Challenges of Integrating Unmanned Aerial Vehicles In Civil Application

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Abstract. Unmanned Aerial Vehicle (UAV) has evolved rapidly over the past decade. There have been an increased number of studies aiming at improving UAV and in its use for different civil applications. This paper highlights the fundamentals of UAV system and examines the challenges related with the major components such as motors, drives, power systems, communication systems and image processing tools and equipment.

1. Introduction
An Unmanned Aerial Vehicle (UAV) is normally an aircraft that launches and flies without a human onboard. The crew is totally replaced by computer system that is pre-programmed before the mission starts or distantly controlled by human. Conventionally, UAVs were firstly designed for military applications, but in recent times, there is large potential for civil purposes such as forest fire fighting, environmental monitoring, communication industry, agricultural monitoring, natural vegetation classification, erosion monitoring, topographic modelling, feature identification, temporal mapping of landscape dynamics, bushfires detection, search and rescue missions. UAVs have many characteristics that are different from conventional aircraft. UAVs system includes many subsystems that are important to achieve their missions. The system consists of the aircraft pay load, ground control station, communication equipments, power subsystem, launch and recovery subsystems. The payload is based on the mission of the UAV. It could be but not limited to cameras, motors, drives, batteries, water, monitoring system and communication relays. This paper is addressing the challenges that facing UAV implementation from different perspectives. Next section presents the two types of motors used in launching and controlling UAV missions. Section 3 discusses the power system of UAVs. The communication system and its challenges are highlighted in Section 4. Section 5 investigates the image processing techniques. Finally, the paper is concluded in Section 6.

2. Motors and drives
The UAV propulsion system comprises of an electric motor, a speed controller, and a propeller [1]. Electric Motor Brushless DC (BLDC) motor has been chosen as the electric propulsion motors for the UAV due to many reasons. It has better performance than conventional permanent magnet dc motor in terms of power capacity, speed, torque, efficiency, and long operating lives [2]. The modelling of BLDC motor is similar to conventional permanent magnet dc motors. The main difference is that the

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BLDC motor is commutated externally by power electronic switches rather than by the brushes and commutator which are built into a standard dc motor. This produces some electronic complexity, as an external controller is required to control the rotor position in real time implementation. In general, modelling the performance of BLDC motors involves current-voltage state-space equations for each motor winding combined with system as an ideal dc machine. In steady state response, the modelling of the BLDC motor considers as one of the challenge to control the BLDC due to the complexity of a steady state modelling [2].

Speed control of BLDC motor is achieved by standard radio control by receiving control inputs from the on-board radio control receiver [3]. The motor speed can be measured by using an optical sensor [1]. Achieving a required velocity in different climate conditions is considered one of the real challenges in practical application [2].

A servo motor is an electric motor coupled with a sensor to get a position feedback. In the case of the UAV, the main function of a servo motor is to control the ailerons and rudder on the plane. The principle work of the servo motor in UAV is based on a comparison between a measured attitude position and a reference attitude. The controller will ensure the error signal to be zero by sending the required commands to the motor to adjust accordingly.

The right aileron motor controls the position of the right wing aileron, and the left aileron motor controls the position of the left wing aileron. The elevator motor controls the altitude of the UAV. The rudder motor controls the position of the rudder. The motor controller or electric speed control (ESC) is used for the throttle [4].

To run UAV motors properly, a stable power source should be provided in order to supply all UAV motors with required power along with less interruption and high stability. In the following section, the challenges arise in power system will be investigated in order to achieve the optimal power system for UAV operation.

3. Challenges of power system
Most UAV’s use batteries as the only source for power supply, because the efficiency of internal combustion engine and gas turbine are low for small scale UAV’s [1]. However, some new researches used additional power supplies such as; photovoltaic and fuel cell as ancillary power supply. Challenges face electrical power systems in UAVs are much more critical than in other applications [5, 6]. Topics below studied challenges faces UAV power system.

