PEGASUS: HIGH RESOLUTION REMOTE SENSING FROM A STRATOSPHERIC UNMANNED AERIAL VEHICLE

J. Everaerts, M. Claessens, J. Biesemans, N. Lewyckyj
Vito-TAP (Flemish Institute for Technological Research, Centre for Remote Sensing and Earth Observation Processes)
Boeretang 200
BE-2400 Mol, Belgium
jurgen.everaerts@vito.be

Key words: High Resolution, UAV, Environmental Monitoring, Crisis Management

Summary:

The Flemish Institute for Technological Research has advocated the use of Unmanned Aerial Vehicles (UAV) as platform for remote sensing instruments for many years. In June 2004, the Flemish Government decided to fund a 'proof of concept' project. This proof of concept encompasses, the construction of a solar-powered stratospheric UAV, capable of multiple months of non-stop operations at altitudes between 14 to 20 km and equipped with a multispectral optical instrument having a 20 cm ground resolution and position accuracy. In the operational stage following the proof of concept, additional instruments such as a laser-altimeter, a thermal camera and a Synthetic Aperture Radar will also be carried.

Flying well above busy air traffic, this system can cover large areas (more than 100 000 km^2 annually). It is also capable to hover over a small region quasi permanently, offering near real-time observations, even when the weather is adverse, thanks to the complementary set of instruments.

The resulting data is perfectly suited for all mapping purposes, except for very large scale; furthermore it can be used in environmental monitoring (crop forecast, water or soil pollution and sanitation, …), crisis management (natural disasters and industrial accidents) as well as for many security and related issues.

1. Introduction

The Pegasus project has been described in [1] and [2]. The basic idea is to use a High Altitude Long Endurance (HALE) platform for remote sensing. This platform should be able to fly at 14-20 km altitude for long duration (i.e. several weeks to many months), being permanently available for aerial survey. Flying in between the areas where manned aircraft operate (500 – 10 000 m) and where satellites orbit (see Table 1), it enjoys the advantages of both types of traditional platforms without their disadvantages.

SATELLITE	ALTITUDE (KM)
Quickbird	450
IKONOS	680
SPOT-5	830

Table 1: Altitude of a few selected satellites

2. Why use a stratospheric platform?

2.1. Traditional platforms

Manned aircraft are well established as platform for all kinds of remote sensing activities, and they have been used for that purpose since over 80 years (e.g. Simmons Aerofilms of the UK was established in 1919). Satellites dedicated for Earth Observation have been active since the early 1970's (ERTS-1 a.k.a. Landsat-1 was launched in 1972). Both have specific advantages and disadvantages, as shown in Table 2 and 3. The criteria that we use to characterize the platforms are :

- Coverage: the extend of the geographical area that can be surveyed by a single platform.
- Update rate: the time needed to renew the survey of a certain area.
- Quality: how well the production processes are documented.
- Spatial resolution: the smallest visible detail in the observations. For digital systems, the ground pixel size.
- Positional accuracy: the georeferencing accuracy of the observations.
- Spectral resolution and precision : how accurately the reflected spectrum is recorded

Coverage	**Local to Regional** Depending on the type of aircraft, survey missions are limited to a few 100's of km to about 1000 km.
Update rate	**Low or non-existing** Only National Mapping Agencies have update programs, and they are measured in years. Usually, aerial survey companies do not invest in regular updates of large areas unless they have a contract to do so. Also, delays due to weather conditions or air traffic control limitations can be very important.
Quality	**Not well documented** Although aerial survey companies deliver data with high quality, their processes are not always well-documented. This implies that data from different suppliers can be inconsistent. Also, changes to production processes in the past have not always been documented.
Spatial Resolution	**High to Very High** Ground resolution is at dm- to cm-level.
Positional Accuracy	**High** Direct of integrated sensor orientation as well as traditional aerial triangulation methods yield sub-pixel georeferencing even with a very limited amount of ground control points.
Spectral Resolution and accuracy	**Not always well controlled** When using film as recording medium, the final resulting image is affected by light conditions and exposure settings, but also to the parameters of the film processing. Furthermore, scanning the aerial film and image processing have a profound impact on the final color balance. Digital sensors and multi- or hyperspectral systems have a calibrated response, but digital aerial cameras have quite wide bands.

