Multiple criteria analysis of remotely piloted aircraft systems for monitoring the crops vegetation status

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Abstract. The paper presents an analysis of Remotely Piloted Aircraft Systems (RPAS) used for monitoring the crops vegetation status. The study focuses on two types of RPAS, namely the flying wing and the multi-copter. The following criteria were taken into account: technical characteristics, power consumption, flight autonomy, flight conditions, costs, data acquisition systems used for monitoring, crops area and so on. Based on this analysis, advantages and disadvantages are emphasized offering a useful tool for choosing the proper solution according to the specific application conditions.

1. Introduction

The precision agriculture is the newest way to solve efficiently the complex problems of crops production management and to develop a sustainable agriculture. According to this, farmers have to manage small areas within the fields instead to use the same management for all cultivated areas. The main goal is to do the right thing, at the right place at the right time [1]. The aim of the precision agriculture is to increase the crops productivity and to reduce the environmental risks.

During the crops vegetation monitoring, farmers must manage a large amount of information about the location and field characteristics and find solutions for solving the problems and optimizing the processes. This mean multi-spectral images of the crops status and areas, geo-referenced and taken over time and a high quantity of data monitoring for inputs and outputs of the harvest [2], [3].

Precision agriculture requires complex and more detailed geo-information about crop vegetation status (soil quality and properties, environment, crops health, yield capacity, applied agriculture technologies such as irrigation, the rate of fertilizer and pesticides).

The development of de high accuracy and miniaturised sensors assure the implementation and the improvement of precision agriculture. New mechatronic systems such as Remotely Piloted Aircraft Systems (RPAS) assure very high performances in farm-level imagery. RPAS are low-cost and light-weight Unmanned Aerial Vehicles (UAV).

For the different agricultural applications, there are taken into account two types of RPAS: flying wings and multi-copters. Farmers need to have a useful tool for choosing the proper solution according to the specific application conditions. For finding a solution, we realised a multiple criteria analysis of technical characteristics, power consumption, flight autonomy, flight conditions, costs, data acquisition systems used for monitoring, crops areas.
2. Theoretical aspects of multiple criteria analysis

The multi-criteria analysis provides techniques for comparisons and rankings of various solutions through the use of a wide range of indicators. This method is applied particularly if the approach using a single criterion is not sufficient. The purpose of this tool is to structure and combine different evaluations to be taken into account in finding a solution when making decisions involves several alternatives and the importance of each of these determines the final decision [4].

In the complex situation of choosing the proper solution of Remotely Piloted Aircraft Systems used for monitoring the crops vegetation status according to the specific application conditions, are simultaneously considered the main criteria of performance and achievement of all specific goals of precision farming. The used criteria are the measures by which alternatives are evaluated and compared in order to determine how they lead to goals.

Each criterion should determine a relevant aspect of the application and be independent of the other criteria used in the analysis. In the multi-criteria analyses, they should be: capable of differentiating between alternatives and able to provide comparisons between alternatives performances, complete, operational, non-redundant and in small numbers [5].

A standard multi-criteria analysis tool is the performance matrix, also called the decision matrix. In it, each row describes an option and each column describes the performance options according to each criterion [4].

To achieve a numerical analysis of the decision matrix, consistent numerical values or weights are assigned to the information. An important step in the multi-criteria analysis is the standardization of the performance matrix. This is the process in which criteria values expressed by different units of measure are converted to a common scale. This allows a comparison between values.

The main steps that involves multi-criteria analysis for choosing the proper solution of Remotely Piloted Aircraft Systems used for monitoring the crops vegetation status according to the specific application conditions are shown in figure 1.

[Diagram of multi-criteria analysis steps]

Figure 1. Multi-criteria analysis steps.

3. RPAS as mechatronics systems

Aerial monitoring of the crops vegetation status can be done with the help of high-resolution images obtained with remote sensing platform type mechatronic systems for low altitude and small unmanned aerial systems. These present the advantages of low operation costs, high spatial and temporal resolution and increased flexibility in programming the image acquisition module.

There are some studies concerning the unmanned aerial vehicles in precision agriculture using multiple cameras equipped with interference filters. The results of these studies show that in order to provide a trustworthy product for farmers, significant progress is required in the design and manufacturing the flying platform, image geo-referencing standardization, establishing the algorithms for information processing and creating the decision support programs [6], [11].

