TECHNICAL ANALYSIS OF UNMANNED AERIAL VEHICLES (DRONES) FOR AGRICULTURAL APPLICATIONS

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Abstract. Constant technological developments of remote sensing techniques utilizing drones (specifically of Unmanned Aerial Vehicles, UAV) are increasing spatial and temporal resolution of data available for land and crop management. However, despite the promising potential, actual implementation of UAVs continues to be quite limited. Low costs and maintenance of the vehicles are advantageous in exploring agricultural applications, however, inadequate performances are still limiting their full capability. Three main categories of unmanned aerial vehicles are determined as: fixed wing, helicopters and multicopters. The performance and applicability of such systems depend on multiple factors such as the aircraft mass, payload capacity, average dimensions, flying range, average speed, expenses, etc. The present paper proposes a technical analysis on unmanned aerial vehicles' performances in order to understand their actual applicability to agricultural operations. In order to achieve this, the technical sheets of over 250 models available on the market have been analyzed and summarized. The aim of the paper is to synthesize specific information in order to acquire a better understanding of effective applicability to the agricultural field.

Keywords: Unmanned Aerial Vehicle, UAV, drone, agriculture, performance.

Introduction

In 2014, the Massachusetts Institute of Technology classified "agricultural drones" at the primary position among the ten breakthrough technologies [1]. Such primacy is a consequence of a general growing interest in Unmanned Aerial Vehicles (UAV) for environmental and agricultural applications. Indeed, many researchers and scientists agree on the substantial role agriculture can play as the largest user of such systems [2; 3]. The exponential growth in the field can be highlighted by the number of worldwide patents indexed in the European Patent Office search engine, reporting "unmanned aerial vehicle innovation" in the title. Similarly, scientific papers indexed by Scopus that discuss UAVs and agriculture are undergoing a constant growth (Fig. 1). On the other hand, mainly due to the recency of such growth, several lacks of knowledge can be recognized, mainly dealing with the cost effectiveness and performance analyses.

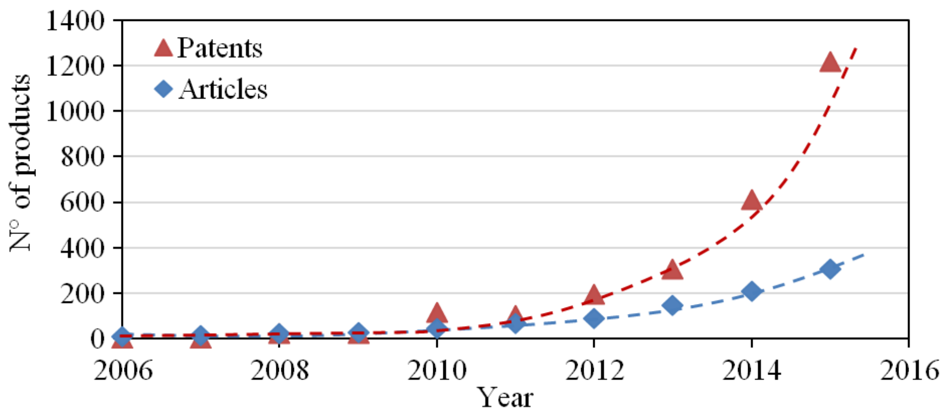

Fig. 1. **Number of patents (reporting unmanned&aerial&vehicle in the title) and scientific articles (reporting unmanned&aerial&vehicle&agriculture in the text) indexed respectively by EPO and Scopus search engines in the last ten years**

The main interest connected with the implementation of unmanned aerial vehicles in agriculture is related to the possibility of implementing autonomous systems for data collection. Certainly, autonomous systems allow execution of multiple operations in an expeditious and effective way, even when accessibility is not simple or possible [4; 5]. Furthermore, the increasing performance and miniaturization of sensors [6-8] has broadened the possibility of loading different instruments on board of UAVs [9] allowing precise monitoring of anthropized areas [10], plants and soils [11; 12]. In the USA, 595 out of 2 734 companies (21.8%) recorded by the Federal Aviation Administration declare drone operation in the agricultural field, and 18.8% of these declare a specific involvement in precision agriculture. Undoubtedly, precision practices also supported by UAVs, together with proper modeling software tools, can provide relevant benefits to agriculture [13; 14].

