THE USE OF UNMANNED AERIAL VEHICLES (UAVS) FOR REMOTE SENSING AND MAPPING

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ABSTRACT:

The ISPRS congress in Istanbul has adopted a resolution that called for the study of the use of Eaves in remote sensing and mapping. In the past four years, a wide range of these platforms has been used in the civil and scientific world, equipped with a multitude of instruments, to deliver data in w variety of applications. It is an area of remote sensing that is very active, but not yet near to consolidation. This paper does not attempt to make comprehensive lists of platforms, instruments or applications. Rather, it tries to give the reader a sample of what is possible today and in the future.

UAVs as remote sensing platforms have given many research groups the opportunity to acquire data at sufficiently low cost to justify the use of remote sensing in the first place. These platforms may therefore become the catalyst for many new users and uses of remote sensing, and will become so even more when airspace regulations have been adapted to accept them as regular aircraft.

1. INTRODUCTION

At the past ISPRS congress in Istanbul, Resolution I.1 was passed, saying:

"The Congress:

Noting

- that unpiloted aerial vehicles (UAVs) provide a new, controllable platform for remote data acquisition;
- that manoeuvrability of UAVs permits remote data acquisition in environments dangerous to human life
- and/or inaccessible to direct examination (e.g. forest fires, volcanoes, toxic spills, transportation disasters,
- etc.);
- that UAVs provide potential for acquiring remote data more rapidly and at lower cost than from piloted aerial vehicles.

Recognizing

- the range of potential applications not readily possible using piloted vehicles over small geographic or site specific
- areas on a real-time basis at affordable costs (e.g., incident analysis);
- that new technologies will be required to design and develop miniature platforms and sensors.

Recommends that

- an inventory of current and technologically feasible miniature sensors be undertaken;
- an inventory of current and possible future civil applications be catalogued and documented as to
- appropriateness, levels of readiness, and comparative cost;
- the performance of the various UAVs and their onboard sensors for various applications be investigated;
- a report of the above findings be produced by ISPRS for the global community."

In what follows, an overview is provided of projects undertaken in the past 4 years using UAV platforms. It does not address the inventories mentioned in the recommendations, however. The Inter-Commission Working Group I/V "Autonomous Navigation" has monitored the progress in this area of research, and has concluded that it is not yet consolidated to a sufficient extent to make inventories useful. As a consequence, most of the issues raised will be addressed by citing examples, rather than lists.

For remote sensing or mapping, military systems cannot be used, in general. Therefore, these systems are not considered in any further.

2. UNMANNED AERIAL VEHICLE SYSTEMS

2.1 Layout of a UAV system

A UAV is the prominent part of a whole system that is necessary to fly the aircraft. Even though there is no pilot physically present in the aircraft, this doesn't mean that the it flies by itself autonomously. In many cases, the crew responsible for a UAV is larger than that of a conventional aircraft.

The aircraft is controlled from the ground (the Ground Control Station or GCS), so it needs reliable communication links to and from the aircraft, but also to the local Air Traffic Control (ATC) authorities if required (usually when flying higher than 150-200 m above the ground). The GCS provides a working space for a pilot, navigator, instrument operator and usually a mission commander.

The data received by the GCS from the instruments is either processed on-site or forwarded to a processing centre. This can be done using standard telecommunication means.

Of course, when operating low-cost systems, most of the GCS functions can be combined in the handheld remote controls that are typical for these systems. In that case, there is no data transmission for the instrument; all data are stored on-board.

2.2 UAV programs

	2004	2005	2006	2007
Civil/Commercial	33	55	47	61
Military	362	397	413	491
Dual purpose	39	44	77	117
Research	43	35	31	46
Developmental		219	217	269

Table 1. Numbers of UAV systems over the past years. (Van Blyenburgh, 2007)

UAVs have been in use by the military for a long time, mainly as shooting targets, and for surveillance. In the past years, there has been considerable activity in the development of UAVs of all possible kinds, and this is well documented on the UVS-International website (UVS-International, 2008). Table 1 shows that there are growing numbers of UAV systems, and that most of them are for military use or part of a development project. This is a truly international activity in which 49 countries around the world are involved (Europe: 23; Asia: 14; South-America: 4; North-America: 3; Australia: 2; Africa: 2).