The multispectral images can be taken with the help of RPASs which are complex mechatronics systems. Various aerodynamic solutions of mechanical structures are part of those mechatronic systems, with high-performance control systems that ensure ultra-efficient monitoring of plant growth. Although in terms of mechanical and aerodynamic, RPAS are divided in two major categories, namely
flying wings and multi-copters. The structure of the control system (shown in figure 2) is the same for both categories.

Figure 2. RPAS control system.

4. Multi-criteria analysis
Mechatronic systems such as RPAS, consisting of mechanical components, electronics and software, ensure to the farmers solutions for monitoring the crops vegetation status. Farmers will be able to benefit from using these mobile aerial mechatronic systems that acquire, process, store and transmit multispectral information from the crops. Obtained data are used as inputs in an innovative technology for interpreting and decision generating with the purpose of improving the precision agricultural management [6].

They show advantages of low operating costs, high spatial and temporal resolution and high flexibility in image acquisition mode programming. There are several studies on the use of RPAS in precision agriculture [6], [7], [8], [9]. The results of these studies show that to provide a performant end product of confidence for farmers, significant processes are needed: the choice of right type of RPAS, design and implementation of the complex flight platform, image geo-referencing standardization, determining algorithms for computing and implementing decision support software [10].

Lately, it is noticed a substantial increase in the interest of UAVs manufacturers in finding and implementing new technical solutions that respond to conditions imposed by these systems applications in precision agriculture.

Operating conditions of unmanned flying mechatronic systems, as RPAS, in agricultural applications are very diverse and complex. A method of analysis and finding the proper solution for specific applications in precision farming is the multi-criteria analysis.

The main problem is choosing the proper solution of the two types of RPASs - planes without a pilot (flying wings) or multi-copters. The basic requirements that must be considered are: the possibility to integrate a system for acquisition, processing, storage and transmission of multispectral information; flight time with imposed load: minimal 20 minutes; number of programmable waypoints: minimum 140; navigation software for laptop, smartphone and tablet; weight with the equipment that must fly: minimum 2kg, affordable costs of acquisition and maintenance [6].

Considering the cost of the equipment with which the drone flies, there are required special security functions: RTL- Return To Launch in case the link with radio transmitter or with the ground station is lost; fail safe on the battery; GeoFence - an automatic flying perimeter in which
the RPAS will be forced to stay; flight parameter warnings emitted from soil, doubling the command links - remote control + remote control station on the ground; warning limit of radio communication with RSSI integrated system on remote control (for identifying the position in case of loss); trajectory registration on the ground station; monitor with video receiver and with navigation data display on the screen, GPS/GSM tracker etc.

In accordance with these conditions, in table 1 are presented the criteria which are the basis of the proposed multi-criteria analysis.

Table 1. Criteria and Range of values.

| Criteria | Range of values |
|----------|----------------|
| Costs    |                |
| C1. Acquisition costs | 12000$-300$ |
| C2. Maintenance costs | 0-800$ |
| C3. Flight autonomy | 10-60 minutes |
| C4. Stop at a fixed point | Yes/No (1/0) |
| C5. Take off/ landing on vertical | Yes/No (1/0) |
| C6. Speed | 30km/h-90km/h |
| C7. Height of flight | Min1 m – Max 2000m |
| C8. Emergency landing mode | Linear landing /vertical drop (1/0) |
| C9. Landing accuracy | 0-5m |
| C10. Covered area in flight (in a single flight) | 4-15km² |
| C11. Lifetime | 1,5-2 years |
| C12. Dimensions – (Wingspan –Diameter) | 0,3-1,8m |
| C13. Energy consumption | 7200-10000mA/h |
| C14. Speed/ Energy consumption | 30/7200 -90/10000km/mA |
| C15. Weight with equipment | 3 – 7 kg |
| C16. Data acquisition systems used for agriculture applications | Yes/No (1/0) |
| C17. Special security functions | Yes/No (1/0) |
| C18. Ground Sampling Distance (GSD) | Down to 5 cm /pixel |

For the criteria listed in table 1 were analyzed the two main options (flying wing and multi-copter), and for each of them were compared three of the main products of the largest manufacturers of RPAS in the world. In this context, by following the steps shown in figure 1, has been made the performance matrix of the analyzed options presented in table 2. For the considerate criteria and in accordance with the specifics of applications concerning the monitoring of the crops status vegetation in the framework of the precision farming, in table 3 have been proposed weights used in the multi-criteria analysis.

