STRATEGIC RESEARCH AGENDA FOR HIGH-ALTITUDE AIRCRAFT AND AIRSHIP REMOTE SENSING APPLICATIONS

C. Barbier[a], B. Delauré[b], A. Lavie[c]

[a]CSL - Centre Spatial de Liège, Av. Pré-Aily, B-4031 Angleur, Belgium – cbarbier@ulg.ac.be
[b]VITO - Flemish Institute for Technological Research, Boeretang 200, BE-2400 Mol, Belgium, - bavo.delaure@vito.be
[c]CTI – Creative Technologies Israel,

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ABSTRACT :

This contribution addresses the remote sensing chapter of the USE HAAS Study, a Specific Support Action of the European Union Sixth Framework Program, aiming at producing a Strategic Research Agenda for High Altitude Aircraft and Airships.

After a brief presentation of the objectives and methodology of the USE HAAS Study, the Strategic Research Agenda for remote sensing shall be addressed by considering candidate applications (with particular attention on fire monitoring and cartography) and basic system buliding blocks (i.e., platform, payload, downlink, processing facility, user portal).

1. INTRODUCTION

The "USE HAAS" study, a Specific Support Action of the European Union Sixth Framework Programme, was carried out to produce a Strategic Research Agenda (SRA) for the European development of High-Altitude Aircraft and Airship (HAAS) platforms, missions and Applications (Barbier, 2005). The following topics were covered :

- analysis of the developments and projects and the world state of the art
- definition the objectives and possible applications based on an analysis of the needs
- organization of different workshops resulting in various WG (Working Groups) with continuous discussions between the workshops
- identification of the potential end-users and technological partners
- understanding of the research needs for the future
- definition of a common research agenda for this technology sector
- final conclusions, policy and strategy definition.

This paper addresses the remote sensing aspect of the USE Haas Study. Security, which makes use of the same techniques and sensors, is considered in other sections of the USE HAAS SRA. This paper is structured as follows :

Typical HAAS remote sensing missions are considered in Section 2. Then Sections 3 and 4 address, respectively, application and payload requirements. The resulting platform requirements are dealt with in Section 4. Conclusions and recommendations are provided in Section 5.

2. TYPICAL HAAS REMOTE SENSING MISSIONS

Although the spectrum of possible HAAS Earth observation missions is virtually continuous, we will concentrate on two regional missions, i.e. forest fire monitoring and mapping.

2.1 Forest Fire Monitoring

2.1.1 Context: Every year, an average 45,000 forest fires break out in Europe. Between 1989 and 1993, 2.6 million hectares of woodland were destroyed by fire in the Mediterranean alone. The consequences of forest fires are human (loss of life), economical (destruction of habitats, forest damage, cost of fire-fighting) and environmental: destruction of fauna and flora.

Most of these fires are caused by man. However, there are many natural factors such as drought, wind speed and topography, which influence the spread of fires and govern their devastating effects. Some forest fire statistics for five Southern EU Member States are produced in (European Commission, 2005).

2.1.2 HAAS for Forest Fire Monitoring: the HAAS capabilities in the context of forest fire management and monitoring are (Caballero, 2005):

Before the fire:

- prevention planning and preparedness (inputs for risk mapping), including: identification and measurement of forest fuel conditions (fuel load, moisture content of live fraction),
- identification and mapping of infrastructures (roads, urban areas), monitoring of potential sources of fire,
- surveillance of human activity,
- local meteorology and micro-meteorology.

During the fire:

- emergency management (advanced commander post), including: quick mapping of the local fire environment (on-demand maps of fuel, infrastructures, etc),
- permanent observation of fuel status and meteorology conditions (moisture, wind)Fire front tracking (position, activity, intensity),
- smoke tracking, detection of spot fires and spotting distance,
- identification of hot spots/areas after the fire, local coverage (relay) in mountainous areas for communication and navigation purposes,

- fire fighting forces position tracking and operations monitoring,
- identification of retardant drops and its efficiency, management coupling of other events/HAAS,
- multi-risk assessment.