3.1. Batteries types and capacities
Batteries are energy storage devices which convert chemical energy to electrical energy and vice versa [7, 8]. There are several rechargeable batteries available on the market right now such as; lithium ion (Li-ion), lithium polymer (Li-Poly), lead-acid, nickel-cadmium (NiCd) and nickel-metal hydride (NiMH), each one of them has different characteristics[8]. However, Li-ion batteries commonly used in many applications like; consumer electronics, power tools, electric vehicles and even in space applications [9]. The reason behind this spread is because Li-ion can overcome many of battery operation challenges, such as:

- Energy density, as it has a very high energy density (see Table 1), that because its electrode made of lightweight lithium and carbon.
- Self-discharge, as it has low self-discharge rate.
- Life cycle, as it has long cycle life and it can achieve hundreds of charge and discharge cycles without significant capacity decrease.

With these important advantages Li-ion batteries were chosen as the power source in many papers [1, 8, 10, 11]. However, Li- Poly battery packs have the same chemical processes as Li- ion battery, except that the electrolyte is in gel form.
Table 1. Energy density of common batteries type.

| Storage material               | Kw.h / Kg |
|--------------------------------|-----------|
| Lithium-ion battery            | 0.875     |
| Alkaline battery               | 0.67      |
| Nickel-metal hydride battery   | 0.288     |
| Lead-acid battery              | 0.17      |

3.2. Ancillary power system

3.2.1. Fuel cells

Fuel cells (FC) proposed in many papers [1, 2, 12-14] as ancillary or alternative power supply for the existing battery, because of the numerous advantages that FC have. Ancillary power system has to have many features to operate UAV efficiently, which is available in FC such as; good energy density, high thermal efficiency, silent, reliable, safe, and eco-friendly. Energy density defined as the energy capacity per unit weight or volume [1], so FCs energy density is better than Lithium-ion battery and Gasoline which shown in Table 2. The FC has a high thermal efficiency due to its electrochemical reaction rather than a combustion reaction, in the conversion path from chemical energy to electric energy.

Current fuel cell aircrafts can be classified by fuel cell types and hydrogen storage methods. The world’s first FC aircraft used liquefied hydrogen to operate the system [1]. Polymer electrolyte membrane fuel cells (PEMFC) used gaseous hydrogen as fuel. Although, it has low operating temperature and relatively high power density, this method consider bulky and heavy since gaseous hydrogen has a large volume. Solid oxide fuel cells (SOFC) were also applied in UAV which uses hydrocarbon fuel at high temperatures, producing a higher power density comparing with PEMFC [15, 16]. Compressed hydrogen gas is commonly used in spite of few drawbacks it has in safety (as it store the gas at high pressure), storage density (which it is low) and in recharging. Sodium borohydride (NaBH₄) or sodium tetrahydridoborate was used as chemical hydrogen storage [17] as an aqueous (watery) solution.

Table 2. Energy density of common storage forms

| Storage material               | Energy type   | Kw.h / Kg |
|--------------------------------|---------------|-----------|
| Lithium-ion battery            | Electrochemical| 0.875     |
| Hydrogen (compressed at 70 MPa)| Chemical      | 34.44     |
| Gasoline (petrol) / Diesel     | Chemical      | 12.88     |

3.2.2. Photovoltaic (PV)

Many researchers used PV cells as UAV power source [11, 18, 19]. However there are many important parameters that can influence the output power and the efficiency of PV Cells. First, the designing of maximum power point tracker (MPPT) have to be efficient and lightweight to maintain voltage and current at maximum power which achieve high endurance flight for UAV. Second, the wind direction plays key role in reducing power required to flying when wind blows from the opposite side of the flight. Wind also can reduce the temperature of the PV cells which increase the efficiency.
Third, during the flight the temperature of the PV cells reduces and causes efficiency improvement. Geographical location and flight orientation are the other discussed factors which influence received radiation and power generation during the flight.

In [11] mono-crystalline solar cells are use as the power source. The PC panels divided into three panels which is right wing, left wing and fuselage (plane body) panel. Under a standard test condition, maximum power of 57.2 W can be generated. The maximum current and voltage point are 1.91 A and 30 V respectively. The electrical characteristics of the panels are listed Table 3. The right wing is almost same as left wing.

| Panel             | Typical peak power | Voltage at peak power | Current at peak power | Short circuit current | Open circuit voltage |
|-------------------|--------------------|-----------------------|-----------------------|-----------------------|---------------------|
| Left wing panel   | 23.23 W            | 30.08 V               | 0.772 A               | 0.839 A               | 37.66 V             |
| Fuselage panel    | 9.6 W              | 29.9 V                | 0.323 A               | 0.341 A               | 37.84 V             |

3.3. Electrical faults
As illustrated in [5, 6] the electrical faults in UAV electrical power system is much more critical than in other application. The electrical fault can damage for filter capacitors, switched and any sensitive components in the network [6, 20, 21]. So a good circuit breaker is necessary to maintain power system safe [6].

