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Mission Planning for the Estimation of the Field Coverage of Unmanned Aerial Systems in Monitoring Mission in Precision Farming

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In the recent years, Unmanned Aerial Systems (UAS) have been largely employed in civil applications, such as aerial photography and topographic mapping, environmental monitoring, search and rescue, prevent of fires and disasters, environmental research and general photography and videos. Nevertheless, according to (AUVSI, 2013), agriculture is the main application where UAS will be employed in the near future. Small Unmanned Aerial Vehicles (UAVs) are flexible, easy to use and relative low-cost; thus, they can be employed in monitoring activities in precision farming, ensuring a prompt reaction to plant disease, lack of plants nutrients and environmental changes that are the main focus for farm efficiency and productivity.
Recent development in high-resolution remote sensing and image processing technology has yield to small-size sensors compatible with small UAV payload weight. Each kind of sensor needs a certain flight pattern over the fields.
However, a Remotely Piloted Aircraft Systems (RPAS) used for specialized operations or experimental activities has to be compliant with National Civil Aviation Authority regulations. On 2015, the Italian Aviation Authority (ENAC) published the second edition of the regulatory issue for this kind of aircrafts.
The aim of this paper is the management analysis of RPAS for their use in survey missions for precision faming, taking into account the Italian regulatory prescription and two different kind of commercial sensors. UAVs are considered similarly to any other farm machine, describing the operative workflow and analysing the elementary time procedures associated to the different ways of planning a flight mission of the UAS on the field to be monitored. Actual rates of works, Effective Field Capacity (EFC) and Field Efficiency (FE), field coverage and survey cost are finally provided. The analysis includes also in-field pre-flight calibration procedures.

1. Introduction

Precision Farming (PF) or Precision Agriculture (PA) techniques even include the possibility of automating as much as possible the execution of crop monitoring tasks (scouting) through the application of technologies able to enhance the capability of observing and measuring the crop variability either in a field or among different fields (F. Mazzetto, 2015).
Many agricultural applications involved UAS platforms. In (Gnyp, M, et al., 2016) a comparison between a tractor-mounted spectrometer and the same one mounted on a UAV platform is carried out to estimate N uptake of winter wheat. A multi-band high-resolution imaging sensor was carried on a multirotor UAV for citrus greening disease detection (F. Garcia-Ruiz, 2012). A radio-controlled unmanned helicopter-based low-altitude remote sensing (LARS) platform was used to acquire quality image of high spatial and temporal resolution in order to estimate yield and total biomass of a rice crop (K. C. Swain, 2010).
Nevertheless, to operate with this kind of aircrafts in the Italian territory (as well as in most European countries), UAVs has to be compliant with the National Aviation Authority regulation (ENAC, 2015). Pre-flight

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and post-flight procedures are necessary to ensure an appropriate level of safety to the specialized operations. A restriction in term of maximum distance of the flying platform to the pilot is also applied.

In this paper we evaluate actual rate of works of UAVs in monitoring mission, considering the unmanned platforms similarly to any other farm machine and providing the platforms performance in term of Effective Field Capacity (EFC) and Field Efficiency (FE), field coverage and survey costs. The analysis takes into account the Italian regulatory prescriptions and two different kind of commercial sensors. The analysis includes also in-field pre-flight calibration procedures and considers both multirotor and fixed-wing platforms.

The paper is organized as follow. Section 2 presents the sensors and the UAVs evaluated in the analysis. Section 3 describes the flight path for the different UAV platforms and the procedures to carry out the monitoring missions. UAVs performances and the cost evaluation are illustrated in Section 4 and 5, respectively. Section 6 includes the results and the comments of the performance analysis and the costs evaluation. The paper ends with the conclusions.

2. Materials and methods

2.1 Sensors

Two different kind of sensors have been considered: active and passive sensors. Their main difference are described in (Erdle K. et al., 2011). The active sensor is the *OptRx®* crop sensor from AG Leader (www.agleader.com). This sensor provides immediately the required Vegetation Indexes (VI, NDVI and NDRE). A data logger elaborates the data acquired by the OptRx® crop sensor and associates these readings to the RTK-based GPS onboard the multicopter to create georeferenced maps. Table 1 shows its main features.

