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Risk Analysis for Apple Orchard Survey and Monitoring Using UAV

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***Abstract*. Risk analysis is an integral part of modern business management because successful business largely depends on the effective implementation of risk analysis. Agriculture is an important sector in the national economy, therefore Industry 4.0 increasingly provides digital solutions in orchard management, which facilitate and simplify decision-making in daily tasks. Meanwhile, unmanned aerial vehicles are applied as the agriculture sector's main monitoring and data acquisition tool. However, this means that it is necessary to pay attention to risk analysis due to the process of managing the orchard, where not only a person and the mechanized equipment controlled by him, which moves on the ground but also flying automated equipment participates. The purpose of the article is to perform the risk analysis for the survey and monitoring of orchards for yield estimation using unmanned aerial vehicles by considering commercial apple orchards in Latvia. The main thing is that most risks are predictable, but planning is necessary to reduce the probability of their occurrence.**

Keywords: decision-making, risk analysis, unmanned aerial vehicle, security, SORA.

I. INTRODUCTION

Like other agricultural sectors, fruit growing faces a series of development challenges today. On the one hand, it is the impact of environmental factors and climate changes: extreme weather conditions such as unforeseeable spring frosts, periods of excessive drought or precipitation, shifts in the phenology of plant development, and emerging new pathogens or the broader spread of existing ones. On the other hand, society demands healthy, pesticide-free, and competitively priced horticultural products. These are pretty contradictory wishes that are difficult for the farmer to fulfill. Therefore, improved cultivation technologies are needed, i.e. see, smart fruit-growing solutions. Smart fruit-growing includes a modern way of farming based on the application of advanced technologies, which includes all cultivation processes to increase efficiency rather than capacity. This means that the tasks of smart fruit-growing are to create an efficient and optimal ratio of input and output through intelligent and goal-oriented analysis, planning, and observation. In order to realize these tasks, it is necessary to have a fast, accurate and sufficient amount of information (data), which the use of UAVs can provide, especially automated data collection and immediate transfer to decision-making systems.

As technology continues to advance, Unmanned Aerial Vehicles (UAVs) have become increasingly popular for various applications, including agriculture. In the context of orchard survey and monitoring, UAVs offer a convenient and efficient way to collect data and monitor, for instance, the health of trees. However, the use of UAVs also comes with potential risks that need to be identified and managed. In this article, the authors will explore the risks associated with using UAVs for orchard surveys and monitoring and discuss how these risks can be mitigated through a comprehensive risk analysis. By analyzing these risks and implementing appropriate measures, fruit

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growers, and orchard managers can ensure that the use of UAVs is safe, efficient, and effective in achieving their agricultural goals.

Risk analysis is currently an integral part of process management. For the implementation of a successful project, it is necessary to evaluate the risks in order to be aware of the potential threat and its impact. Risk assessment is not only a voluntary decision of the project implementer but in some sectors and areas, it is regulated with the help of regulatory acts. In order to be able to fly with a UAV, it is necessary to develop a risk analysis plan, which must be coordinated with the relevant institutions (Latvian Civil Aviation Agency (hereinafter - LCAA)).

The purpose of the article is to perform the risk analysis for the survey and monitoring of orchards for yield estimation using UAV by considering commercial orchards in Latvia.

II. MATERIALS AND METHODS

In the study, the risk analysis is based on the Specific Operations Risk Assessment (SORA) methodology, as the authors develop Unmanned Aerial System (UAS), which includes a UAV, Android control (Android mobile application), and a base station.

SORA is a methodology for classifying the risks posed by UAV flights into a specific operational category and establishing risk mitigation and safety objectives. It helps the operator to determine operational limitations, training objectives for personnel, as well as technical requirements for the UAV and develop appropriate operating procedures, which are the operator's manual [1] (Fig. 1.).