3.4. Weight
Light weight has to be one of the designer objectives when designing UAVs [6, 22]. So the total electrical power system weight must be minimized in order to capitalize the efficiency of the power system.

In next section, a comprehensive study on challenges of communication system in UAV will be investigated in order to achieve the safe and efficient control with UAV.

4. Challenges of communication system
Communication system play an important role in UAV since it is required to operate with less human efforts. The communication system of UAV could be divided to three different parts: the ground control station (GCS), the transceiver on the aircraft and finally the radio communication link between the control station and the aircraft [23]. This section addresses some challenges that are facing UAV communication system.

4.1. Ground control station (GCS)
The control station is normally the centre where the operation and mission of the UAV are managed and monitored. Moreover, it considers as the interface between the human and aircraft. The operator sends commands to the UAV via the GCS during the uplink operation to control and guide the UAV in its mission. Meanwhile, the GCS receives data from the UAV during the downlink and forwards it to the operator. The data may include position information, mission status and other important information [23]. Three types of ground control station were proposed. The tradition control station where many devices are used to monitor and control UAV mission. More advanced station called mini or portable station is proposed in [24]. The third type is what is called unmanned ground vehicle (UGV) [25]. The key element in GCS is the computer and the monitor software. Many researches were conducted to develop the different types of GCS. Kang and Yuan [24] proposed a software of
multi layer flight model used in GCS to monitor the UAV path. The problem with the UAV software is the compatibility since one type of GCS software is only suitable for a specific UAV system unless interface standard is used. Challenges of minimizing the human efforts in the ground station such as mission planning instead of path planning and oral command control were discussed in [26]. UAVs should have the ability to process the commands and convert them to a useful mission. More research is required on multi platform mission and changing the mission profile during the flight. Unmanned ground platform that launch, monitor and refuel the UAV was presented in [25]. The main challenges in this type of GCS are how to manage the landing process accuracy of the UAV and the self refuel of UAV in addition to support more than one type of UAV. In summary, a low cost and autonomy platform is still a challenging issue [27].

4.2. The communication link

The need to establish high performance link requires the characterization of the radio communication channel between the UAV and the ground station. In addition, Small grazing angle between the transmitter and the receiver cause strong fading and multipath interference. Deep signal losses may also occur when the UAV is maneuvering the antenna orientation changes [28, 29]. Statistical prediction models for multipath, attenuation and scintillation is required and it is an interesting research area. Lemorton et al [30] shows that the available models for terrestrial links and earth to satellite links is not suitable enough to be used for UAV, they added that some modification is required specially for low elevation angle. The communication links discussed in the literature could be divided to three types of technology: radio communication [29, 31], low earth-satellite [31] and free space optics (FSO) [32-37]. The first two links have long range communication (up to 30km). However, the bandwidth is limited to hundreds of kbps. Using Orthogonal Frequency Division Multiplex (OFDM) in radio communication based transceiver increases the data rate up to some Mbps. But at the same time, the appearance of Inter-Carrier Interference (ICI) due to high speed of the UAV reduces the performance of the communication system [29]. The third technique which is FSO has a short communication link (Line of site and up to 8km) and it is highly affected by atmosphere [33]. On the other hand, it has high bandwidth with 2.5 Gbps [34] and up to 10 Gbps experimentally [35]. In brief, FOS technique could be for air to air communication between UAV networks. Meanwhile the radio communication is still required for long range communication between the UAV and the GCS with many considerations. In addition to the long range and the UAV speed, statistical prediction models for radio channel are open research trends to reduce the effects and overcome the path losses.