After the fire:

- post-fire recovery management, including: quick and accurate measurement of fire scars, estimation of damages and losses,
- assessment for relief funds dimensioning,
- estimation of priorities of post-fire treatment,
- recovery and erosion risk prevention operations,
- monitoring of burned area evolution (illegal activities).

2.1.3 Typical application requirements (Caballero, 2005):

Spatial dimension:
Before a fire starts: synthetic risk maps over a large region (i.e., 100 x 100 km, medium resolution, 1/25000).

Once a fire starts: detailed information over a small area (i.e., 10 x 10 km around the fire outbreak, high resolution, 1/5000).

Each decision context requires an adequate level of information granularity without exceeding cost and covering information needs.

Regional risk assessment must be consistently combined with on-demand local assessment.

Temporal dimension:
Before the fire starts :

- Long-term risk prevention planning (1 year)
- Short-term risk mapping (1 week)
- Preparedness (1 day)
- Fire detection (every 15 minutes)

Once fire starts:

- Quick local mapping (within the first 30 minutes after fire)
- Monitoring of fire front (every 30 minutes)
- Tracking of forces position (every 5 minutes)

Information updating rate must be adequate to the decision-making context, without exceeding costs and covering information needs

Others:
HAAS products should be coupled and compatible with other spatial and non-spatial information sources, corresponding to existing or upcoming ad-hoc information networks and on-ground sensors in inter-operable environments

Specific sensors should be developed and implemented in forest fire managements (including micro-meteorology observation devices).

2.2 Mapping

2.2.1 Context: Remote sensing data collection from aerial and spaceborne platforms operating in different altitudes is a growing market since years. The ASPRS-NASA-NOAA sponsored 10 years forecast (Mondello et al., 2004) has indicated the direction in which the remote sensing community is evolving. Some relevant conclusions are:

- There are high requirements in position and elevation accuracy, and in spatial and spectral resolutions (exemplified in the trend towards multi and hyper spectral sensors).
- Both aerial and spaceborne remote sensing are growing and augmenting each other. In several cases, satellite and aerial data producers have formed strategic partnerships to enhance each other's marketing opportunities.

2.2.2 HAAS for Mapping : Using traditional platforms to provide data for the changing requirements is difficult because :

- Spaceborne instruments cannot generate dm-level resolution and positioning for imagery in a consistent way, their overpasses are fixed, so they cannot collect imagery at any given time or when the area is covered by clouds.
- Manned airborne platforms are very flexible, offer superior image resolution and positioning accuracy, but they have to operate in congested air space and take cloud cover into account. As they are quite expensive to operate, they are only put to use when conditions are very close to optimal.

HAAS systems have the potential to address the increasing demands of the market. They are more flexible than conventional platforms, because they operate above air traffic and weather phenomena, and are not bound to an orbit. Furthermore, as they remain above a local region persistently, they can be considered to be a local geostationary platform, allowing high temporal updates (even continuous monitoring) with high spatial resolution. As such, this allows demanding mapping applications to use remote sensing (e.g. car navigation databases need to be up-to-date; it is not acceptable to offer car navigation owners a situation that is no longer correct). The permanent availability of HAAS platforms gives them a considerable advantage compared to traditional platforms, even if they work at higher speeds. The HAAS platform has the ability to exploit gaps in the cloud coverage resulting in a larger coverage annual coverage. This is shown in a performance comparison between a HALE UAV multispectral camera with airborne cameras (Everaerts, 2004) taking into account representative meteorological conditions for Belgium. Table 1 shows the area in (km^2) that can be covered in one survey season (March-September) by a multispectral sensor embarked on a HALE UAV and three commercial airborne camera systems on a manned airplane. This shows that at small ground sampling distances the HALE UAV is superior in terms of covered area.

As conclusion it can be stated that HAAS combines the possibility to cover regional areas with high resolution imagery. This way this innovative platform has the ability to bridge the gap between the airborne and spaceborne platforms.