The passive sensor is the *RedEdge* multispectral camera from Micasense Inc. (www.micasense.com). The RedEdge is an advanced multispectral camera specifically designed for small UAS. It can capture simultaneously five discrete bands and it exploits a narrowband optical filter to provide full imagery resolution for each band. A GPS is connected to the camera to geo-referencing the multispectral images acquired. Table 2 shows its main features. Its Ground Sampling Distance (GSD) depends on the flight altitude as reported in table 3.

Table 1: AgLeader OptRx crop sensor main features (www.agleader.com)

VI Acquired	Measurement range	Angle of view	Weight	Cost
[-]	[m]	[deg]	[g]	[€]
NDVI, NDRE	0.25 ÷ 2	45 ÷ 10	430	~ 3000

Table 2: Micasense RedEDge multispectral camera main features (www.micasense.com)

Bands Acquired	GSD	Capture Rate	Angle of view	Weight	Cost
[-]	[cm/pixel]	[-]	[deg]	[g]	[$]
BLUE, GREEN, RED, REDEDGE, NIR	8 cm/pixel (per band) @ 120 m AGL	1 capture per second (all bands) 12-bit RAW	47.2	200	5900

Table 3: GSD for the Micasense RedEdge at different flight altitude

H [m]	50	70	100	120	150
GSD [cm/pixel]	3.4	4.8	6.8	8.2	10.2

2.2 Unmanned Aerial Systems

The UAS designed by MAVTech s.r.l. (www.mavtech.eu) specifically for this application have been considered. Three different UAVs have been developed: a powered multirotor, the Q4P-Rotor, a lightweight multirotor, the Q4L-Rotor and a fixed-wing UAV.

The Q4P-Rotor (Figure 1) is a multicopter characterized by four booms and four rotors. The four booms are foldable to ease the transport. The diagonal wheelbase is 1.20 m and it has a take-off mass of about 7.5 kg, with 1.3 kg payload weight. Four high efficiency brushless DC motors, 74 cm (29 in) carbon propellers and a 6 cells LiPo battery with 16000 mAh capacity guarantee a flight endurance up to 38 min. The core of the Q4P-Rotor is the Pixhawk autopilot. Its firmware has been modified to achieve very precise terrain following in automatic flight, by using a laser range finder sensor. This feature is necessary due to the kind of sensor (Active sensor) used in this application.

The Q4L-Rotor (Figure 2) is the lighter version of the Q4P-Rotor. This multirotor has been designed to carry light payload and be very small in dimension to ease the transport. The MTOM is 1.8 kg and the diagonal wheelbase is 0.6 m. The Q4L-rotor is able to carry on board a payload of 300 g and in has a flight endurance of about 25 min. It is equipped with the Pixhawk autopilot and it is capable to follow a sequence of waypoint in automatic flight.

The fixed-wing UAS is the AGRI-2000 (**Errore. L'origine riferimento non è stata trovata.** 3). It has a tailless integrated wing-body configuration, two twin non-movable vertical fins, electric propulsion and pusher propeller. The wingspan is 2120 mm, the MTOM is 4.0 kg and it is able to fly for over 60 minutes at a cruise speed of 15 m/s. The on board autopilot, the Pixhawk autopilot from 3D Robotics (www.3dr.com), drives the AGRI-2000 through a sequence of waypoint in automatic flight. The flight plan is sent to the autopilot by the mission planner software (http://ardupilot.org/planner/index.html). A bidirectional telemetry reports the aircraft position and status on the monitor of the ground control station.

Figure 1: The Q4P-Rotor

Figure 2: The Q4L-Rotor

Figure 3 – The AGRI-2000

2.3 Mission planning

Flight path

The flight path is planned according to the sensor requirements. The active sensor needs a flight path with grid amplitude that can vary from 10 to 30 meters. A geo-statistic interpolation is performed to obtain the vigour map overall the field. The passive sensor needs an overlap of 75% between each image. The grid amplitude depends on the flight altitude of the survey as well as the time-lapse between two consecutive photos, which depends also on the UAV flight speed. Figure 4, 5 and 6 illustrates the flight plan for the three different platforms.