By applying the weightings of each criterion in the options analysis, it has been able to make out the ranking of these possibilities.
Table 2. The performance matrix of the analysed options [12],[13],[14],[15],[16],[17].

| Criteria | SKYWALKER F1 | SENSIFLY F2 | DRAGANFLY TANGO F3 | DJI PHANTOM3 M1 | PARROT AGRO M2 | DRAGANFLYER-X4-P M3 |
|----------|--------------|-------------|---------------------|----------------|----------------|---------------------|
| C1.      | 2400$        | 12000$      | 10000$              | 2250$          | 600$           | 12500$             |
| C2.      | 100$         | 0           | 0                   | 500$           | 300$           | 300$               |
| C3.      | 60 minutes   | 45 minutes  | 50 minutes          | 15-23 minutes  | 22 minutes     | 20-25 minutes      |
| C4.      | No           | No          | No                  | Yes            | Yes            | Yes                |
| C5.      | No           | No          | No                  | Yes            | Yes            | Yes                |
| C6.      | 45km/h       | 40-90km/h   | 50-60km/h           | 57km/h (16m/s) | 46km/h (13m/s) | 50km/h             |
| C7.      | 100m         | 70m         | 120m, max 640m      | 60m, min 1m- max 120m | 60m, min 1m- max 120m | 60, min 1m- max 2400m |
| C8.      | Linear landing | Linear landing | Linear landing | Vertical drop | Vertical drop | Vertical drop |
| C9.      | Linear landing with ~ 5 m accuracy | Linear landing with ~ 5 m accuracy | Linear landing with ~ 4 m accuracy | Vertical drop | Vertical drop | Vertical drop |
| C10.     | 15m²         | 10 km²      | 12km²               | 5km²           | 4km²           | 5km²               |
| C11.     | 1,5 years    | 1,5 years   | 1,5 years           | 2years         | 2years         | 2years             |
| C12.     | 1,8m         | 0,96 m      | 1,5m                | 0,35m          | 0,3            | 0,8m               |
| C13.     | 10000mA/h    | 9000mA/h    | 8000mA/h            | 10000mA/h      | 7200mA/h       | 10000mA/h          |
| C14.     | 45km/10000mA | 90km/9000mA | 60km/8000mA         | 57km/10000mA   | 46km/7200mA    | 50km/10000mA       |
| C15.     | 3kg          | 0,71 kg     | 6,8kg               | 1,3kg          | 0,6kg          | 3,8kg              |
| C16.     | Yes          | Yes         | Yes                 | Yes            | Yes            | Yes                |
| C17.     | Yes          | Yes         | Yes                 | Yes            | Yes            | Yes                |
| C18.     | -            | Down to 2 cm /pixel | Down to 3 cm /pixel | Down to 5 cm /pixel | Down to 3 cm /pixel |

Table 3. Proposed weights used in the multi-criteria analysis.

| Criteria | C1. | C2. | C3. | C4. | C5. | C6. | C7. | C8. | C9. | C10. | C11. | C12. | C13. | C14. | C15. | C16. | C17. | C18. |
|----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|
| Weights  | 0,2 | 0,05| 0,1 | 0,05| 0,05| 0,05| 0,05| 0,05| 0,03| 0,03  | 0,03  | 0,03  | 0,03  | 0,03  | 0,03  | 0,03  | 0,03  |

The matrix of performance has been normalised after vector method using the formula (1) for criteria C3, C4, C5, C6, C8, C10, C11, C12, C13, C14, C15, C16, C17, C18, which have been maximised, and the formula (2) for criteria C1, C2, C7, C9, C18 which were minimised.

\[ r_{ij} = \frac{a_{ij}}{a_{ij}^{\text{max}}} \]

\[ a_{ij}^{\text{max}} = \max_i \{a_{ij}\} \]
where $a$ is the value of the RPAS type characteristic for the corresponding criterion, $r$ is the normalised value of $a$, $i = 1$ to the option number ($i = 1 \ldots 6$) and $j = 1$ to the criteria number ($j = 1 \ldots 18$).

$$r_{ij} = 1 - \frac{a_{ij}}{a_{ij}^{\text{max}}} = \frac{a_{ij}^{\text{max}} - a_{ij}}{a_{ij}^{\text{max}}}$$

(2)

where parameters are the same as in equation (1).

These results are shown in table 4.