Ground pixel size	UAV	ADS40	DMC	UltraCam
0.15 m	60 910 – 77 820	41 340 – 64 400	53 680 – 83 620	46 030 – 71 700
0.20 m	98 530 – 125 890	56 100 – 87 380	71 790 – 111 830	61 650 – 96 020
1.00 m	98 530 – 125 890	415 380 – 647 020	447 330 – 696 790	396 500 – 617 610

Table 1. Area (in km2) that can be covered in one survey season (March–September) by a multispectral HALE UAV sensor and three commercial airborne cameras (Everaerts, 2004)

2.2.3 Typical application requirements: Making maps using remote sensing is well-established. Traditionally, this has been done by photogrammetric techniques (delineating objects in a 3D view constructed by stereo imagery), in mostly interactive processes. Some advances have been made to extract information from images in an automated way, but this is usually successful for very dedicated applications only (e.g. for military purposes, where well-defined objects are searched for), not yet for generic mapping. The result is a geometrically correct positioning of (a selection of) elements that are of interest (a so-called legend). The cadastral map is used for taxation, but also serves as base map in some countries (e.g. The Netherlands).

Spatial:
Carthographic requirements depend mainly on the scale of the final product; even when digital products are generated, the map content will be defined by the scale the maps will be printed. For topographic mapping, a precision of about 25 cm is usually sufficient; for engineering, these requirements are much stricter, sometimes even on the 5 cm level.

Sensor:
The main data source for carthographic mapping is large format metric imagery (film or digital). Small scale mapping has also been done on SAR data. For elevation information, SAR and LIDAR instruments are additional data sources.

Temporal:
Revisit cycles for mapping are usually long (up to the order of years). This could reduce drastically in the future with the increasing interest in up-to-date car navigation information.

2.3 Multimission Platform

Figure 1 shows an example scenario for a multi-application mission making use of several HAAS platforms and combining telecommunications, security and Earth observation functionalities (REF Vol3). Such missions should be compared to equivalent satellite missions to better estimate the potential market for HAAS regional Earth observation.

In the scenario pictured in
Figure **1**, two basic remote sensing applications are covered (although the sensor suite embarked on each platform may be able to cover other applications): A UAV monitors forest fires in Spain, while an airship surveys traffic over some Italian motorways. Each platform transmits remote sensing data to a dedicated local ground station by some high-rate data link, where the data shall be pre- and post-processed, archived, and possibly distributed to users. A maintenance and control facility is housed in a central ground station, and communicates with the platforms via a low-rate link. Further platforms may be kept in standby mode to serve further applications or to enhance the focus on a high priority application. It is vital in such a concept that each platform has a flexible sensor concept with the possibility to support several sensors at the same time or to exchange sensors on ground during a maintenance period. This enables an efficient adjustment of the system capabilities to the current needs and hence allows saving resources.

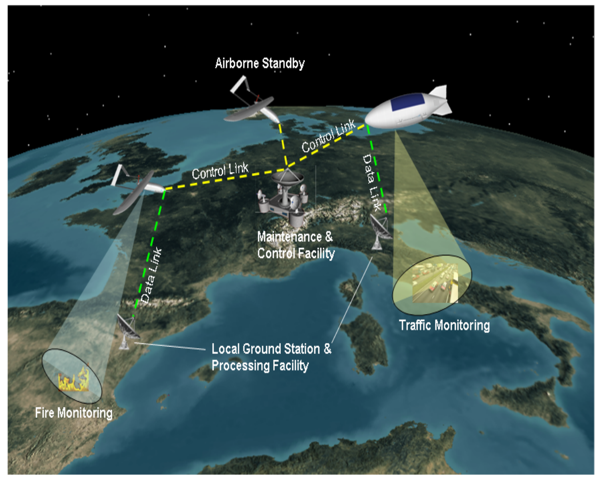

Figure 1. HAAS Multi-application mission scenario

Furthermore, this example scenario is flexible enough to accommodate elements coming from existing spaceborne or airborne systems, showing that HAAS is more of a complement than a competition to satellites or aircrafts. As an example, communication satellites might assist in over-the-horizon data and TM/TC links; or larger scale data might be provided by remote sensing satellites flying over the regions of interest. An important parameter is the time scale at which such multi-applications, multi-platform systems can be implemented. Two elements have to be taken into account in this respect: A substantial part of the needed sensors and data processing techniques are already available for carrying out the targeted mission, while the bottleneck is more on the platform in terms of mass, power and endurance. First research programs based mainly on small unmanned aircrafts (UAV) have approved the functionality of platform, payload and application potential. A pragmatic demonstrate-first-and-convince approach should be initiated, making use of whatever sensors and platforms are available. In this respect, it is clear that e.g. mapping HAAS services can be addressed now, while other applications like forest fire monitoring, being more demanding in terms of endurance and sensors, belong to the medium- or long-term perspective.