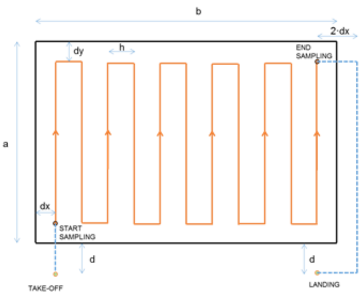

Figure 4: Q4P-Rotor flight path

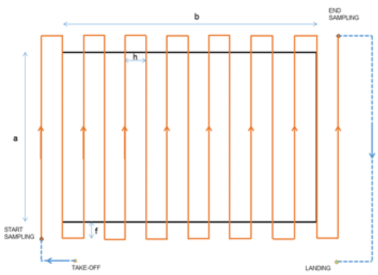

Figure 5: Q4L-Rotor flight path

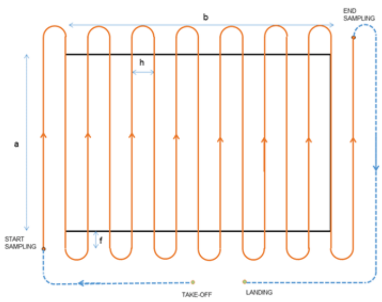

Figure 6: Agri-2000 flight path

In-field Procedures

The work rate of the system for a daily monitoring activity is computed considering UAVs similarly to any other farm machine. Figure 7 illustrates the sequence of the modules to perform the monitoring activities, starting from the access to the parcel to the exit from the same parcel. In particular, for the flight mission set-up procedures, an extra time of 5 min is included for the passive sensor to execute the sensor calibration.

2.4 Theoretical Field Capacity (TFC), Effective Field Capacity (EFC) and Field Efficiency (FE)

Theoretical Field Capacity (TFC), Effective Field Capacity (EFC) and Field Efficiency (FE) are computed similarly to any other farming machine. The equation proposed in (M. Hanna, 2016) have been reviewed as follow:

$$TFC = h \cdot V \cdot \frac{3.6}{10} \quad \left[\frac{ha}{h}\right] \qquad (1)$$

Where h is the grid amplitude ant V is the UAV flight speed.

$$EFC = \frac{A}{T_m + T_a} \cdot \frac{1}{60} \quad \left[\frac{ha}{h}\right] \qquad (2)$$

Where Tm is the time ([min]) necessary to complete the flight module previously described, while Tf ([min]) is the time necessary for the flight mission set-up.

$$FE = \frac{EFC}{TFC} \cdot 100 \quad [\%] \qquad (3)$$

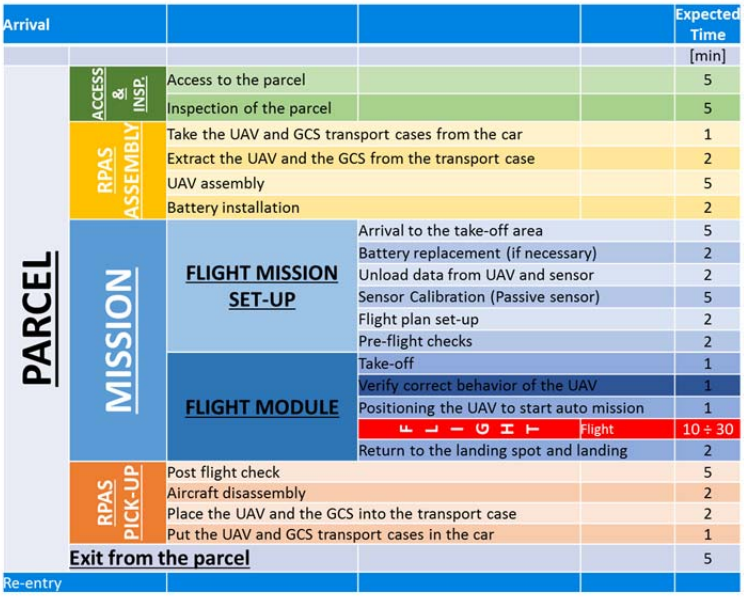

Figure 7: In-Field procedures.

2.5 Cost evaluation

A cost evaluation has been carried out for the three different platforms taking into account:

- maintenance of the system, which depends on the flight hours of the UAV
- an amortization schedule (just 2 years, due to both aeronautic requirements and a very short expected economic life)
- system management, which includes the cost of the pilot and the RPAS insurance
- data processing, which include the amortization plan of the sensor
- travel costs

Table 4 shows the cost evaluation for the three platforms. The cost evaluation does not include an economic margin for an operator that want to provide this service to a farmer or an agronomist.