**Table 4.** The normalised matrix of performance.

| Criteria | C1. | C2. | C3. | C4. | C5. | C6. | C7. | C8. | C9. | C10. | C11. | C12. | C13. | C14. | C15. | C16. | C17. | C18. |
|----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|
| **F1**   | 0,808 | 0,8 | 1   | 0   | 0   | 0,5 | 0,17 | 1   | 0   | 1,75 | 1    | 1    | 0,45 | 0,44 | 1    | 1    | 0    |
| **F2**   | 0,04 | 1   | 0,75 | 0   | 0   | 1   | 0,42 | 1   | 0   | 0,67 | 0,75 | 0,53 | 0,9  | 1    | 0,1  | 1    | 1    | 0,6  |
| **F3**   | 0,2 | 1   | 0,83 | 0   | 0   | 0,67 | 0   | 1   | 0,2 | 0,8  | 0,75 | 0,83 | 0,8  | 0,75 | 1    | 1    | 1    | 0    |
| **M1**   | 0,82 | 0   | 0,38 | 1   | 1   | 0,63 | 0,5 | 0   | 0,33 | 1    | 0,19 | 1    | 0,57 | 0,19 | 1    | 1    | 0,4  |
| **M2**   | 0,952 | 0,4 | 0,37 | 1   | 1   | 0,51 | 0,5 | 0   | 0,27 | 1    | 0,16 | 0,72 | 0,64 | 0,09 | 1    | 1    | 0    |
| **M3**   | 0   | 0,4 | 0,42 | 1   | 1   | 0,55 | 0,5 | 0   | 0,33 | 1    | 0,44 | 1    | 0,5  | 0,56 | 1    | 1    | 0,4  |
| **Weights** | 0,2 | 0,05 | 0,5 | 0,1 | 0,05 | 0,1 | 0,05 | 0,05 | 0,05 | 0,03 | 0,05 | 0,03 | 0,03 | 0,05 | 0,05 | 0,03 | 0,03 |

By adding the scores corresponding to each criterion it has been obtained the ranking of analysed options, shown in table 5.

**Table 5.** Option ranking.

| Criteria | SKYWALKER | SENSIFLY eBee | DRAGANFLY TANGO | DJI Phantom3 Agro | PARROT | DRAGANFLYER X4-P |
|----------|-----------|---------------|----------------|------------------|--------|-----------------|
| **F1**   | F1        | F2            | F3             | M1               | M2     | M3              |
| **Scores** | 0,60 | 0,48 | 0,51 | 0,65 | 0,57 | 0,52 |
|          | 1,59      |               |                |                  |        |                 |

By analysing the obtained results, we can affirm that in the case of middle-size farms the best solutions of RPAS with high performances and accessible acquisition and maintenance costs, which can ensure multispectral information relating to the crops vegetation status for precision agriculture applications are the multi-copters.

As it can be seen in table 5, the sum of the scores obtained in the case of multi-copter aerial mechatronic systems type is 1,74 and in the case of the flying wings the amount is 1,59.

5. Conclusions

During the crops vegetation monitoring, producers must manage a large amount of information about the location and field characteristics and find solutions for solving the problems and optimizing the processes.
Farmers need to have a useful tool for choosing the proper solution according to the specific application conditions and for solving the main goal which means to do the right thing, at the right time at the right place. For precision agriculture, high-resolution images must be obtained with remote sensing platform type mechatronic systems for low altitude and small unmanned aerial systems. These present the advantages of low operation expenses, high spatial and temporal resolution and increased flexibility in programming the image acquisition module.

For finding a solution, we realised a multiple criteria analysis of technical characteristics, power consumption, flight autonomy, flight conditions, costs, data acquisition systems used for monitoring, crops areas. The main problem is choosing the proper solution of the two types of RPASs - planes without a pilot (flying wings) or multi-copters.

Starting from the basic conditions to be satisfied by the RPAS (the possibility to integrate a system for acquisition, processing, storage and transmission of multispectral information; flight time with imposed load: minimal 20 minutes; number of programmable waypoints: minimum 140; navigation software for laptop, smartphone and tablet; weight with the equipment that must fly: minimum 2kg, affordable costs of acquisition and maintenance), were analysed a series of technical solutions realised by the leading manufacturers in the field.

In this study, the multi-criteria analysis was used for comparisons and rankings of various solutions through the use of a wide range of indicators.

The conclusion of this study shows that in the case of middle-size farms the best solutions of RPAS with high performances and accessible acquisition and maintenance costs, which can ensure multispectral information relating to the crops vegetation status for precision agriculture applications are the multi-copters.

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