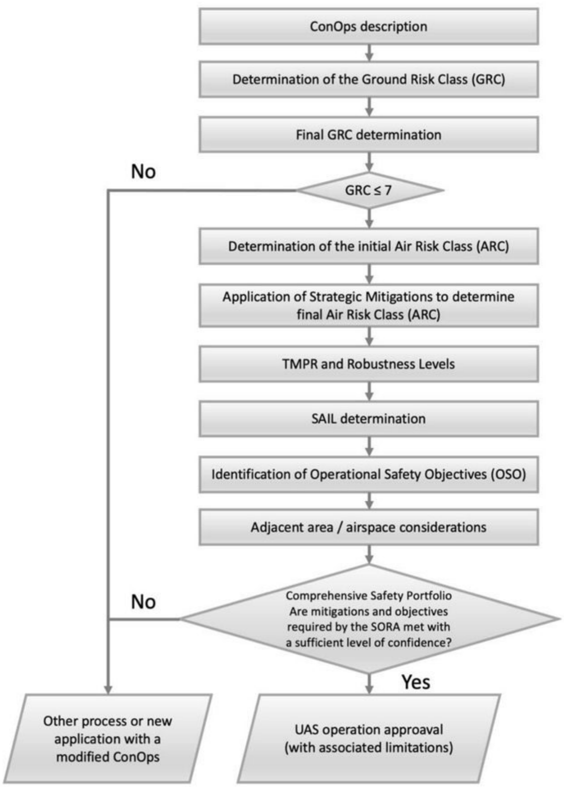

Fig. 1. SORA methodology 10 steps [2].

(ConOps – Concept of Operations)

Our study is scoped by orchard monitoring and yield forecasting. It provides a possibility to apply small and light UAVs of C0-C1 models because it is not required to transport any kind of cargo like pesticides. Therefore, authors restricted analysis with C1 maximal parameters, which define the functional requirements like maximum take-off mass less than 900 g, including payload; a maximum speed in level flight of 19 m/s, etc.; considering to Regulation (EU) 2019/945 (R945).

Existing Institute of Horticulture agrotechnical trial plantations were chosen for UAV test flights, yield development data collection, and risk analysis. These plantations are designed according to the trends of modern fruit growing. The modern commercial orchards are structured as fruiting walls of trees on tree-height-reducing rootstocks providing corridors of space for harvesting and orchard management tasks (Fig. 2).

Fig. 2. Photo of commercial orchard.

The experimental trial, where UAV flight tests took place, represented a diversity of apple cultivars ('Alesja', 'Antonovka', 'Beforest', 'Belorusskoje Malinovoye', 'Dace', 'Daina', DI-3-90-45, DI- 93-4-22, 'Edite', 'Eksotika', 'Felicita', 'Gita', 'Lora', 'Monta', 'Saltanat', No. 28-97-4, 'Zarja Alatau'), grafted on dwarfing (B.396, M.9, B.9) and semi-vigorous (MM 106) rootstocks. The distance between rows of trees was 4 m for dwarfing rootstocks, while for semi-vigorous rootstocks - 4 - 5 m, with the distance between trees in a row - was 1 to 3 m. Some orchards can have bird nets. Therefore, it was considered to fly between fruit walls. Meanwhile, the photo is obtained after each *N* meters to simplify the geopositioning of trees (Fig. 3).

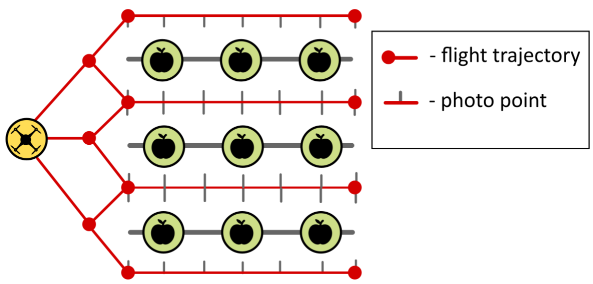

Fig. 3. Flight trajectory of UAV for orchard monitoring.

When performing a risk analysis according to the UAV and flight location mentioned in the methodology, the following and restrictions apply: flights are conducted in the territory of Latvia and flights are conducted over private property up to 30 m belonging to the UAV operator.

The CORAS method was applied for the security risk analysis of UAS [3]. The high-level analysis was completed including approval stage. The objective of the high-level analysis is to get an overview of the main risks, which will identify the non-functional requirements of UAS.

Risk assessment is performed based on the two-dimensional risk assessment matrix, assessing the probability of risk occurrence and possible consequences (Tab. 1., 2., 3.). According to Tab. 3, low risk (L) - 1-2, medium risk (M) - 3-6, and high risk (H) - 7-12.