Table 4: RPAS cost evaluation

		Q4P	Q4L	AGRI-2000
Maintenance	[€/flight hour]	35.58	8.10	7.24
Amortization plan	[€/h]	5.86	3.89	3.58
System management	[€/h]	32.50	32.50	32.50
Travel costs	[€/h]	14.06	14.06	14.06
Data processing	[€/h]	18.37	19.74	19.74
Total	**[€/h]**	**70.79 + 35.58 x flight hours**	**70.19 + 8.10 x flight hours**	**69.88 + 7.24 x flight hours**

3. Results and discussion

Table 5, 6 and 7 shows the platforms performances in terms of area monitored per day, TFC, EFC and FE, for the three different platform and for different values of area monitored (A), flight speed (V), grid amplitude (h) for the Q4P rotor carrying the active sensor and altitude (H) for the UAVs carrying the passive sensors. The flight time to perform the flying mission and to complete the flight module and the number of mission per day are also provided.

According to the tables, if the areas to be monitored have a relative low extension (i.e. 5 ha per field) the Q4P-Rotor monitors higher surface per day than the AGRI-2000 and the Q4L-Rotor (165 ha for the Q4P-Rotor, 150 ha for the AGRI-2000 and 76 ha for the Q4L-Rotor). The Q4P-Rotor has the highest value of EFC as well as FE. In contrast, if the areas to be monitored have higher extension (10-50 ha), the AGRI-2000 monitors higher surface per day than the other platform and it has the highest values of EFC, while the Q4P-Rotor is always the platform with the highest FE.

The row highlighted in red are not feasible. For the Q4P-Rotor and the Q4L-Rotor the flight time exceeds the endurance of the platforms. Whereas for the AGRI-2000 the time lapse requested between two successive photos is higher than the capture rate of the camera. It is very important to take into account of these implications when planning the monitoring mission.
Table 8, 9 and 10 illustrates the cost per hectares for the three different platform and for different values of area monitored, flight speed, grid amplitude for the Q4P rotor carrying the active sensor and altitude for the UAVs carrying the passive sensors.

Table 5: Q4P-Rotor flight time, module time, number of mission per day, hectares monitored per day, hectares monitored per hour, TFC, EFC, FE.

A	V	h	Flight Time	Module Time	N miss	Area/day	TFC	EFC	FE
[ha]	[m/s]	[m]	[min]	[min]	[-]	[ha/d]	[ha/h]	[ha/h]	%
5	3	10	31.3	36.3	12	60	10.8	8.3	77%
5	3	30	13.8	18.8	23	115	32.4	16.0	49%
5	5	10	18.8	23.8	18	90	18.0	12.6	70%
5	5	30	8.3	13.3	33	165	54.0	22.6	42%
10	3	10	60.5	65.5	6	60.0	10.8	9.2	85%
10	3	30	24.9	29.9	15	150.0	32.4	20.0	62%
10	5	10	36.3	41.3	10	100.0	18.0	14.5	81%
10	5	30	15.0	20.0	22	220.0	54.0	30.0	56%

Table 6: Q4L-Rotor flight time, module time, number of mission per day, hectares monitored per day, hectares monitored per hour, time-lapse between two consecutive photos, TFC, EFC, FE.

A	V	H	h	Flight Time	Module Time	N miss	Area/day	t photo	TFC	EFC	FE
[ha]	[m/s]	[m]	[m]	[min]	[min]	[-]	[ha/d]	[s]	[ha/h]	[ha/h]	%
2	4	50	10.9	13.5	23.5	19	38.0	2.05	15.7	5.1	32%
2	4	120	26.2	10.5	20.5	21	42.0	4.91	37.7	5.9	16%
2	5	50	10.9	10.8	20.8	21	42.0	1.64	19.6	5.8	29%
2	5	120	26.2	8.4	18.4	24	48.0	3.93	47.1	6.5	14%
4	4	50	10.9	23.2	33.2	13	52.0	2.05	15.7	7.2	46%
4	4	120	26.2	15.7	25.7	17	68.0	4.91	37.7	9.3	25%
4	5	50	10.9	18.5	28.5	15	60.0	1.64	19.6	8.4	43%
4	5	120	26.2	12.5	22.5	19	76.0	3.93	58.9	10.9	19%

Table 7: AGRI-2000 flight time, module time, number of mission per day, hectares monitored per day, hectares monitored per hour, time-lapse between two consecutive photos, TFC, EFC, FE.

