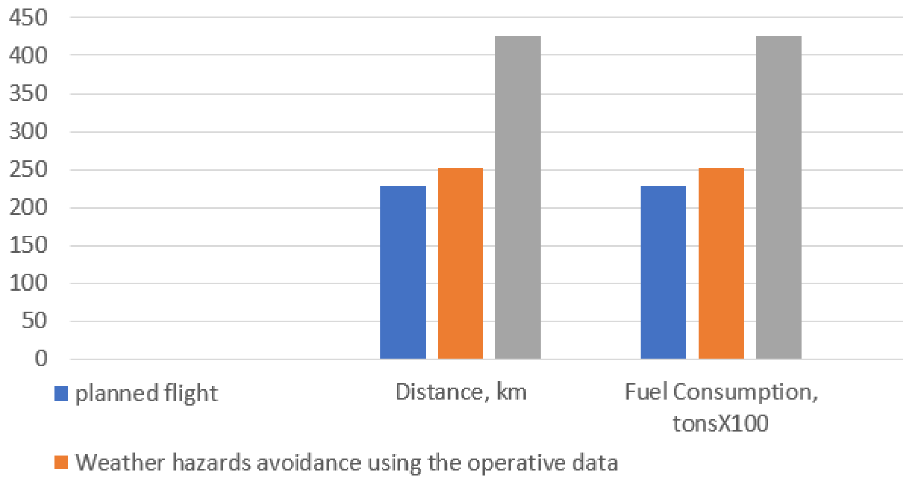

Figure 1: Comparison of flight parameters for simulated flight trajectory correction when weather hazards avoidance.

It is possible to see from the comparison of simulated data results, that the real-time data about hazards can significantly increase flight efficiency compared with situations when in-flight trajectory correction is made based on routine and forecasted data obtained before the flight starts.

The simulation in the paper [22] was done based on the concept of operatively shared information and utilizing unmanned aircraft as mobile sensors to obtain information about weather and parameters of the atmosphere along the flight routes. Similar concepts were developed for general aviation and some of them were presented in [23, 24]. Paper [25] also considers the drone as a sensor to assist in gathering the big data.

3. Architecture of advanced weather monitoring in the urban environment is based on data fusion

The general data fusion that is used to create the common information space for advanced weather service is shown in Figure 2.