As depicted in Figure 2 and Figure 3, three main UAVs platform configurations are commonly recognized [15; 16].

- Fixed wing – Features stationary wings in the shape of an airfoil to create the lift needed when the vehicle reaches a certain speed.
- Helicopters – Rotorcrafts spinning a single set of rotor blades attached to the central mast to generate the lift in combination with or combined with a tail rotor (or counter central rotor) to control yaw.
- Multicopters – Rotorcrafts featuring a multiple set of rotor blades (typically 4 to 8) to obtain lift and control movements (yaw, roll, and pitch).

Such diverse configurations influence the overall UAV performance with important effects or drawbacks on their applicability for agricultural use. However, only few papers provide information on drone performances, and the available data are old dated or on a limited range of models [17; 18]. The scope of the present paper is to observe state-of-the-art influences on unmanned aerial vehicles available on the market, to gather the main technical parameters and performances, and to highlight how such characteristics can be applied to agricultural needs.

Fig. 2. **Three examples of UAVs:** a – fixed wing; b – helicopter; c – quadrotor

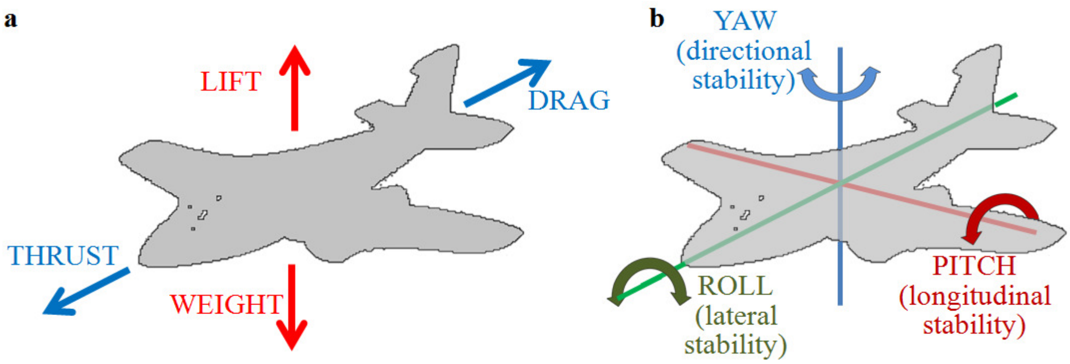

Fig. 3. **Aerodynamic forces (a) and 3 axis of movement of manned or unmanned aircrafts (b)**

Materials and methods

In the last few years, the unmanned aerial vehicle market has exploded. Presently, models are available from a few tens up to hundred thousands of Euros. However, agricultural interest can be limited to those vehicles where a minimum payload is guaranteed to allow implementation of specific sensors or devices for product delivery. Therefore, lower boundaries can be defined, primarily based on payload. In the present paper, the technical sheets of 269 different UAV models have been collected and analysed. Models have been identified considering different sources, principally ascribable to the U.S Federal Aviation Administration (FAA) and to the European Aviation Safety Agency (EASA). Drone databases, manufacturers' websites, and e-commerce marketplaces have eventually been explored to complete data collection for different models (see Table 1). For each model the following parameters have been collected: platform configurations and the number of wings/rotors; average and maximum speed; mass and dimensions; flying conditions; payload capacity and flight time.

The market is continuously evolving, and subsequently, the gathered figures can undoubtedly be affected by errors or deviations due to a limited accuracy of the data-sheets themselves; nevertheless, they constitute an interesting reference to understand effective applicability of UAVs.