4.3. Aircraft system

The communication system located at UAV consists of an antennas and air data terminal (ADT) which includes transceiver, modems and processors. This system is important to communicate with the GCS or even with other UAVs [23]. UAV antenna requires special consideration such as smaller size, lighter weight and larger gain. Another restriction is the impossibility of mounting turntable or scanning antenna array. These facts bring the necessity to develop special antennas and select the optimum location of the antennas on the UAV. In [28] A MIMO wireless channels between UAV and ground station has been assessed experimentally. They found that the effect of multipath interference can be alleviated by the use of directive antennas on the ground, and that multiple antennas on the UAV provide a more robust radio channel in front of the antenna changes of orientation when the UAV is maneuvering. Boev designed and fabricated a flat toroidal antenna with two resonant frequencies [38]. Adaptive vertical array antenna technique was proposed by Park et al [39] to overcome altitude limitation of the UAV caused by restricted antenna coverage of the ground station.

5. Challenges of image processing

UAVs are traditionally used for military purposes. However, its civil applications are gaining momentum since progress within the fields of digital sensors, navigational equipment, and small-scale aircraft have all reduced the cost of the fundamental components of UAVs [40]. These applications
can include: agricultural monitoring, natural vegetation classification, erosion monitoring, topographic modeling, feature identification, temporal mapping of landscape dynamics, bushfires detection, search and rescue mission. Compared with more traditional aircraft or satellite based platforms, the UAV is distinguished by its unique characteristics of the captured data. Its low operating altitude allows for the generation of ultra-high spatial resolution data over relatively small spatial extents [41].

There have been many UAV studies related to remote sensing. Berni et al. [42], Dunford et al. [41], Hunt et al. [43], Laliberte et al. [44], Lelong [45], and Xiang and Tian [46] looked at multispectral UAV imagery for both agricultural monitoring and natural vegetation classification. These studies highlighted some of the benefits and challenges associated with the use of UAV. For example, Berni et al. [42] have demonstrated that results obtained with a low-cost UAV system for agricultural applications yielded comparable estimations, if not better, than those obtained by traditional manned airborne sensors. The main limitations encountered by their UAV system were the endurance (20 min) and the low flight speed (30 km/h), limiting the productivity to 70 hectares per flight.

Lelong et al. [45] designed a cost-effective multispectral sensor based on commercially available digital cameras, adapted with relevant filters to perform six aerial acquisitions of wheat crop micro plots during the growing season, at very low altitude. Several vegetation indexes relevant for vegetation analyses were derived. The authors sought relationships between these indexes and field-measured biophysical parameters, both generic and date-specific. Due to a high amount of noise in the data, it was not possible to obtain a more accurate model for each date independently. A validation protocol showed that it is expected to have a precision level of 15% in the biophysical parameters estimation while using these relationships. More studies are needed to improve the precision. The error can be reduced if both vibration control and new image algorithms are developed.

Xiang and Tian [46] have developed an improved remote sensing system based on an autonomous UAV. An experiment using the developed UAV system to monitor turf grass glyphosate application demonstrated the system. The results proved that the UAV system provides a flexible and reliable method of sensing agricultural field with high spatial and temporal resolution of image data.

Zhao et al. [47] and Lin et al. [48] used UAV-based LiDAR for topographic modelling and feature identification. UAVs were used for stereo-image 3D landscape modelling by Stefanik et al. [49]. Thermal UAV applications for emergency services including bushfires and search and rescue were presented by Rudol and Doherty [50], Hinkley and Zajkowski [51] and Pastor et al. [52]. Sung [53] suggests an image processing algorithm that allows for UAVs to detect and track approaching aircraft in real time using a vision sensor mounted on a UAV. This algorithm computes image homography from an image sequence to detect any moving objects in the view. Then a Probabilistic Multi-Hypothesis Tracking (PMHT) method is applied to track and manage the detected objects. Finally it is again used to determine whether an aerial vehicle is in a potential collision course or not.

6. Conclusion
Some of the challenges of integrating UAVs in civil applications have been discussed in this paper. The factors that curb the performance of UAV includes but not limited to: UAV mission, weather, weight, availability of ancillary power system, distance between UAV and GCS, task duration, mission path and UAV speed. Nowadays, research works are focusing on: In BLDC motor as rotor position is needed to be probably located we have to improve the feedback control during real time operation Weather can cause a big disturbance for UAV velocity so future works have to insure a stable fly with a constant velocity regardless the weather. The development of the ancillary renewable power system which can operate the UAV for longer period is one of the most important challenges for UAV power systems. Low cost and autonomy platform are still challenging issues. Moreover, statistical prediction models for radio channel are open research trends to reduce the effects and overcome the path losses.
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