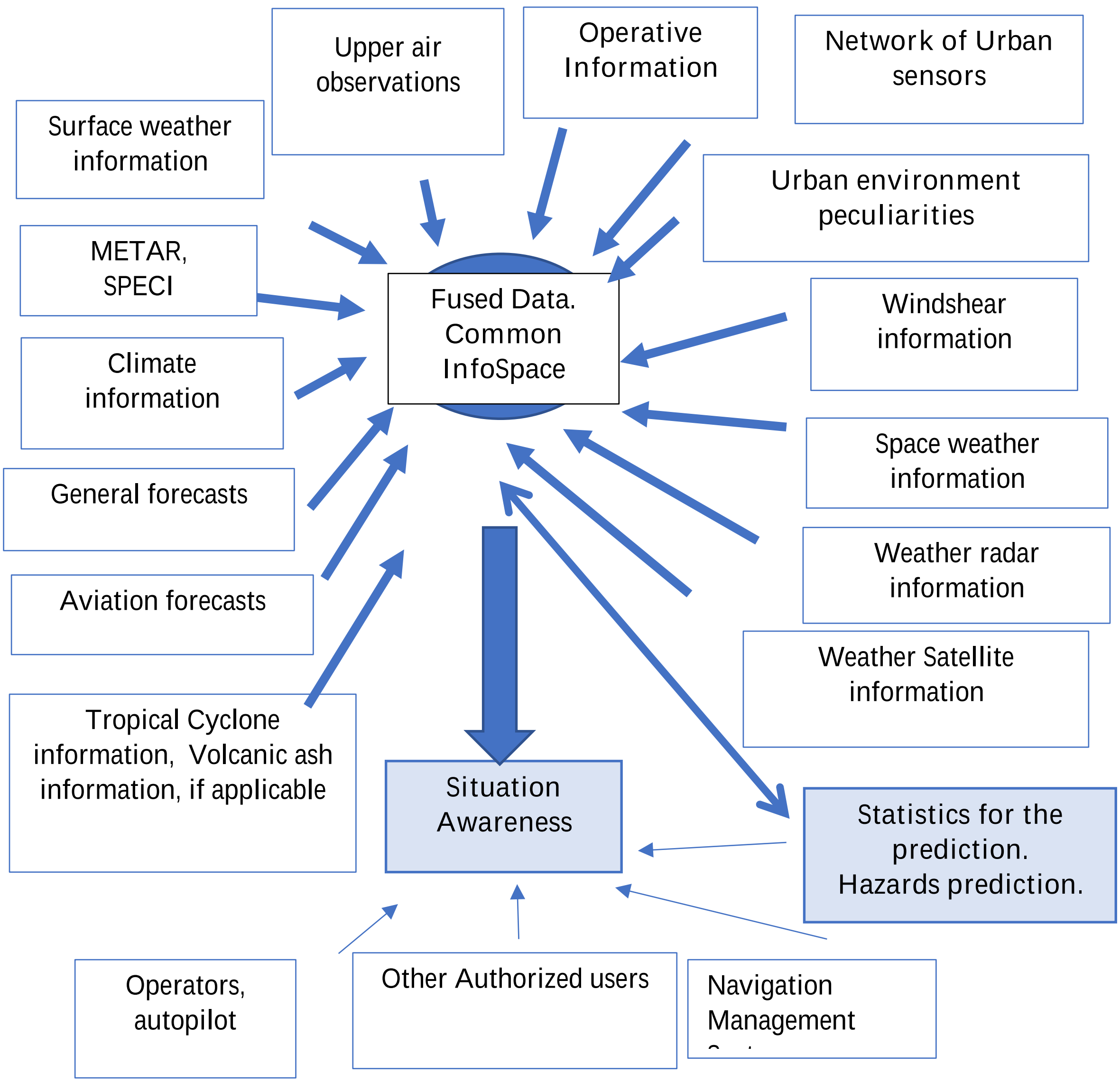

Figure 2: General architecture of common information space for advanced weather service and weather-related hazards forecast.

Information from the unmanned aircraft that performs the flight in urban areas as well as distributed sensors that are used to measure atmospheric characteristics are used as the source of information about the potential hazards in addition to the general weather information [26, 27]. In this context and taking into account the Next Generation consideration of modern and future aviation concepts the common Infospace for all participants of air traffic for their equal awareness with reliable, real-time, available on-demand can be the key factor.

The data that compose the operative component can be obtained from different space segments and include satellite and radar information, information from different sensors including those that can be used in the frame of the smart cities concept, and verbal information of the observer or operators. It, in turn, forms a huge volume of information that has different formats and is transferred via different communication lines. Peculiarities of the initial data characteristics should be taken into account when considering the mechanism of the data exchange.

The diagram that illustrates the components of the operative part of common information space is shown in Figure 3 as well as some tasks that should be solved when merging and dissemination of meteorological data.