Table 1

Sources used for data collection

Source	Description	Website
U.S. Federal Aviation Administration	Drone Exemptions Database	aes.faa.gov
European Aviation Safety Agency	Definition rules and links	easa.europa.eu
Graphiq inc.	Drones database	drones.specout.com
UAV Global	Drones database	www.uavglobal.com
Drone Flayers	Drones database	www.droneflyers.com
Drone & Copter Reviews	Drones database	www.dronecopterreviews.com
Drone Select	Drones database/marketplace	droneselect.com
RobotShop inc.	UAVs marketplace	www.robotshop.com
Phillips Drones	UAVs marketplace	dronelife.com
Tumblr, Inc	UAVs marketplace	dronetradr.tumblr.com
B&H Foto & Electronics Corp.	Electronics marketplace	www.bhphotovideo.com
Amazon Inc.	Electronics marketplace	www.amazon.com
Manufacturers	Manufacturers websites	--

Results and discussion

In recent past, the UAVs market was dominated by helicopters and fixed wing systems. In the last decade, however, attention has been shifting to multicopters, which cover more than 50% of the available models. Helicopters and multicopters have the advantage of allowing stable flying conditions, including low speed and stationary flight if needed, which appear to be recommendable when precision data sensing or precision product delivery is expected by the flying systems. On the contrary, fixed wing systems still cover 40% of the available models, mainly as a result of their relatively large aerial coverage. At present, most of UAVs are battery powered, whereas only 11% of the models implement contrasting propulsion systems (internal combustion engines or alternative thermal systems).

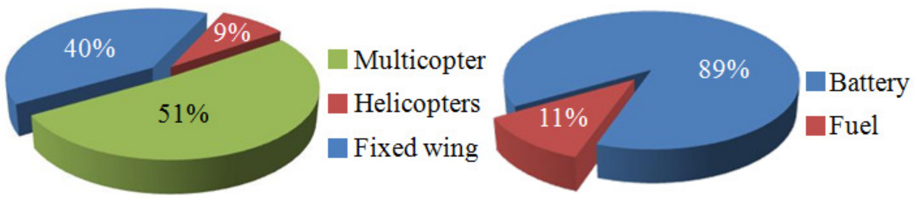

Fig. 4. **Main UAVs platform configurations (left) and propulsion systems (right)**

Due to specific aerodynamic configuration, lift technology, and propulsion systems, various UAVs exhibit different cruise speeds, generally higher in the case of fixed wing systems (ranging between 15 and 50 $m \cdot s^{-1}$), that typically present limited drag, and lower as in the case of multicopters (ranging between 3 and 20 $m \cdot s^{-1}$). Helicopters are positioned intermediately, with speeds ranging between 10 and 30 $m \cdot s^{-1}$ (Table 2).

Table 2

Typical cruise speeds for different unmanned aerial vehicles

Speed	Multicopters	Helicopters	Fixed wing
Maximum speed, $m \cdot s^{-1}$	3-20	10-30	15-50
Average speed, $m \cdot s^{-1}$	4	7	13

With regard to the range, rotary wing systems customarily exhibit shorter flight time, mainly due to relatively high mass, while large airfoil guarantees greater aerodynamic efficiency; hence, higher autonomy to fixed wing systems. As reported in Figure 5, most multicopters can fly up to 30 minutes, helicopters between 15 and 45 minutes, while fixed wings provide an autonomy typically comprised between 30 and 60 minutes. Such values are similar or slightly higher than the values reported in bibliography, mainly due to recent advances in rechargeable battery materials [17].

Combining average speeds and average range values, it can be noted that different distances can be covered by the three kinds of platforms within a single flight: 3-4 km in the case of multicopters, 10-15 km in the case of helicopters, 25-35 km for the fixed wings. Depending on the UAV fliying altitude and sunsequently on the considered surface coverage (i.e. the width *L* dominated by on-board sensor or delivery apparatus, as depicted in Figure 6a), this corrpesonds to a maximum range of 1-8 ha, 4-12 ha or 10-40 ha per flight, respectively in the case of multicopters, helicopters and fixed wings.