2.3 UAV related regulations

Manned aircraft and their pilots are subjected to many regulations, imposed by local aviation authorities (e.g. FAA in the USA) or supranational entities (e.g. Eurocontrol, or ICAO). Most of these regulations have safety as a driver, and therefore air transport is one of the safest ways of travelling
So, it is quite normal that these authorities are concerned when aircraft are proposed without a pilot in the craft. UAV systems are not yet accepted in the normal air traffic, mainly because they do not have ‘sense-and-avoid’ ability.
Driven by military users of UAVs, many initiatives have been taken to integrate UAVs within the civil air traffic. Others are still running, but it is expected that the legal framework around UAVs will not be ready before 2012. Until that time, all flights will have to take place in segregated airspace, in air test ranges, or above the sea (outside of air traffic corridors).
The most accessible air space is at low altitude. In most countries, one can execute flights without working with air traffic control if one stays below 150-200 m. It is at this low altitude that many experimental UAVs are being deployed, many of them of interest to the remote sensing community.
Another part of the air space that is almost empty is situated at very high altitude (above 15 km). However, to get there, an aircraft needs to travel through the air layers occupied by air traffic, so this will probably need a segregated part of the air to be created during ascent and descent.
Communication between aircraft and GCS requires radio frequencies with sufficient band width to be allocated. As yet, there is no such frequency band allocated to UAVs by the International Telecommunication Union (ITU). This means that a UAV system may have to use different radio frequencies in every country it is operated in.

2.4 UAV classification

Low altitude systems (up to 150-200 m) fly underneath the air traffic. They can be operated with ease, but usually only within sight of the pilot. This limits the area that can be covered in a single mission (minutes to about one hour). On the other hand, they can be brought to the survey area by car or truck, and operated by many. These systems are very attractive for research groups involved in instrument design and thematic research, because they offer a low cost, flexible way to acquire data.
A tethered balloon (Çabuk, 2007; Vierling, 2006) or blimp (Martinez Rubioa, 2005) is probably the simplest UAV conceivable. It is easily controlled (especially its altitude), but of course quite unstable if the wind speeds grow. The balloon can be adapted to the size and mass of the instruments that need to be carried.

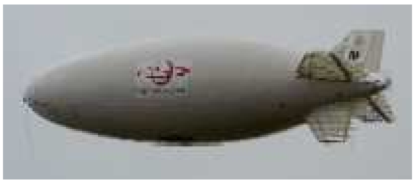

Fig. 1 Free-flying low altitude blimp (© Sanswire, 2007)

Free-flying blimps are offered to the users as platform for monitoring and survey
Small micro-UAV airplanes have been designed and built by many aircraft design schools. Some are as small as a few centimetres, and all are able to carry only modest payloads (about 100-200 gram). To generate enough lift, they have to fly at considerable speed, which may be a concern if they fail at low altitude. Fig 1 shows a typical micro UAV with a wingspan smaller than 30 cm. This one is developed by the University of Ghent, Belgium.

Fig. 2 A micro UAV designed to carry video and still imagery systems.

Larger fixed wing low-altitude aircraft are being used in agriculture (Cropcam, 2008) and multipurpose monitoring (Aerosonde, 2008). These systems are able to fly autonomously (Aerosonde, for instance, was the first UAV to fly across the Atlantic Ocean, in 1998). This is however not currently allowed in most countries.

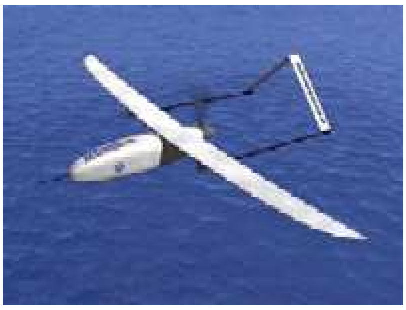

Fig. 3. Aerosonde (© Jon Becker, Aerosonde Pty Ltd)

Unmanned helicopters come in many types and sizes. In Japan, for instance, hundreds are used in agriculture, used as platforms to plough, sow, spray, etc. This business is worth 100 million USD every year (Newcombe, 2007).