Table 2: Properties of manned airborne platforms

Coverage	**Global** Polar satellites pass over every location on Earth with a fixed interval, so every location can be observed. Only at reduced spatial resolution, a true global observation is possible (e.g. SPOT-Vegetation, at 1 km ground pixel size). So-called High Resolution satellites take snap-shots of areas for which their customers have interest.
Update rate	**High** Most operational (as opposed to experimental or scientific) satellites have attitude control, to allow short revisit times (e.g. although IKONOS has a revisit time of 140 days at nadir, it can re-observe the same location within 3 days by changing its attitude).
Quality	**Constant** Satellite observations are usually processed by a very limited number (usually : one only) of processing centers.
Spatial Resolution	**Low to Medium** Ground resolution is at km- to m-resolution.
Positional Accuracy	**Low to medium** Geo-positioning accuracy for high resolution satellite systems is of the order of several pixels. Only when using a significant amount of ground control, accuracy at the same level as the ground resolution is achieved.
Spectral Resolution and accuracy	**Calibrated** Only digital sensors are used on satellites nowadays, all well calibrated.

Table 3: Properties of satellite platforms

Apart from this comparison, an important difference between airborne and satellite systems is that satellite systems cannot be serviced. If a sensor on the satellite fails, the entire mission may be compromised. Also, the cost of a satellite system is orders of magnitude higher than airborne systems, although this doesn't necessarily means that satellite data are more expensive.

2.2. Air traffic

Mid-European countries are amongst the most heavily overflown regions in the world [3], with more than 1 million overflights per year over Belgium alone. As a result, aerial survey is severely regulated and the execution of survey flights is strongly impeded. Most areas are under permanent Air Traffic Control, for which aerial survey flights is not a priority. To overcome this restriction, flights can be conducted either below 1 000 m or above 14 km, outside which the airspace is free.

The latter solution is preferred as it offers larger coverage capability (larger swath width) and is not affected by the turbulences that are present closer to the ground. The lower stratospheric environment is quite favorable for remote sensing :

- The temperature is quite constant (very limited daily variation), although it is cold (-55 to -70 °C);
- Air pressure is about 100 mbar, 10% of the ground level value;
- Humidity is close to zero, so there are no clouds;
- Wind speeds are minimal in summer time: < 10 m/s (1 sigma) and <20 m/s (3 sigma), see Figure 1.

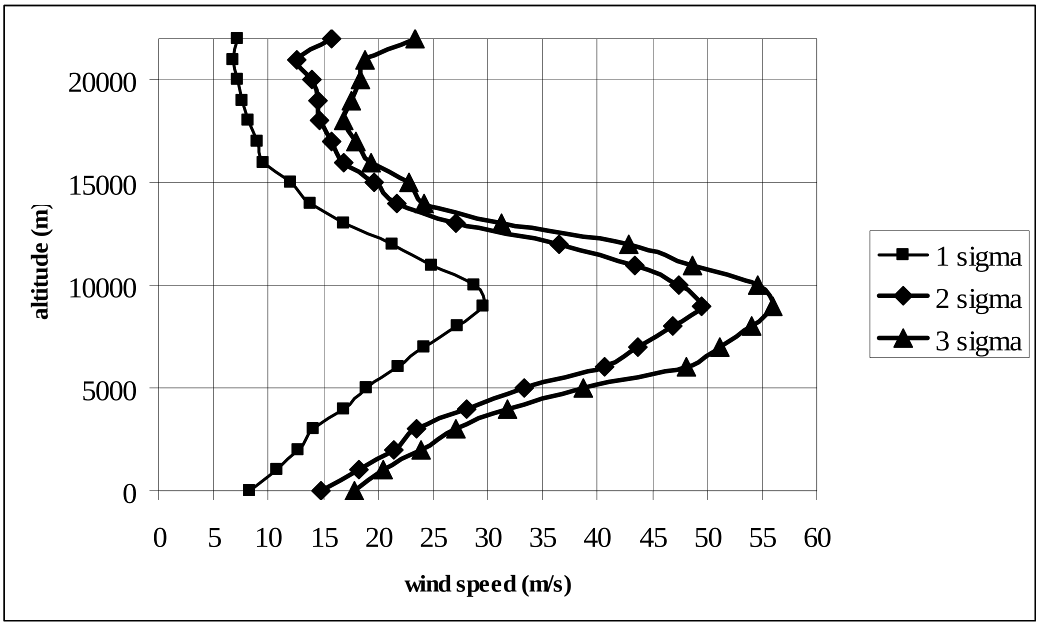

Figure 1: wind speeds statistics for altitudes up to 22 km (from atmospheric soundings conducted at Den Helder, The Netherlands, in the March to September period). The maximum at 9-10 km altitude is the so-called Jet Stream.