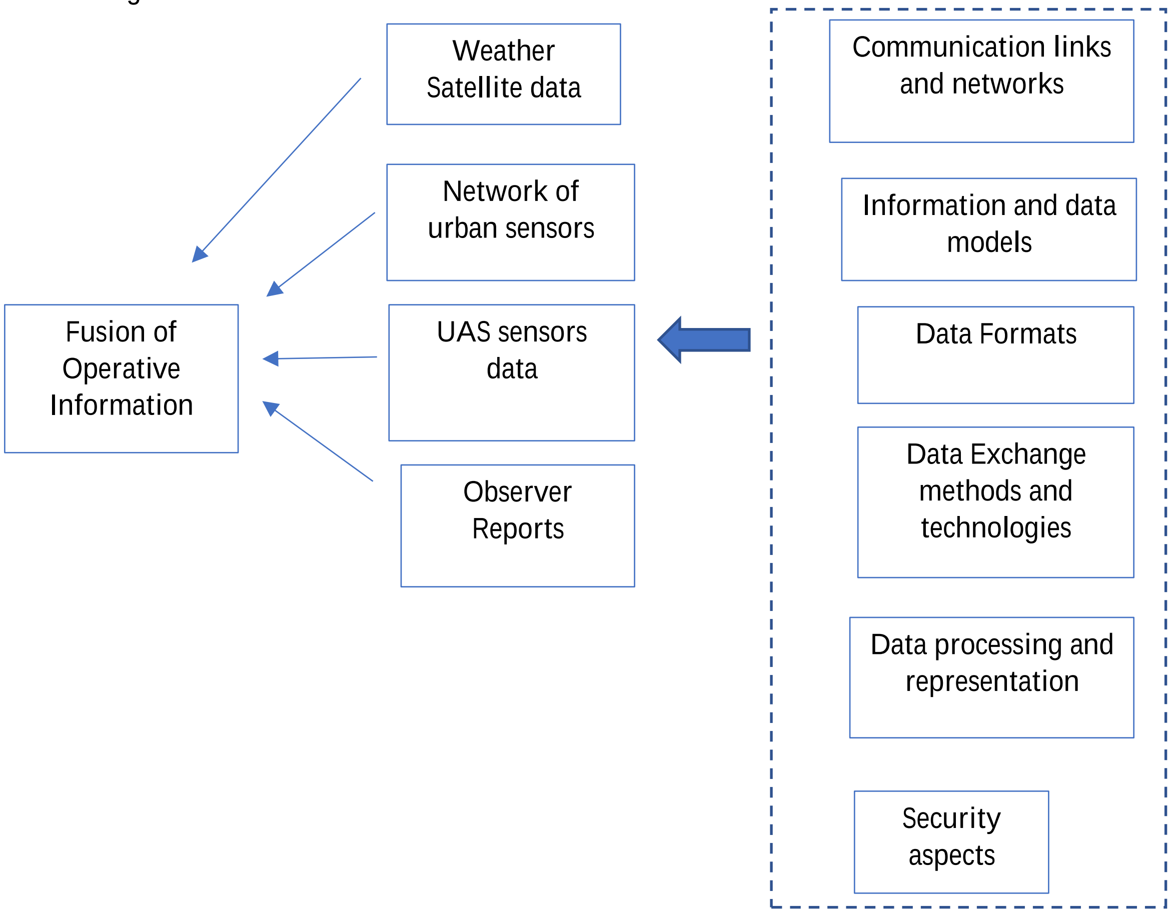

Figure 3: Operative information component of the common information space for advanced weather service of air navigation.

The characteristics indicated in Figure 3 can be selected taking into account that weather data is collected from the diverse sets of tools from the different spatial segments. These segments include: ground-based, space-based, and segment of dynamic tools for operative data obtaining.

These peculiarities of the fusion of multi-source data require to consider the characteristics that should be taken into account when operative data exchange and dissemination when advanced weather monitoring when UAS operation in an urban environment [28, 29].

When operative meteorological data exchange it is necessary to provide interoperability between diverse participants and also take into account the next characteristics of the transferred data:

- Complexity of the transferred data;
- The frequency of data updates;
- The multi-nature and multi-source character of the data;
- Transferred data size;
- Formats of the data from the different sources.

This can be classified as characteristics of the data set. Also, it is important to consider the characteristics of the environment of the data exchange when advanced meteorological service of UAS flight. As it was mentioned it is implied that data is merged into a single space from the sources from different segments. The authorized users have access to the common info space. Under such conditions, the environmental characteristics under consideration can be:

- Data flow – the architecture of data flows that can help to choose the data exchange methods; In this context, the steaming-like methods should be considered as those that fit the operation with a huge number of sources of data that transfer information into single info space and when users make access in asynchronous mode;
- Formats, versions of software, applications, and other tools of the users that are used to indicate, represent information, or provide decision support based on the automatic data exchange;
- Security management systems for security control when data obtaining, processing, and dissemination. It is crucial to provide data availability, integrity, and confidentiality (if required). Also, attention should be paid to the nonrepudiativity of the obtained information.
- Data transformation requirements: the automatic data processing for creating the set of data according to the standard format.

Also, attention should be paid to the economical side which includes time of data exchange, quality of transferred and processed data, and costs of procedures.

The quality of the data and time of data exchange when the operative provision of flight participants with meteorological information plays the most important role in flight safety.

4. Algorithm of weather-related hazards forecast based on fused statistical data

The presented approach of data exchange considers the data fusion for further processing to predict formation potentially hazardous for UAS flight areas of dangerous weather. This is especially important for the forecast of highly dynamic phenomena including strong and gusty wind, turbulence, and wind shear that can arise abruptly and locally. As it was mentioned in [8], the prospective technologies for hazards prediction are AI, machine learning, and big data processing. One of the methods to process big data for machine learning is the pattern creation based on statistics.