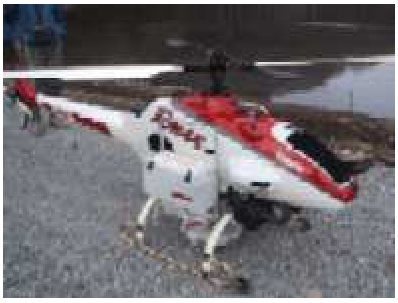

Fig. 4 Yamaha R-MAX

These helicopters have also been equipped with imaging instruments to monitor crop growth, detect diseases and vegetation stress due to water shortage. Fig 4. shows the Yamaha R-MAX.

Powered paragliders are interesting because they need very little ground support, use proven technology, carry substantial loads and are low-cost compared to other low-altitude systems. They have been flown successfully in remote areas that cannot be addressed economically with conventional survey equipment (Thamm, 2006).

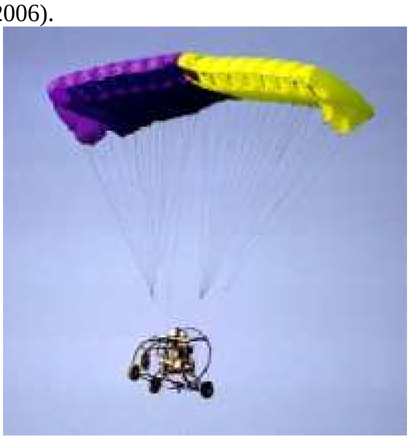

Fig. 5 Powered paraglider (Thamm, 2006)

Medium altitude systems have little use for the civil or scientific community in general: they are designed to operate in the same airspace as air traffic. Some military systems designed for these altitudes boast exceptional endurance, which would be interesting for large scale survey. In Belgium, there are plans however, to use military UAV systems (B-Hunters) to improve the persistent monitoring of the (relatively small) territorial waters.

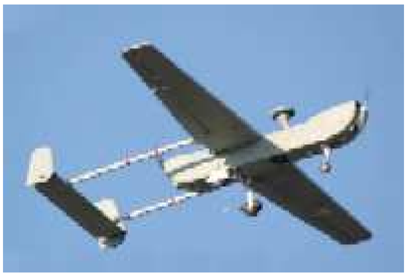

Fig. 6 B-Hunter (© Tom Brinkman, www.aerobel.be)

High altitude systems that have been proposed are either blimps or fixed wing aircraft. To have any use at all, they also need to have very long endurance, measured in days and weeks rather than in hours. Thus they need to use the sun as power source (nuclear power may be possible, but is not accepted as sufficiently safe).

Blimps need to be very voluminous to carry a substantial payload (since their lifting ability is directly related to the air pressure around them), but then they also require significant power to allow them to counter the winds at high altitude, which is provided by a solar array on the envelope of the blimp during day time and by rechargeable batteries or regenerative fuel cells at night. Several programs have been initiated, but up to now, they have not led to a flying system (Sasa, 2004; Dong-Min, 2003).

For fixed wing aircraft, the limiting factor is the solar power that is available (1360 W/m^2, converted with less than 20% efficiency). Lift for fixed wing aircraft depend on the air density, the wing surface and the airspeed. In the lower stratosphere, the air density is very low (10-15 % of ground level density), so it is very important to design an extremely low-mass system. This was realized by QinetiQ (UK) in their Zephyr program, culminating in a 54 hour endurance flight that reached an altitude superior to 17.5 km, in the White Sands Missile Range, NM, USA, in August of 2007. An alternative design, by AeroVironment (USA) was a flying wing of more than 75 m wingspan, that reached more than 30 km altitude in 2001.

Fig. 7. Zephyr being launched (© QinetiQ)

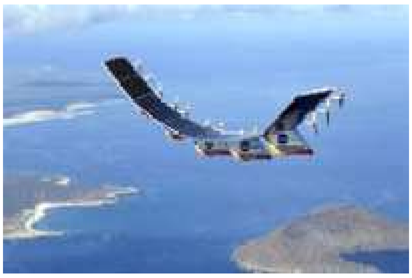

Fig. 8 Aerovironment Helios (© Aerovironment)

At VITO, the Pegasus project was proposed as early as 2000, aiming to use a High Altitude Long Endurance (HALE) UAV for remote sensing. The UAV, called Mercator, is related to the QinetiQ Zephyr systems (Fransaer, 2004).