2.3. Cloud cover

Cloud cover is probably the most important factor for the efficient operation of aerial or satellite survey. Airborne missions are usually only conducted when there is no more than 1/8 of the sky covered by cloud. According to the IKONOS product guide "All IKONOS imagery contains less than 20% cloud cover. Customers can designate a single coordinate within the image that must be cloud free"[4]. The same applies to Quickbird imagery [5]. This implies that it can take a long time before a larger area (e.g. a country) is completely covered by high resolution satellite imagery. In Belgium, the statistics from Brussels International Airport were collected for a few years in the recent past. These are shown in Figure 2.

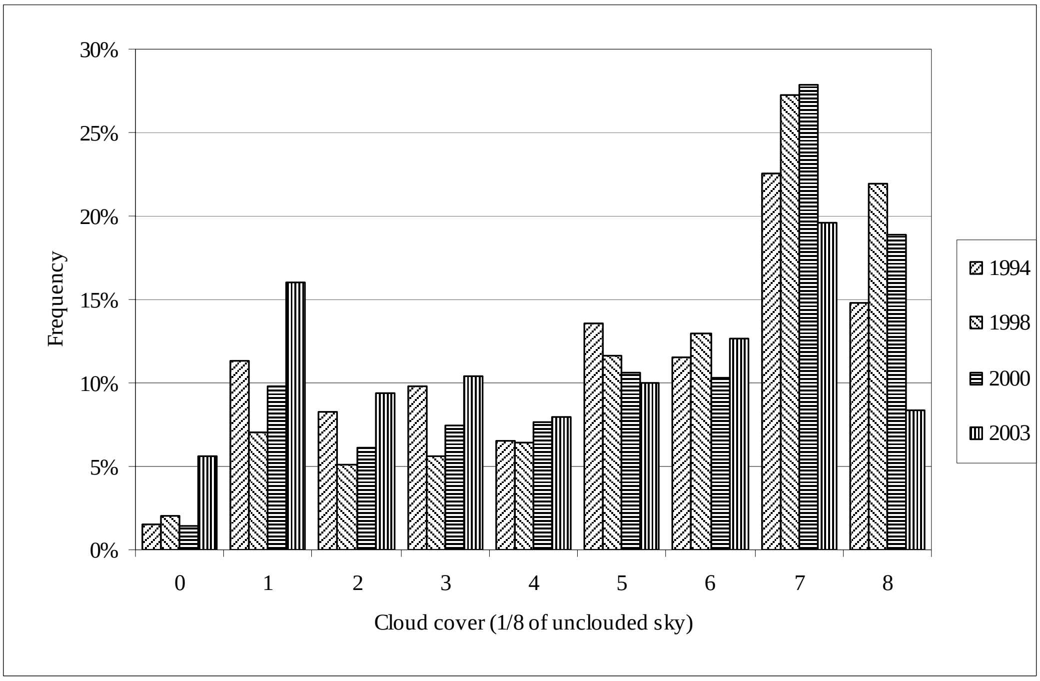

Figure 2: Cloud cover statistics in the March through September period at Brussels International Airport (Belgium) in 4 selected years in the recent past. Note that 2003 was an exceptionally favorable year.

Performing aerial or satellite observations under these cloud cover conditions is difficult:

- Aerial survey flights are only performed when the conditions are optimal (not more than 1/8 of cloud cover), so it may take a long time before a survey is completed;
- The orbital motion of satellites defines the time of overpass over a specific region. If there is too much cloud cover, the opportunity is lost, and one has to wait until the next overpass.

A solution to this problem is to have a platform that is permanently available for survey, flying above the area of interest.

This could be a geostationary satellite, but due to the distance to the Earth's surface (35 786 km) and the position (above the equator) of this platform, it is difficult to conceive a payload that is capable of producing high resolution imagery. All areas that are not on the equator are observed in a slant direction, which is far from ideal for metrology applications.

The other alternative, taking into account the air traffic problems as well, is to use a High Altitude Long Endurance platform.