We propose an algorithm that is based partially on the statistical data of wind-related phenomena and local variations taking into account the next impacting factors:

- Wind velocity;
- Local topography;
- Urban peculiarity (buildings, their dimensions, orientations concerning the wind direction; the presence of heating elements that increase the convection; vertical farms, etc.);
- Diurnal and seasonal peculiarities of local characteristics.

The developed algorithm also uses the models for low-level turbulence forecast and can be used to verify the models as well. An example of the model can be found in [30]. The visualization model is presented in [31]. The developed algorithm can be represented in the diagram shown in Figure 4.

The algorithm shown in Figure 4, processes the statistical data about wind flow deflection, appearance of eddies, and turbulent flows after the particular artificial and natural obstacles of the urban environment. The collected statistics include the set of states that can be represented as.

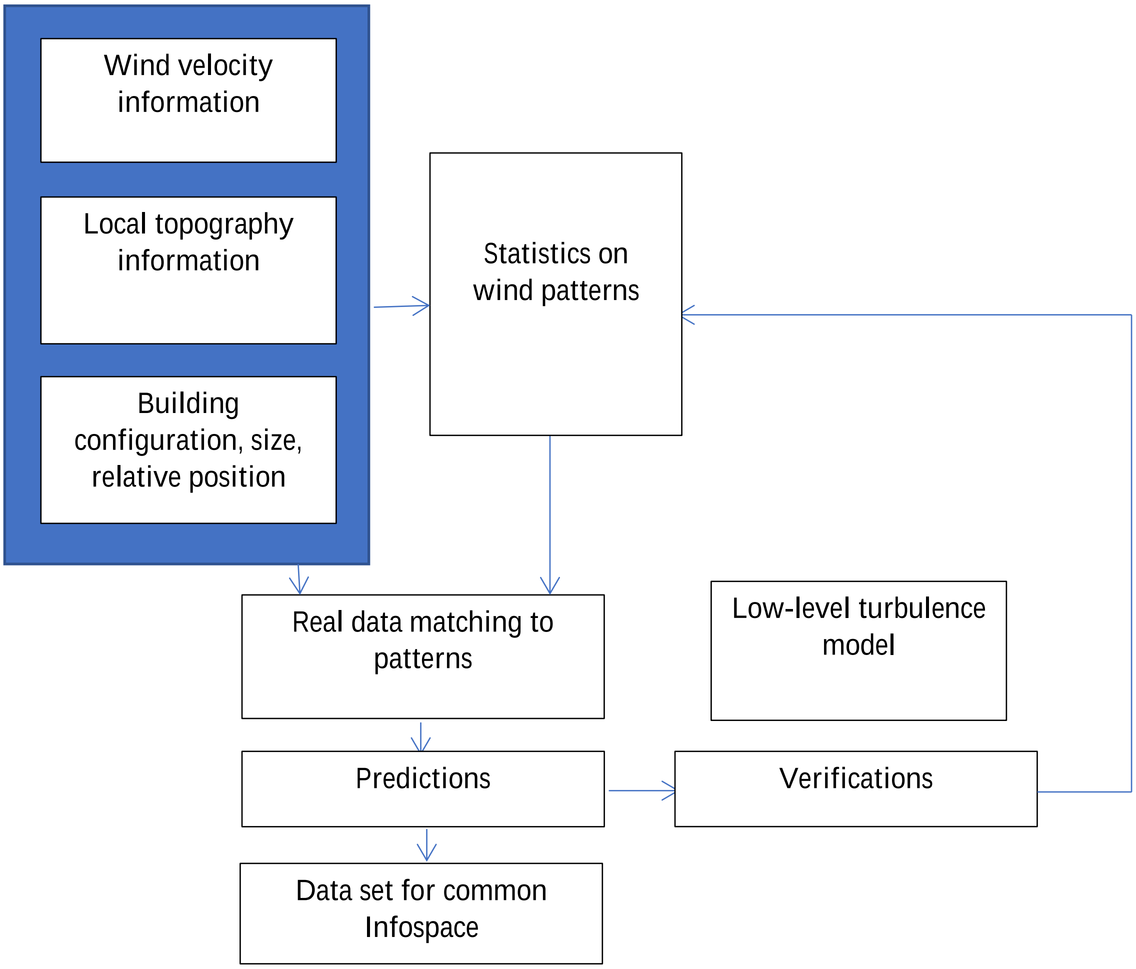

Figure 4: Block diagram of the fused data processing based on statistics and Low-level turbulence model (LLT) model.