In May 2007, the US Defence Advanced Research Projects Agency (DARPA) announced the VULTURE Air Vehicle Program. This is aimed at developing a heavier-that-air platform that can maintain an airborne payload on station for an uninterrupted period of over 5 years. In April 2008, first phase contracts were awarded to three contractor teams headed by Aurora Flight Sciences, Boeing and Lockheed Martin. (DARPA, 2008)

3. REMOTE SENSING INSTRUMENTS

Low altitude UAVs are used to carry light-weight instruments. In most cases, these consist of off-the-shelf component such as consumer digital cameras (Eisenbeiss, 2006; Haarbrink, 2007, Martinez Rubio, 2005)). At low altitude, it is possible to achieve very high resolution, and it has been shown that consumer grade SLR cameras offer sufficient precision and stability to allow photogrammetric extraction of information (Shortis, 2006). Other instruments include (combinations of) imaging systems covering visible to thermal spectrum, with multi- or hyperspectral sampling, miniature RADAR, passive microwave radiometers, and LiDARs (Vierling, 2006; Sugiura, 2005; Sugiura, 2007; Martínez-de Dios, 2006; Archer, 2004).
On the other hand, UAVs are also used as a test bed for new instruments or integration of instruments (Colomina, 2007) This is of significant importance, as it allows research groups that specialize in instrument design to test prototypes on a regular basis.
At VITO, a high resolution wide swath digital camera is under development for flight on Mercator within the Pegasus project. This camera uses extremely light-weight subsystems to reduce the total mass to less than 2.5 kg and still generate 30 cm ground sampling distance from 18 km altitude (Delauré, 2007).
In short, UAVs have carried instruments that cover the whole range of the spectrum that remote sensing has addressed. Usually, however, it is not possible to carry the instruments that have been conceived for larger manned platforms, so innovative solutions have been found.

4. APPLICATIONS

Many remote sensing applications have benefited from the use of UAVs. In most cases, this was due to the cost of the mission, the need for rapid response or the fact that observations need to be carried out in an environment that may be harmful or dangerous to an aircrew.
A striking example is the adoption of remote sensing using UAVs in archaeology (Çabuk, 2007; Eisenbeiss, 2006; Martinez Rubio, 2005). The main purpose is to document archaeological sites, and to provide 'a bigger picture'. The accuracy requirements are not very high, although it has been shown that e.g.; elevation accuracy using a helicopter UAV and a consumer digital cameras (Canon EOS-D60) yields elevation models that are comparable to ground laser scanner measurements.
Vegetation monitoring has also been successfully done using UAVs. A HALE UAV, Pathfinder Plus was used to demonstrate this on a coffee plantation in Hawaii (Herwitz, 2004); others have studied rangelands (Rango, 2006), and in Japan these systems are considered to be an integral part of farm equipment (being catalogued as 'flying ploughs'; Newcombe, 2007).
Rapid response imaging using UAVs has received a lot of attention as well. This has been demonstrated for road accident simulations (Haarbrink, 2006) and in many cases of forest fire monitoring (Réstas, 2006; Martínez-de Dios, 2006; Casbeer, 2006). UAVs have also been proposed as platforms to monitor volcanoes (Buongiorno, 2005).
A final example of the flexibility of UAVs is their use in traffic monitoring (Puri, 2007; Doherty, 2004)

5. CONCLUSIONS AND OUTLOOK

The number of UAV systems used in remote sensing and mapping have soared in the past four years. Coming in almost all possible forms and sizes, they have flown a multitude of remote sensing instruments for many applications. Much of this work is still in the research phase, and there are few "off-the-shelf" systems that offer complete solutions to a user. UAVs have given remote sensing a new appeal for scientists, who will now be able to conduct research in a much more flexible way. It is easy to foresee that, when all aviation regulations have been adapted to include these systems into the general airspace, UAVs will rapidly become the preferred platform for development of remote sensing instruments and applications.

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