2.4. High Altitude Long Endurance Platform

A stratospheric long endurance platform can be designed to offer all the advantages of manned airborne and satellite systems, without their disadvantages :

- Coverage: a single platform will cover an area of 125 000 km^2 or more, taking the meteorological conditions of mid-European countries into account.
- Update rate: the platform is well suited to hover over an area, generating continuous coverage. This is especially useful when monitoring crisis situations (natural disasters and/or industrial accidents).
- Quality: a single unit will process all data, through so-called processing chains which yield constant documented quality.
- Spatial resolution: 15 – 20 cm ground resolution is achievable
- Positional accuracy: the same methods as for airborne survey can be used, resulting in sub-pixel georeferencing
- Spectral resolution and precision: the response curves for the sensors will be pre-calibrated and be validated by observing targets of known spectral signature.

Figure 3: The Pegasus 1:2 scale model

The Pegasus platform should be permanently available during at least 6 months and preferably longer. As a consequence, it should use an power source that is very long lasting. This could be a nuclear system [6], but this is not acceptable from a political point of view. The only other power source that is available is solar. It is not available during night time, however. For night time operation, batteries are to be used: supplying the aircraft with energy by illuminating it with microwave or laser beams [7] has been suggested and even tested, but it relies on a permanent unobscured line-of-sight between the power emitter and the aircraft, which is unlikely if cloud cover statistics are considered. Regenerative fuel cell technology has a large potential to replace batteries in the future (over 1000 Wh/kg expected), but this still needs to be realized. The length of the longest night determines the weight of the battery subsystem (currently, batteries having 300 Wh/kg are available [8]).

Another consequence to the long endurance is that the platform cannot be manned. Providing life support at stratospheric altitudes (breathable air, heating, food, etc., …) would make the design virtually impossible. Leaving all life support functions out allows a very lightweight design.

The platform's flight capability can be realized as an aerodynamic (airplane) or aerostatic (blimp or balloon) type of system. Due to the low density of the air at 20 km altitude, an aerostatic system requires very large volumes of helium gas to lift any significant payload and flight systems (to carry 500 kg of payload to 20 km altitude, a blimp with a total volume of 180 000 m^3 is required, with a total mass of 12 600 kg [9]), which make the system very hard to construct and to operate. A light-weight aerodynamic design is also possible. This has a wingspan inferior to 20 m, and a total weight below 35 kg for a payload mass of 2 kg. The design, construction and operation complexities of using this type of system are significantly smaller than an aerostatic design, so this is preferred for the Pegasus project. Figure 3 shows a picture of the half-size scale model.

3. Remote sensing instruments

To fully address the remote sensing market and other applications that need remote monitoring, a number of complementary high resolution instruments are planned for development. They are documented in more detail in [1].

- Multispectral Digital Camera (MDC): 20 cm ground resolution and georeferencing accuracy, up to 10 narrow spectral bands in VNIR over a 2.4 km swath from 20 km altitude.
- LIDAR: 15 cm elevation accuracy and 0.25 pt/m^2 point density.
- Thermal Digital Camera (TDC): 1.5 m spatial resolution in 2 thermal IR bands.
- Synthetic Aperture Radar (SAR): 2.5 m spatial resolution over a 4.5 km swath.

The MDC and LIDAR combined yield high precision 3D information; the TDC allows night observations as well as heat loss studies; the SAR has an day-and-night, all-weather observation capability, which is needed in crisis management situations.

4. Data processing

Due to the long duration of the flights of the platform, on-board storage is not a viable option. Therefore, all data that is acquired is directly down linked to a moveable ground reception station (typically the size of a freight container) which is connected to the central processing unit. This unit archives the incoming data and processes it, together with ancillary data (e.g. GPS data from reference stations in the survey area) to a standard level 1 product. This processing includes:

- Geometric and radiometric calibration (i.e. compensation for lens distortion, sensor response as a function of wavelength);
- Geometric correction (georeferencing, including dGPS/INS integrated sensor orientation);
- Atmospheric correction (compensation for the absorption/refraction/dispersion properties of the atmosphere, so that the at-instrument spectra are transformed to at-object spectra)

The aim of the Pegasus project is to implement this in a processing chain, with minimal (preferable none) operator interaction, so that the final product has a constant and documented quality. On request, further processing will also be possible (e.g. orthorectification, feature extraction, image classification and interpretation). These requests will be made via an Internet portal interface.