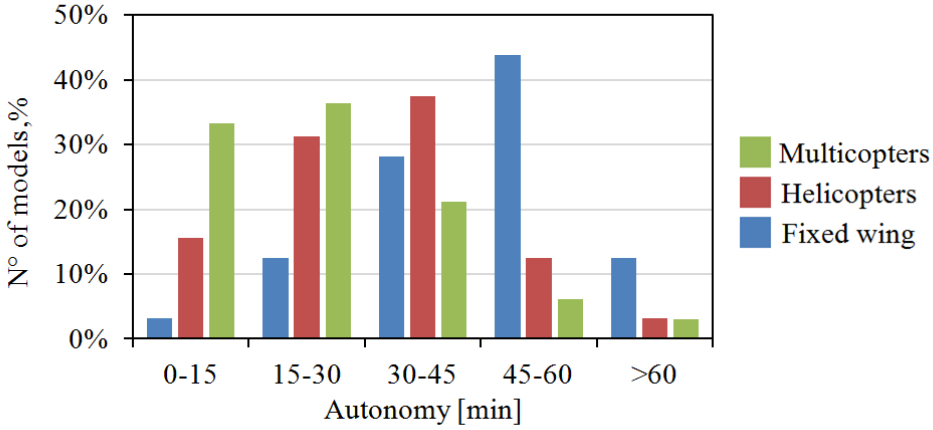

Fig. 5. **Flight time for different UAVs**

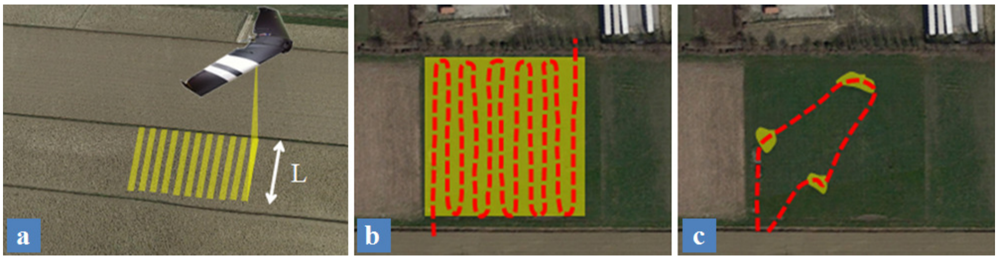

Fig. 6. **(a) Dominated width *L* by UAV on-board sensor or delivery apparatus; (b) raster and (c) point to point strategies in UAVs missions**

As expected, the performance is very much influenced by the flight strategy and can vary in the case raster (Fig. 6, b) or in the case which point to point approaches (Fig. 6, c) are adopted. Specifically, when raster approaches are considered, a large amount of time can elapse due to overlapping needs in neighbour passes; conversely, in point to point approaches, time can be spent due to transfer between different areas of interest. Flight range is dependant not only on specific UAVs configuration, but also an important role is played by the total load and by the battery pack, which are highly correlated to the total mass of the UAV (Figure 7). For instance, the battery equipment provides constant power for long field use, yet its mass negatively influences the UAV flight time. Typically, a percentage ranging between 20 and 25% of the total mass is represented by the battery pack (Figure 7a), while only the residual 25-35% mass capacity can be devoted to the payload, sensors, or other devices useful for different flight scopes (Figure 7b). To the authors' knowledge, such values are not available in bibliography and constitute a relevant reference to support feasibility analysis of flying operations. Also, the financial value exhibits a significant linear correlation with the UAV mass ($R^2 = 0.718$). Such costs are very much influenced by the material and component quality, production volumes, and by other market variables; however, as a general statement, it can be noted that "ready to fly" systems have an average cost of about 2160 EUR per kilogram of flying unit (Figure 8). Compared to the reference costs available in bibliography (2900 EUR·kg^{-1} [18]), such value is slightly lower: this is due to progressive technological advance and scale economies in the UAVs market.