3 PAYLOAD REQUIREMENTS

3.1 End-User Needs

The basic requirements can be classified as geometric requirements (incl. field of view, spatial resolution and accuracy), and spectral requirements (spectral region, number of bands, bandwidths). Since security and Earth observation applications make use of basically the same techniques, the corresponding requirements will be examined simultaneously.

Security and Earth observation missions require HAAS platforms capable to provide quasi-stationary positions as well as defined movements with as constant as possible forward velocities depending on the selected set of sensors. The later one is necessary to fulfill the physical requirements of imaging sensors like synthetic aperture radar or optical line scanners. The mission length will range from one day through to continuous deployment, depending on the scenario and development timescales. As in the case of telecommunications it is not important that the mission be delivered by a single HAAS, instead multiple platforms can be used either simultaneously in order to enhance the focus on a region of interest or as replacement to extend the duration of a mission.

Table 2 is a summary of user requirements based on the mission examples considered in the HAAS Study. Although not meant to be exhaustive or comprehensive, this table is representative for the security and Earth observation sector. Blanks are used when there was either no requirement at all, or the requirements were not yet consolidated enough or when they were strongly dependent on the specific scenario.

Appl.	Spat. Res.	Spat. Acc.	Swath Width	Swath Length	Endur.	Revisit Time	System Response Time	Spectral Requ.	Platform stability
Border	0.1 m	10 m	20 km	500 km	> 1 year	30 min	5 min	Radar, IR	GPS/IMU
Pipeline	0.05 m	5 m	400 m	Length of pipeline	> 1 year	14 days	14 days	Radar, optical, Lidar, hyperspectral	GPS/IMU
Crisis	0.2 m	0.5 m	2 km	2 km	1 month	< 10 min	10 min	Radar, IR, optical	GPS/IMU
Disaster	5 m	10 m	100 km	100 km	½ year	5 hours		Radar, IR, optical, hyperspectral	GPS/IMU
Observation of a Refugee Camp	1 m	1 m	5 km	5 km	½ year	1 hour	10 min	Radar, IR, optical	GPS/IMU
Forest Fire	20 m	10 m	100 km	200 km	½ year	< 10 min		Radar, IR	GPS/IMU
Traffic Monitoring	1,5	< 10 m	20 km	20 km	2 months	1 min	10 min	Optical, IR, radar	GPS/IMU
Cartography	0.05-0.5 m	0.05-0.5 m	2 km	2 km		1 – 10 years		Optical, IR, radar	GPS/IMU

Table 2. Security and remote sensing user requirements

3.1.2 Payload for Security and Earth Observation applications: To fulfill the various required capabilities, the platform needs to be equipped with different sensor technologies like e.g. high resolution radar, infrared, optical or hyperspectral sensors as well as communication and/or processing equipment. It turned out that security and Earth observation applications require basically the same sensor technology. The following gives an overview of the available remote sensing technologies as well as further enabling technologies to arrive at exploitable products to fulfill the mission requirements.

Surveillance Radar is a non-imaging technique by sending out short high power microwave pulses in regions of interest and to measure the reflected energy to detect objects and to determine their direction and their distance.

Synthetic Aperture Radar (SAR) imaging systems provide a two-dimensional view of the electromagnetic reflectivity characteristic of the area illuminated by the radar. Today's achievable image resolution is about 1 m for spaceborne systems and as little as 0.2 m for air-borne systems. The main advantages are that the technology is independent of the distance to the target, the time of day and the weather conditions. However, because of system inherent features (speckle) and the imaging geometry, special effects occur (shadowing, fore-shortening) that make the image interpretability more difficult than for optical sensors.

Interferometric SAR uses the phase information contained in two SAR images taken from slightly different positions to develop terrain models and detect ground surface movements in the cm range (e.g. after earthquakes).