For real-time applications (e.g. traffic monitoring or crisis management) only the most essential processing will be done, basically reconstructing the image from the data stream. In that case, a turn-around time of less than 10 minutes is foreseen.

5. Applications

The Pegasus project is driven by the remote sensing market needs, as user acceptance of a new idea is essential for its success. When defining the payload and platform requirements, internally conducted market studies as well as publicized studies (e.g. [10]) were taken into account. Sometimes, new applications will become (economically) possible for the first time, because the instrument/platform combination allows for high resolution data acquisition in spatial, spectral and temporal sense.

The basis of the applications are the level 1 data that are produced in a standard way. Within the Pegasus project, some of these applications will be developed, to show the usability of the data, but for the majority of the applications, we will rely on third party development. We will mention just a few.

5.1. Mapping

For all but the most demanding mapping purposes, 20 cm precision is sufficient. The Pegasus system will deliver objective 3D information, which can be used to extract vector information without having to resort to stereo-evaluation which is labor intensive. In most cases, the image itself will be sufficient if the elevation data is provided in the background. This will allow the end-user to select and map the elements of interest himself, when it is required.

5.2. Crop monitoring and precision farming – spectral data extraction

These applications focus on the health status of the vegetation in the course of the growing season. Using spectral information, stress in vegetation can be detected before it is visually evident. This requires a careful selection of spectral bands (and most importantly in the near-IR band) and a high temporal resolution (one or two weeks).

The choice of spectral bands can be predefined by using a hyperspectral instrument (e.g. CASI or HYMAP) and then determining the most significant bands for the application using wavelet decomposition. This bandset is then uploaded to the MDC, and observations specifically suited for crop monitoring can be made.

5.3. Crisis management

During a crisis (man-made or natural), the authorities need up-to-date information about the situation in terms of spatial extent (e.g. flooded area) and direction or evolution (e.g. how forest fires are spreading), all in a matter of minutes. Later on, insurance companies may need high resolution images to evaluate claims.

The Pegasus system addresses this by offering a set of instruments to allow continuous observation and a platform that can be made to circle over the affected area for prolonged time. Furthermore, the processing chain philosophy guarantees very fast throughput.

6. Conclusion

The Pegasus system proposes an alternative to the traditional airborne or spaceborne systems for remote sensing, combining their advantages while minimizing their draw-backs. It will operate for long duration (up to 8 months) at altitudes up to 20 km, providing high resolution spatial, spectral and temporal data.

Its data will be directly downlinked to a ground reception station, which forwards all data to the central processing unit. Here, archiving and processing up to level 1 is performed in an automated way. For crisis management, a turn-around time of less than 10 minutes is foreseen, after which the data can be consulted via Internet.

References

[1]. Everaerts, J., Lewyckyj, N., Fransaer, D., 2004. PEGASUS: Design of a Stratospheric Long Endurance UAV System for Remote Sensing. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Volume XXXV, Part B2.

[2]. Fransaer, D., Vanderhaeghen, F., Everaerts, J., 2004. PEGASUS: Business Plan for a Stratospheric Long Endurance UAV System for Remote Sensing. Accepted for *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* Volume XXXV, Part B2.

[3]. EUROCONTROL Air Traffic Statistics and Forecasts Service (STATFOR), 2003. Forecast of Annual Number of IFR Flights (2003-2010). Volume 1.
http://www.eurocontrol.int/statfor/forecasts/STATFOR%20Forecast%202003-2010%20vol1%20v10.pdf

[4]. Space Imaging, 2004. IKONOS Imagery Products and Product Guide.

[5]. DigitalGlobe, 2002. Quickbird Imagery Products Product Guide.

[6]. Graham-Rowe, D. 2003. Nuclear-powered drone aircraft on drawing board , *New Scientist*, 22 February 2003

[7]. http://www.spaceref.com/news/viewpr.html?pid=12743

[8]. Tudron, F.B. *et al*, 2004. Lithium-Sulfur Rechargeable Batteries: Characteristics, State of Development, and Applicability to Powering Portable Electronics. http://www.sionpower.com/files/PowerSources2004.pdf

[9]. Küke, R., 2000. HALE Aerostatic Platforms, TN-4 : System considerations. ESA Study 13243/98/NL/JG.

[10]. Mondello, C., Hepner, G.F., Williamson, R.A., 2004. 10-Year Industry Forecast. Photogrammetric Engineering and Remote Sensing 70 (1), pp. 5 – 76.