Input data as general meteorological information:

$$\mathrm{W} = \{W_s, W_d, D_0, O_0, \mathrm{T}, \mathrm{H}, \mathrm{E}\}. \quad (1)$$

where W_s and W_d are the general wind speed and direction correspondingly; D_0, O_0 are the obstacle dimensions and orientation with respect to the initial wind flow; T is temperature; H is humidity; E is equipment that can influence the heat of urban ilands or similar effects.

The temperature and humidity can sufficiently influence the instability creation, thus influencing the final results. Output data as the correlation of general information and hazards in a particular urban environment [32, 33]:

$$\mathrm{W} = \{W_s(\mathrm{x,y,z}), W_d(\mathrm{x,y,z}), W_{s\,max}(\mathrm{x,y,z}), W_{s\,min}(\mathrm{x,y,z}), F_g(\mathrm{x,y,z}), \mathrm{EDR}(\mathrm{x,y,z})\}. \quad (2)$$

where $W_s(\mathrm{x,y,z}), W_d(\mathrm{x,y,z})$ are the wind speed and direction after the obstacles correspondingly in particular and fixed zone n the space; $W_{s\,max}(\mathrm{x,y,z}), W_{s\,min}(\mathrm{x,y,z})$ are the maximum and minimum wind speeds in particular and fixed zone in the space correspondingly; $F_g(\mathrm{x,y,z})$is the gust factor, that can be used to anticipate the turbulence; $\mathrm{EDR}(\mathrm{x,y,z})$ is the eddy dissipation rate, a parameter that is proposed for turbulence evaluation.

As it is possible to see from Figure 4, the known models of LLT and wind shear can be used for training and further prediction.

The important step of the algorithm is the feedback for data set formation for different urban conditions. For example, the wind-related hazard creation can be accelerated by the operation of particular industrial equipment as conditioning or even abate because of vertical farms. The operation of special equipment that is used in modern cities or proposed as prospective for smart cities can have marked seasonal variation or interconnected with particular atmospheric parameters such as temperature, humidity, etc.

5. Simulation of flight path correction based on fused information

The initial approach to simulate the optimal flight path to avoid hazards connected with meteorological factors is shown in Figure 5.

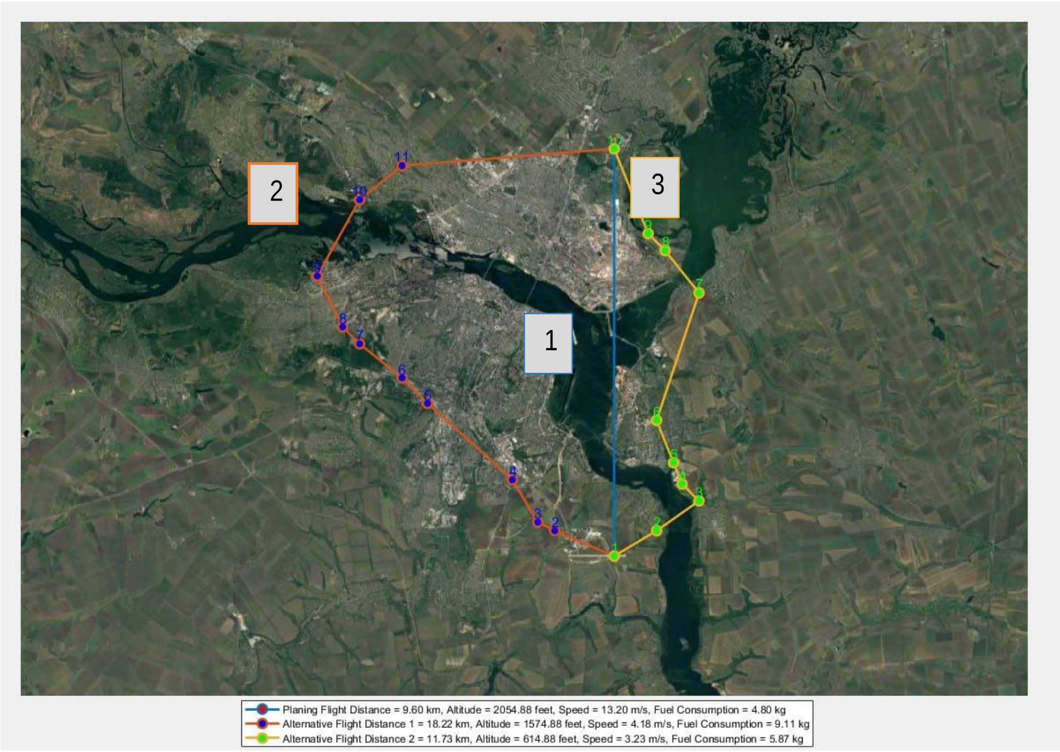

Figure 5: Simulation of trajectory recalculation based on fused real-time data.