TABLE 1 CHARACTERISTICS (DEFINITIONS) OF THE CATEGORY "PROBABILITY"

Probability	***Characterization***	***Quantitative assessment***
Rare	So rarely possible during UAV operations that no compliance is required	1
Unlikely	This is not expected to occur, but may still occur during UAV operations due to certain circumstances	2
Often possible	It is expected that this may occur during the operation of the UAV	3

TABLE 2 CHARACTERISTICS (DEFINITIONS) OF THE CATEGORY "IMPACT"

Impact	***Characterization***	***Quantitative assessment***
Insignificant effect	Failure conditions that would not affect UAV operation, data and human safety	1
Low impact	Conditions that do not significantly reduce UAV performance apply.	2
Dangerous	Refers to conditions that reduce the UAV's ability to perform tasks accurately or completely. Conditions that result in danger for non-human objects	3
Catastrophic	Covers conditions that render the operation of the UAV no longer possible to use Conditions that result in dangerous conditions for human health or life apply.	4

TABLE 3 RISK PROBABILITIES - IMPACT ASSESSMENT MATRIX

Impact Probability	***Insignificant effect***	***Low impact***	***Dangerous***	***Catastrophic***
Rare	*1*	*2*	*3*	*4*
Unlikely	*2*	*4*	*6*	*8*
Often possible	*3*	*6*	*9*	*12*

III. RESULTS AND DISCUSSION

The latest technological advances allow UAVs to become an effective monitoring tool for improving orchard management, which can provide growers with much more detailed and accurate information about the health status of fruit plants, geometric variables, physiological variables, etc. [4]. However, various challenges have to be faced in the use of UAVs in the inventory and monitoring of orchards.

The diversity of the natural outdoor environments and the vast amount of diversified data types required to plan and deploy autonomous agri-field operations still comprise significant bottlenecks. Indicatively, challenges exist even at the seemingly superficial level, for example, calculating an autonomous vehicle's optimal route planning (i.e., generating a safe path between a source and a destination point) [5], [6].

Orchards (the source of the fruit industry chain) require site-specific or even individual-tree-specific management throughout the growing season—from flowering, fruitlet development, ripening, and harvest—to tree dormancy. The recent increase in research on deploying UAVs in orchard management has yielded new insights but challenges relating to determining the optimal approach (e.g., image-processing methods) are hampering widespread adoption, largely because there is no standard workflow for the application of UAVs in orchard management [7] but automation and precise orchard management not only brings more profits to growers but also reduces the damage to the environment [2].

The constantly growing number of operations employing UAVs requires not only the identification of hazard sources or risk assessment recommended by the applicable regulations but also comprehensive risk management [8].

The use of UAVs for apple orchard survey and monitoring is subject to certain risks, particularly in adverse weather conditions (Fig. 4). UAVs are susceptible to wind, rain, fog, and other weather conditions that can affect their stability and maneuverability. For example, strong winds can cause a drone to drift off course or lose altitude, which could result in a collision with a tree or other obstacles in the orchard. Rain or fog can also interfere with the drone's sensors and camera, which could lead to poor data quality or even a complete loss of data. Therefore, it is important to assess weather conditions before deploying a UAV and to avoid using it in unfavorable conditions. By doing so, the risk of accidents, equipment damage, and data loss can be minimized, ensuring a safe and successful apple orchard survey and monitoring operation.

To ensure continuous and reliable monitoring using UAVs, regular maintenance is essential (Fig. 4). Routine maintenance tasks include checking the UAV's batteries, propellers, and sensors for signs of damage or wear, and cleaning the camera lens and other components to ensure optimal performance. It is recommended to perform maintenance tasks before and after each flight to ensure that the UAV is in good working condition. In addition to routine maintenance, regular calibration of the UAV's sensors is also important to ensure accurate data collection. Calibration should be performed periodically based on the manufacturer's recommendations or after any significant changes to the UAV's hardware or software. It is also important to keep the UAV's firmware up-to-date to ensure that it is operating with the latest security patches and software updates. By performing regular maintenance and calibration tasks, the risk of equipment failure and data loss can be minimized, and the UAV can continue to provide reliable and accurate data for apple orchard surveys and monitoring.