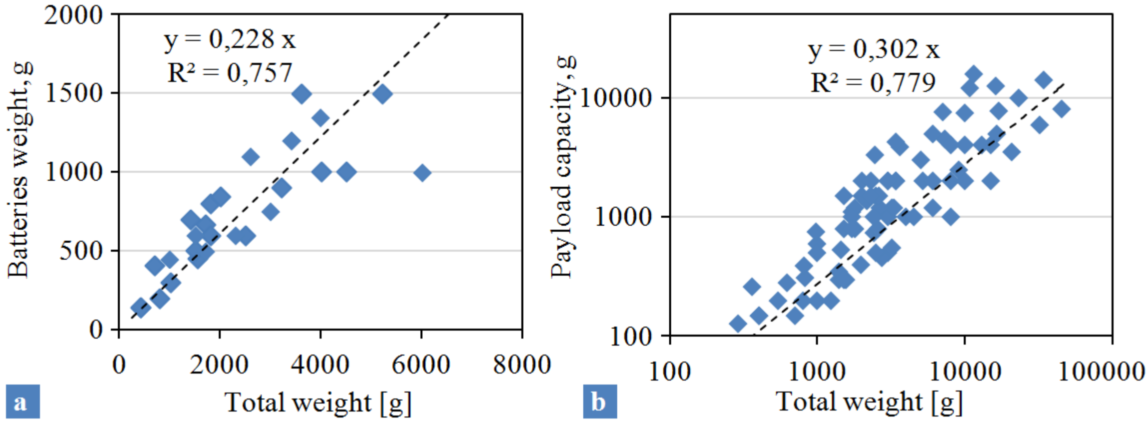

Fig. 7. **Battery pack mass (a) and payload capacity (b) as function of total mass. Data for payload capacity graph are in logarithmic scale, in order to ease interpretation of growth**

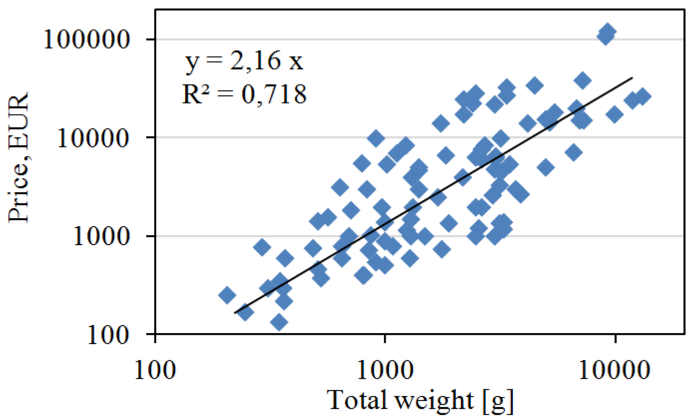

Fig. 8. **Average costs for commercial flying drones. Logarithmic scale representation is proposed in order to ease interpretation of growth**

The payload capacity, flight range, and financial factors are the three essential parameters that influence the choice and implementation of unmanned aerial vehicles in agriculture. The payload capacity has to compensate for loading on board of different components. Even though miniaturization has allowed reduction of mass, in most of cases, the payload capacity ranges at least between 300 and 1000 g, due to:

- RGB camera (100-400 g)
- other sensors (thermal, multispectral,...) for data collection (300-600 g)
- actuators and control electronics (50-200 g)
- pivoted support (gimbal) allowing orientation of the installed devices (100-250 g)
- other materials or devices (variable mass).

With regard to the last point, it should be noted that whenever UAVs are implemented not only for data collection, but also for plant protection or pest treatment, loaded products (pesticides or agrochemicals) can exponentialy increase the total mass. Sensors or devices essential to accomplish data collection or the required tasks should prefearably be much lighter than the payload capacity in order not to excessively affect the flying time. As a consequence, UAVs with mass ranging between 2 and 5 kg are desired, with costs ranging between 5 and 10 thousand EUR, including the sensor costs. In case agrochemicals have to be loaded, such costs can easily accumulate..

Considering a reasonable working life for a UAV of about 400 flying hours, an average of 6000 ha, 8000 ha, and 12000 ha can be maneuvered by multicopters, helicopters and fixed wing systems, respectively. This signifies that 0.8-2 EUR·ha^{-1} can be spent for data collection due to UAV depreciation. Such cost is relatively low, or at least comparable with other means for data collection such as satellite or airborn systems, but with the advantage of a higher tempestivity and higher resolution in data mining.

Conclusions

The agricultural sector can benefit significantly from implementation of unmanned aerial vehicles with the potential to improve the soil and plant knowledge, efficiency of input, and economical and environmental sustainability. However, their effective implementation depends upon some mandatory critical aspects that must be considered, including the configuration, mass, payload, flight range and costs. Cost effectiveness can be proven in cases where UAV can be applied to cover large land areas; nevertheless, improvements remain crucial with regard to battery duration, and consequently, payload and flight autonomy.

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