In this picture we can see the relief that can be quite complex for low level flight of unmanned aircraft during particular seasonal situations. These include the summer sunny days when convection can be rapidly changed by sinking air over the water surface and opposite situation during the clear nights. The low-level flying also can be under the condition of unstable communication in the considered area.

In the Figure 5 we can see three simulated situations. One, the almost straight one is the intentional flight path. This is the shortest distance between two points and is indicated as the flight route 1. In the case of formation of unfavorable for flight situation, the flight path is recalculated based on relief peculiarities, area of the associated weather that is more probable for considered conditions. This is the flight route 2. This is the longest flight path. The simulation of flight 3 is based on the fused real-time information collected in the nearby area.

The information is processed and allow to find the routes with atmospheric characteristics do not exceed the threshold values of parameters that correspond to the characteristics of particular unmanned aircraft and its mission.

As it is possible to see from Figure 5. The operational flight path 3 is longer than the planned trajectory, but much shorter that is trajectory that is calculated based on general weather information. The comparison of the key economical parameters of simulated trajectory recalculations is shown in Figure 6.

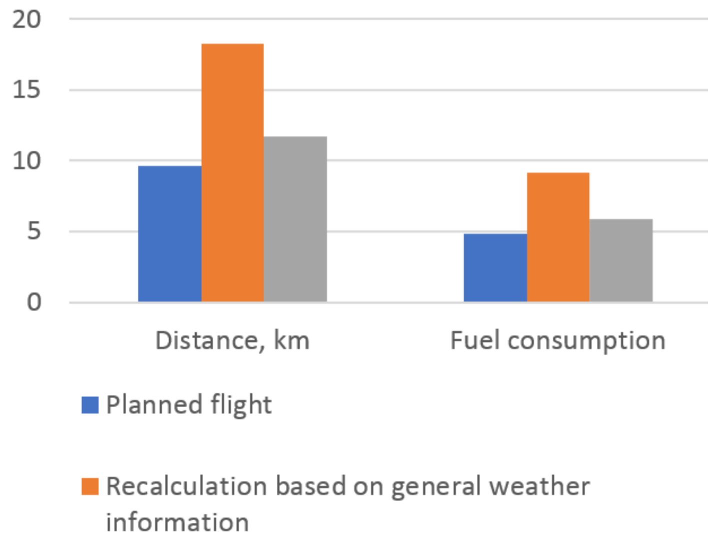

Figure 6: Comparison of flight parameters based on simulations of trajectory recalculation using the general meteorological information and fused real-time data.

The simulation results and comparison of key flight parameters demonstrate the evident gain in flight time and fuel consumption and keeping the flight safety as priority when obtaining, fusion and processing of real-time data about weather conditions.

6. Conclusions

In this paper, we considered one of the modern technologies that can be used for development and realization of modern and prospective concepts including Industry 4.0 and Society 5.0. These are the unmanned aircraft systems. The safe UAS operation is based on timely, reliable, operative information. But from another side it can be considered as the instrument to obtain and disseminate information. Therefore, we have analyzed the concept of common info space using the fused meteorological information obtained from different sources including dynamic. This is based on the distributed network of UASs to obtain operative information focusing on weather-related hazards along the flight path. Also, the network includes sensors that can be used for smart cities, IoT, IoE and measure the parameters of the atmosphere. The approach is aimed at completing the meteorological service of participants of air traffic in the frame of the concept including UAM, Industry 4.0 and Society 5.0.

The paper considers the possibilities of modern and prospective technologies to collect, fuse, and process diverse weather data including real-time data in the common information space. This common infospace are also proposed to use for exchange with operative information. The algorithm that is based on statistical meteorological data analysis for machine learning to indicate and forecast potentially hazardous areas for unmanned aircraft flight and missions was proposed. The data exchange pattern in the advanced system for weather service of aviation was also considered and characteristics that should be taken into account were discussed.

References

[1] What is industry 4.0? URL: https://www.ibm.com/topics/industry-4-0.