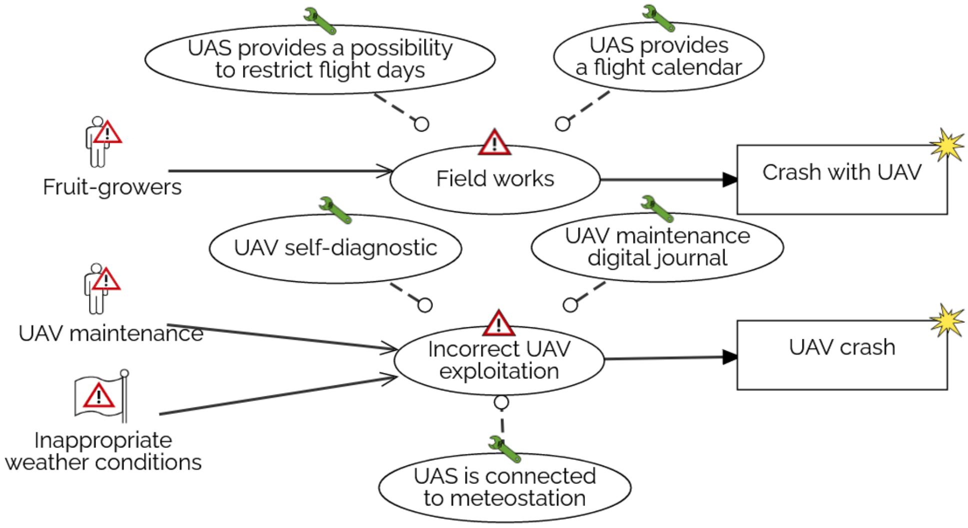

Fig. 4. Treatment of UAS exploitation risks.

Considering the generally accepted management practices of orchards, the inter-rows are used as movement lanes for employees and equipment and are used in all orchard care activities: tree training, soil treatment, pesticide application, harvesting, and yield transport. UAVs also use the same lines to navigate during data collection. Therefore, it is essential to coordinate time and space between UAV flying and orchard management activities (Fig. 4). Therefore, the principal risks of using UAVs could be the following:

- Collisions and injury to garden management personnel who are not warned in time and are in the garden during the operation of the UAV. This can be especially relevant for workers who work with mechanical tools (electric tree training shears, hand-held pesticide sprayers) that make noise and thus mask the approach of UAVs.

- Collision with garden equipment (tractors that do soil management, pesticide spraying) whose drivers are entirely focused on the work to be done, while the cabin of the equipment and the noise it makes mask the approach of the UAV.

Speaking about software development and algorithms, it is important to verify flight regions considering restricted and private territories. Another requirement for UAV fly mission planning is power battery consideration, which is called the drone arc routing problem. The more novel idea is the vehicle-drone arc problem, which considers mobile UAV stations, which is an interesting solution for future studies [9]. If the planning algorithm is correct, another challenge is GPS coordinate precision, which must be sufficiently accurate, because the distance between rows of trees can be 1 meter (Fig. 5).