A	V	H	h	Flight Time	Module Time	N miss	Area/day	t photo	TFC	EFC	FE
[ha]	[m/s]	[m]	[m]	[min]	[min]	[-]	[ha/d]	[s]	[ha/h]	[ha/h]	%
5	12.5	50	10.9	9.2	19.2	23	115.0	0.65	49.1	15.6	32%
5	12.5	150	32.7	5.9	15.9	28	140.0	1.96	147.3	18.9	13%
5	15.0	50	10.9	7.7	17.7	25	125.0	0.55	58.9	17.0	29%
5	15.0	150	32.7	4.9	14.9	30	150.0	1.64	176.7	20.1	11%
50	12.5	50	10.9	69.9	79.9	5	250.0	0.65	49.1	37.5	76%
50	12.5	150	32.7	29.9	39.9	11	550.0	1.96	147.3	75.2	51%
50	15.0	50	10.9	58.3	68.3	6	300.0	0.55	58.9	43.9	75%
50	15.0	150	32.7	24.9	34.9	12	600.0	1.64	176.7	85.9	49%

4. Conclusions

Platform performances and cost evaluation of monitoring mission with UAVs has been carried out. If the monitoring mission requires to survey crop fields with relative low extension, the Q4P Rotor is the best platform in term of hectares monitored per day. Instead, as the dimension of the single monitored area increases the AGRI-2000 becomes the platform with higher hectares monitored per day. The AGRI-2000 is overall the most economic platform. The Q4P-Rotor is 50-100% more expensive than the AGRI-2000, while the Q4P-Rotor is 10-75% less expensive than the Q4L-Rotor. The Q4P-Rotor gets close to the AGRI-2000 costs when the grid amplitude of its surveys is increased to 30 m (lower spatial resolution).

Low-level flight mission are not feasible for the fixed-wing UAV, due to the incompatibility with the time lapse of the sensor. If an application requires higher spatial resolution (low values of GSD), the fixed-wing platform cannot carry out the mission.

This analysis does not take into account the kind of scenario. The multirotor platform could be a successful solution against the fixed-wing platform because it can carefully land, even on irregular terrain and preserve the flying platform and the sensors carried on board from damage.

Table 8: Active Sensor and Q4P-Rotor net costs of the survey for different values of area monitored per mission, flight speed and grid width

A	V	h	Area/hour	Costs	A	V	h	Area/hour	Costs
[ha]	[m/s]	[m]	[ha/h]	[€/ha]	[ha]	[m/s]	[m]	[ha/h]	[€/ha]
5	3	10	7.5	13.15	10	3	10	7.5	13.03
5	3	30	14.5	6.56	10	3	30	18.8	4.60
5	5	10	11.3	8.52	10	5	10	12.5	7.82
5	5	30	20.6	4.41	10	5	30	27.5	3.46

Table 9: Passive Sensor and Q4L-Rotor net costs of the survey for different values of area monitored per mission, flight speed and grid width

A	V	H	Area/hour	Costs	A	V	H	Area/hour	Costs
[ha]	[m/s]	[m]	[ha/h]	[€/ha]	[ha]	[m/s]	[m]	[ha/h]	[€/ha]
2	4	50	4.8	15.69	4	4	50	6.5	11.58
2	4	100	5.3	14.09	4	4	100	8.0	9.33
2	4	120	5.3	14.08	4	4	120	8.5	8.79
2	5	50	5.3	14.10	4	5	50	7.5	9.98
2	5	100	6.0	12.28	4	5	100	9.5	7.84
2	5	120	6.0	12.27	4	5	120	9.5	7.81

Table 10: Passive Sensor and AGRI-2000 net costs of the survey for different values of area monitored per mission, flight speed and grid width

A	V	H	Area/hour	Costs	A	V	H	Area/hour	Costs
[ha]	[m/s]	[m]	[ha/h]	[€/ha]	[ha]	[m/s]	[m]	[ha/h]	[€/ha]
5	12.5	100	16.9	4.30	50	12.5	100	56.3	1.34
5	12.5	150	17.5	4.14	50	12.5	150	68.8	1.09
5	15	100	18.1	3.99	50	15	100	62.5	1.20
5	15	150	18.8	3.85	50	15	150	75.0	0.99

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