[2] P. Oliveira, E. Craveiro, J. Bezerra, E. Oliveira, D. Nascimento, What is Industry 4.0: a Review of the Literature Using the Conceptual Bibliographic Method, International Journal of Professional Business Review 8(12) (2023) 1–31. doi: 10.26668/businessreview/2023.v8i12.4171.

[3] B. Salgues, Society 5.0. Industry of the future, technologies, methods and tools, John qiley and Sons, Inc. (2018) URL: https://www.wiley.com/en-

us/Society+5.0%3A+Industry+of+the+Future%2C+Technologies%2C+Methods+and+Tools-p-9781119527633#description-section.

[4] T. Fernandez-Carames, O. Blanco-Novoa, I. Froiz-Miguez, P. Fraga-Lamas, Towards an Autonomous Industry 4.0 Warehouse: A UAV and Blockchain-Based System for Inventory and Traceability Applications in Big Data-Driven Supply Chain Management. Sensors 19(10) (2019) 23–94. doi: 10.3390/s19102394.

[5] Y. Znakovska, Y. Averyanova, 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.

[6] L. Barney, K. Ballard, B. Buck, M. Underwood, R. Chartran, Simulation of a Representative Future Trajectory-Based Operations Environment. NASA/TM. Hampton, Virginia: National Aeronautics and Space Administration, Langley Research Center, 2020. URL: https://ntrs.nasa.gov/api/citations/20205006885/downloads/NASA-TM-20205006885FINAL.pdf.

[7] New Aviaiton Ecosystem. Roadmap. IATA. URL: https://www.iata.org/contentassets/c3f5994d248e45cb877774b41e7b3103/new_aviation_ecosystem_roadmap.pdf.

[8] Future of Aviation. URL: https://www.icao.int/Meetings/FutureOfAviation/Pages/default.aspx.

[9] Urban Air Mobility. URL: https://www.easa.europa.eu/en/domains/drones-air-mobility/drones-air-mobility-landscape/urban-air-mobility-uam.

[10] UAV accidents report 2019, Ministry of Land, Infrastructure, Transport and Tourism. URL: https://www.mlit.go.jp/jtsb/annualreport2019e/annualreport2019e.pdf.

[11] K. Adkins, M. Akbas, M. Compere, Real-Time Urban Weather Observations for Urban Air Mobility. International Journal of Aviation, Aeronautics, and Aerospace 7(4) (2020) 1–27. doi: 10.15394/ijaaa.2020.1540.

[12] 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, AMS, United States, 2018, pp. 1–11. URL: https://ams.confex.com/ams/97Annual/webprogram/Manuscript/Paper309274/J3_1_Exploring_Range_of_Weather_Ranquist.pdf.

[13] M. Rajawat, Weather conditions and its effect on UAS, International Research Journal of Modernization in Engineering Technology and Science 12 (03) (2021) 1–7. URL: https://www.irjmets.com/uploadedfiles/paper/volume_3/issue_12_december_2021/17501/final/fin_irjmets1641191312.pdf.

[14] 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.

[15] Y. Averyanova, Y. Znakovska, The Spatial Relationships of Meteorological Data for Unmanned Aerial System Decision-Making Support, in: Proceedings of the Electronic Governance with Emerging Technologies: First International Conference, EGETC 2022, Communications in Computer and Information Science, vol 1666, Springer, Cham, 2022, pp. 64–80. doi:10.1007/978-3-031-22950-3_6.

[16] P. James, S. Matthias, Weather Guidance for Unmanned Aircraft Systems, National Center for Atmospheric Research, 2017. URL: https://ral.ucar.edu/aap/weather-guidance-for-unmanned-aircraft-systems-uas.

[17] Z. Bottyan, Z. Tuba, Z. Gyongyosi, Z. Andras, Weather Forecasting System for the Unmanned Aircraft Systems (UAS) Missions with the Special Regard to Visibility Prediction, Hungary. Critical Infrastructure Research Project (2016) 23–35. doi: 10.1007/978-3-319-28091-2_2.