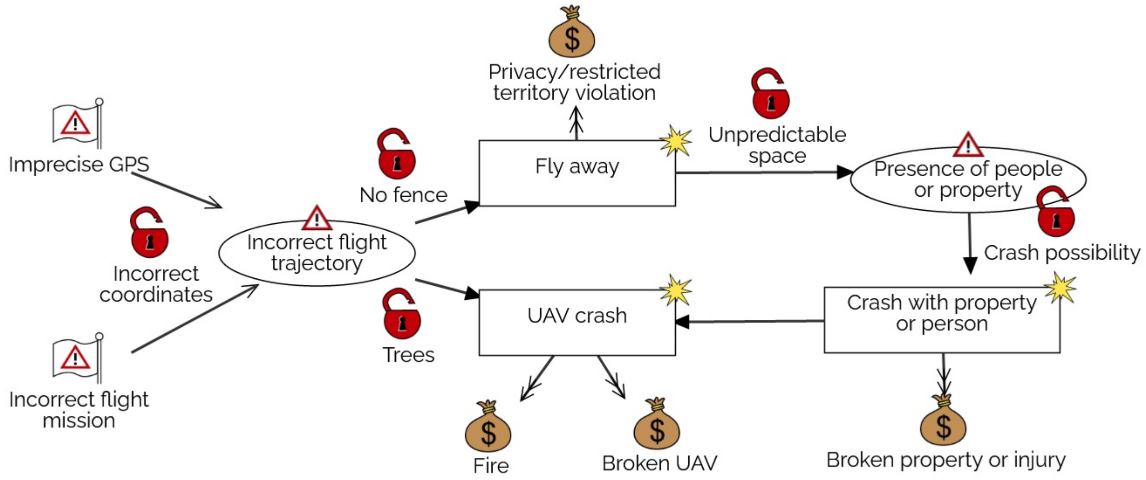

Fig. 5. Risks of uncontrolled flight.

For successful risk management, a risk register is created, where it is possible to easily see the risks that need attention, what risk mitigation measures need to be implemented to reduce risk (Tab. 4). The risk register was created from a business point of view, assessing the risks of possible financial losses that may occur to the owners of commercial gardens.

TABLE 4 RISK REGISTER

Name of the risk	***Description of the risk***	***Consequences of risk***	***Probability***	***Impact***	***Risk: L, M, H***	***Risk mitigation measures***
Risks arising between the UAV and the objects being surveyed						
Getting tangled up	The UAV gets caught by the branches or bird nets of the object while in flight	The UAV is damaged or destroyed	2	2	M	Determining the exact flight path. Using sensors to avoid
Crashing into the survey object	The UAV crashes into the survey object during flight	The UAV is damaged or destroyed	2	3	M	Determining the exact flight path. Using sensors to avoid hitting the tracked object.
Risks arising between UAV and human						
UAV collision with a person doing work in the orchard	A UAV crashes into a person in flight, who is working considering work plan	The UAV is damaged and/or a person is injured	1	4	M	The location time of people in the orchard and the flight time of the UAV are coordinated by UAS.
		The UAV is damaged or destroyed	1	4	M	
	A person disturbs the UAV (unauthorized presence)	The UAV is damaged or destroyed	1	4	M	Place warning signs about a possible UAV flight, limit private territory
Risks arising between the UAV and another technique						
UAV collides with machinery employed in a commercial orchard	During the flight, the UAV crashes into the machinery employed in the commercial garden	The UAV is damaged or destroyed	1	4	M	The location time of the machinery employed in the commercial orchard and the flight time of the UAV are coordinated by UAS.
		Equipment damage is caused	1	3	M	

The UAV flies while the machinery is working in the garden	The liquid damages the UAV	The UAV is damaged or destroyed	1	4	M	
Risks arising under the influence of weather conditions						
Wind too strong	UAVs cannot fly short time period	Necessary data is not collected	3	2	M	Work planning and coordination considering meteorological conditions
Heavy rain	UAVs cannot fly	Necessary data is not collected	3	2	M	
Thunderstorm	UAVs cannot fly	Necessary data is not collected	3	2	M	
Risks arising from the operation of UAVs						
Inadequate UAV technical condition	UAV breaks down under normal use due to failure to properly assemble/test before the flight.	The UAV is damaged or destroyed	1	4	M	Follow UAV operating requirements carefully. UAS provides a maintenance journal.
Departure outside the designated flight area	During the flight, the UAV violates the boundaries of the territory intended for flight	A UAV is lost	1	4	M	Geo-fensing, return-to-home
		A person is injured	1	4	M	
		Third party property is damaged	1	3	M	
		The restricted area is being violated	1	4	M	

All of them are medium risks, they depend on human activity, and they can be reduced if appropriate risk mitigation measures are implemented. The highest risks are related to weather conditions, on which possible risk mitigation measures are conditional.

The future trend of UAV development is related to trustworthy UAS development, which complies with ideas about robots and Industry 5.0.

IV. Conclusions

In order to be able to fully use UAVs for the survey and monitoring of commercial apple orchards, it is necessary to comply with the legislative requirements of the specific country where flights are planned. Determine exactly the technical parameters of the UAV intended for flight and then comply with the rules and requirements that are set according to the SORA methodology. Identify potential risks, assess them, and develop appropriate measures to reduce the impact of risk. Our study was related to the orchards located in Latvia

Risk management is widely used in various industries. From the IT point of view, risks are potentially perceived as a negative phenomenon that can cause possible losses.

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