Moving Target Indication (MTI) uses SAR methods for determining the velocity of objects from phase-shift information.

Optical imaging systems are based on cameras in the visible spectrum. Modern designs usually use a small, rectangular piece of silicon (charge-coupled device, CCD or complimentary metaloxide semiconductor, CMOS) rather than a piece of film to receive incoming light, which is transformed on the spot into a digital format. There is a huge number of sensors already available for any kind of platform. A disadvantage of this technique is the dependency on weather conditions.

Thermography involves the use of imaging detectors which pick up the infrared radiation emitted by a body and convert it into a visible image of that body. Various airborne camera systems are available on the market.

Hyperspectral sensors measure the degree of spectral reflection by natural and artificial objects. Many elements on the Earth's surface (vegetation pigments, minerals, rock, artificial surfaces) have specific absorption characteristics in defined wavelength bands, which allows a quantitative analysis. The use of imaging systems makes it possible to identify objects by both their spectral signatures and their three-dimensional characteristics.

LIDAR (Light Detection and Ranging) is a laser light-based optical detection technique used to determine gas concentrations by tuning the laser wavelength to the spectral signature of the gas to be detected.

Microwave radiometers measure the emission and reflection properties of objects in the microwave region. Various experimental systems have been developed with promising results.

Sensor motion compensation (D-GPS/IMU)

The focusing and georeferencing of most sensor data requires a D-GPS/IMU system. The necessary degree of accuracy depends on applications and sensors. The forward velocity during imaging should be as stable as possible. The orientation of the platform needs to ensure a homogenous illumination of the target area.

Onboard processing:

Onboard processing is essential to overcome the potential bottlenecks of data transmission capacity. Onboard processing units for HAAS platforms are based on the heritage of airborne units that will need further developments to adjust them to the specific environmental conditions in the stratosphere. The strong limitations that spaceborne sensors have with respect to onboard processing due to cosmic radiation are expected not to be relevant for HAAS platforms. Onboard processing includes the following tasks: data management, feature extraction, classification, filtering, encryption and data compression.

Data transmission:

The high spatial resolution and wide field of view requirements lead to very high instantaneous data rates in the sensors. A minimization of the data transmission rates is a trade-off with onboard processing capacities. Available technologies for data transmission are microwave data links in X- and Ku-band. Optical data links may be required as an alternative for very high data rate demands. They are emerging on the market. They require high platform stability.

Advanced data transmission concepts have the potential to overcome data rate bottlenecks by elongating the time of transmission (e.g. using optical data links from moveable imaging platforms to a stationary data transmission platform with a permanent X-, Ku-band downlink to Earth)

Ground processing:

Ground processing includes :

- Processing of the remote sensing data (e.g. image) including atmospheric, geometric and radiometric corrections.
- Information extraction from the images like e.g. speed of cars or detection of plumes.

Time aspects of processing (e.g., delivery time) and corresponding technical issues are relevant since they may require additional algorithm development and/or additional hardware processing capacity.

4. PLATFORM REQUIREMENTS

The main requirements for the platform capabilities with respect to mass, volume, power consumption and date rate are derived from the user requirements on the payload. The key parameters driving these figures are the spatial resolution and the field of view requested from the sensor. Based on the summarized payload user requirements in Section 3, the platform requirements were estimated as an order of magnitude for typical high resolution sensors (1 m) and very high resolution sensors (0,1 m) offering a wide field of view suitable for multi-application missions (see Table 3). The figures were estimated for a sensor altitude of 20 km, whereas lower altitudes require less resources (is less demanding on the platform) and higher altitudes require more resources. The same applies for the spatial resolution: lower resolutions require less resources and higher resolutions require more resources. Note that hyperspectral sensors with a resolution of 0.1 m are not used.