[18] J. Shinkyu, Y. Kangkuk, S. Donghoon, Hazardous flight region prediction for a small UAV operated in an urban area using a deep neural network, Aerospace Science and Technology, 118 (2021) 107060, doi: 10.1016/j.ast.2021.107060

[19] Yu. Averyanova, O. Shcherbina, F. Yanovsky, I. Ostroumov, N. Kuzmenko, O. Solomentsev, Model for Wind-Related Phenomena Estimation Using Polarization Characteristics of Microwave Radar Signal, in: Proceedings of the 16th International Conference on Advanced Trends in Radioelectronics, Telecommunications and Computer Engineering Proceedings, 2022, pp. 173–177. doi: 10.1109/TCSET55632.2022.9767049.
[20] Yu. Averyanova, O. Shcherbina, F. Yanovsky, I. Ostroumov, N. Kuzmenko, O. Solomentsev, Polarimetric-radar drop size evaluation for wind speed estimate based on Weber criterion, in: Proceedings of the Signal Processing Symposium Proceedings, 2021, pp. 17–22. doi: 10.1109/SPSympo51155.2020.9593349.
[21] M. Ivanytskyi, Y. Znakovska, Y. Averyanova, UAS Flight Trajectory Optimization Algorithm Based on Operative Meteorological Information, CEUR Workshop Proceedings, 3426, (2023) 287–297. https://ceur-ws.org/Vol-3426/paper23.pdf.
[22] Info-Centric National Airspace System. URL: https://www.faa.gov/about/office_org/headquarters_offices/ang/icn.
[23] Initial Concept of Operations for and Info-Centric National Airspace System, URL: https://www.faa.gov/about/office_org/headquarters_offices/ang/icn/delivering#conops.
[24] A.N. Rudiakova, Y.A. Averyanova, F.J. Yanovsky, Aircraft Trajectories Correction using Operative Meteorological Radar Information, in: Proceedings of the International Radar Symposium, 2020, pp. 256–259. doi: 10.23919/IRS48640.2020.9253799.
[25] J. Rezende, R. Silva, M. Souza, Gathering Big Data in Wireless Sensor Networks by Drone, Sensors 20 (23) 6954 (2020). doi: 10.3390/s20236954.
[26] I. Ostroumov, et al., Relative navigation for vehicle formation movement, in: Proceedings of IEEE 3rd KhPI Week on Advanced Technology (KhPIWeek), IEEE, Kharkiv, Ukraine, 2022, pp. 1–4, doi: 10.1109/KhPIWeek57572.2022.9916414.
[27] N. Kuzmenko, I. Ostroumov, Y. Bezkorovainyi, O. Sushchenko, Airplane Flight Phase Identification Using Maximum Posterior Probability Method, in: Proceedings of IEEE 3rd International Conference on System Analysis & Intelligent Computing (SAIC), Kyiv, Ukraine, 2022, pp. 1–5, doi: 10.1109/SAIC57818.2022.9922913.
[28] O. Sushchenko, Y. Bezkorovainyi, V. Golitsyn, N. Kuzmenko, Y. Averyanova, M. Zaliskyi, Integration of MEMS Inertial and Magnetic Field Sensors for Tracking Power Lines, in: Proceedings of IEEE XVIII International Conference on the Perspective Technologies and Methods in MEMS Design (MEMSTECH), Polyana, Ukraine, 2022, pp. 33–36, doi: 10.1109/MEMSTECH55132.2022.10002907.
[29] O. Sushchenko, et al., Airborne sensor for measuring components of terrestrial magnetic field, in: Proceedings of IEEE 41st International Conference on Electronics and Nanotechnology (ELNANO), IEEE, Kyiv, Ukraine, 2022, pp. 687–691. doi: 10.1109/ELNANO54667.2022.9926760.
[30] Fast Eddy Model. URL: https://github.com/NCAR/FastEddy-model.
[31] K. Ito, H. Ohba, S. Mizuno, Visualization model for low-level turbulence using temporal rate of change of headwind of an aircraft, Preprint, 2023. doi:10.21203/rs.3.rs-3623292/v1.
[32] H. Sincavage, J. Jurecka, Turbulence. Types, Tips, and Mitigation. URL: https://www.weather.gov/media/zla/Jurecka_Sincavage%20Turbulence%20-%20SAWS%202023%20-%20Types%20Tips%20Mitigation.pptx.pdf.
[33] D. Munoz-Esparza, R. D. Sharman, J. K. Lundquist, Turbulence Dissipation Rate in the Atmospheric Boundary Layer: Observations and WRF Mesoscale Modeling during the XPIA Field Campaign, Mon. Wea. Rev. 146 (1) (2017) 351–371. doi: 10.1175/MWR-D-17-0186.1.