	1 m			0,1 m		
	SAR	Optical/IR	Hyperspectral	SAR	Optical/IR	Hyperspectral
Payload mass	25 – 100 kg	20 - 30 kg	20 – 30 kg	80 – 250 kg	40 – 60 kg	-
Payload volume	0,5 m^3	0,1 m^3	0,1 m^3	1 m^3	0,3 m^3	-
Power consumption	0,2 – 1 kW	< 100 W	< 100 W	0,5 – 4 kW	0,1 – 0,5 kW	-

Table 3. Platform needs for High Resolution Sensors

Other requirements to be considered include :

Data rate:
Typical instantaneous data rates of the individual sensors are in the order of 2 GBit/s for high resolution applications. This requires very high data transmission capacities of the platform as well as advanced onboard processing capabilities.

Velocity: 10 – 200 m/s (SAR, optical)
In principal SAR and optical sensors are flexible with respect to platform velocity. Nevertheless low velocities (<10 m/s) are more critical since the integration time increases and motion compensation becomes more difficult especially to compensate velocity changes during the integration time. High velocities (> 200 m/s) are unfavorable since they require higher pulse repetition frequencies (PRF) in SAR and higher scanner frequencies in optical sensors and therefore higher peak power demands during imaging. Moreover, high PRFs may limit the available swath width for SAR.

The forward velocity during imaging should be as stable as possible. The orientation needs to ensure a homogenous illumination of the target area, minimizing image blurring due to the motion of the platform.

Endurance:
The payload does not introduce additional restrictions to the system endurance as long as the power supply and the data transmission are ensured.

Stability:
The focusing and georeferencing of SAR and optical data requires a D-GPS/IMU system. The necessary degree of accuracy on applications and sensors. Differential GPS requires a contact possibility to a GPS base station on ground.

5. CONCLUSIONS AND RECOMMENDATIONS

HAAS missions and applications have the potential to fill in the ***missing link*** between airborne and spaceborne missions. Since they fly in high altitude but still much lower than satellites, their type of observation is regional and the spatial resolution is much better. Due to its short distance relative to the Earth, to its constant availability and possibility to maneuver between clouds it is possible to realize high resolution imagery combined with regional coverage (whereas airborne sensors are restricted to local coverage)

The ***superior flexibility and the constant availability*** of the HAAS allow providing remote sensing data and communication services fast, at high update rates and over a specific target area.

The ***sensor technologies*** are already on a ***high level of maturity***. They need ***customized developments*** to meet the specific capabilities and the environment of HAAS platforms. The development will take advantage of similar improvement requirements from airborne and spaceborne missions.

Basically the ***same sensors*** are required by a ***large number of observation missions***.

High-bandwidth downlink is necessary to support data from multiple sensors.

Need of ***standard data interfaces*** to allow easy integration in standard data processing and downlink systems.

Implementation of ***on-board processing*** (data management, feature extraction, classification, filtering, encryption, data compression) should be investigated.

Standard payload bays should be available for ***fast and flexible change of payload modules***.

Platform can and should provide observation and communication capabilities at the same time, leading to the concept of HAAS as a ***multi-mission platform***.

Using the ***same platform for multiple missions*** including several payloads could ***improve the economics*** of a High Altitude System. One single platform can be equipped with several sensors and telecommunication payloads to provide different services at the same time or without the need of changing the payload.

Bottlenecks for the use of HAAS for remote sensing and communication applications are ***mostly on the platform*** and not on the sensors.

HAAS offers considerable potential to support a range of valuable applications and services. These ***applications and services will meet society's needs***, contribute to European objectives and generate wealth.

REFERENCES

Barbier, C., 2005. "High Altitude Aircraft and Airships (HAAS)" , http://www.usehaas.org (accessed 25 September 2006).

"Study on the use of remote sensing technologies for natural gas transmission pipeline monitoring" – Final Report, DLR/e.on Ruhrgas, July 2000.

D. Caballero, "HAAS Applications in Integrated Forest Fire Management – Some Ideas for HAAS FF Services Design and Implementation", presentation materials, USE HAAS Workshop Nr 1, RMA, Brussels, 12 July 2005.

European Commission, "Forest Fires in Europe 2004", Official Publication of the European Commission, S.P.I.05.147 EN © European Communities 2005.

Everaerts, J., 2004. PEGASUS – bridging the gap between airborne and spaceborne remote sensing. New Strategies for European Remote Sensing, pp. 395-401, Millpress, Rotterdam, The Netherlands.

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

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