LOW COST UAV FOR POST-DISASTER ASSESSMENT

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Commission VIII, WG VIII/2

KEY WORDS: UAV, Disaster Management, Photogrammetry, Autopilot

ABSTRACT:

The main objective of early impact analysis after a disaster is to produce georeferenced data about the affected areas, in support of humanitarian action. Crucial information are the identification of the hitten areas and the estimation of the number of people involved. Satellite imageries are mainly used as input data for early impact analysis at small and medium map scale (i.e. floods events). Analyses aimed at defining the damages to infrastructures and/or to facilities (i.e. earthquakes) require suitable data for large scale analyses, as far as high resolution satellite images. Unfortunately, such images are not always available in a few days after the event, therefore in situ surveys are preferred. ITHACA (Information Technology for Humanitarian Assistance, Cooperation and Action) - a non profit association with the main goal to carry on operational and research activities in the field of geomatics for analysis, evaluation and mitigation of natural and manmade hazards - is developing a low cost mini UAV (Unmanned Aerial Vehicle) devoted to the early impact analyses. The aim of the UAV project is to develop a low cost aerial platform capable of autonomous flight and equipped with a photogrammetric payload for rapid mapping purposes. The main requirements for this type of UAV are to be easily transportable and usable on the field, autonomously, by a couple of operators. Therefore, it was decided to customise the MH2000 platform designed and patented by the Department of Aerospace Engineering (DIASP) of the Politecnico di Torino. The current configuration of the UAV allows to carry onboard digital sensors for video and imagery acquisition. The sensors are mounted in a pod placed on the belly of the fuselage, that can be remotely controlled through a direct link to the autopilot board that allows to schedule automatic acquisitions at defined time intervals or planned positions. A real-time video downlink of the over-passed areas is provided. Several test flights were performed in order to set up the control parameters of UAV and to analyse the capability of performing autonomous flights according to the defined flight-path. Two photogrammetric surveys aimed at calculating the achievable 3-D accuracy have been peformed over a flight centre and an archaeological site (both located in Italy). Results of both tests will be shown in detail.

1. INTRODUCTION

1.1 Motivation and aims

ITHACA (Information Technology for Humanitarian Assistance, Cooperation and Action) - a non profit association with the main goal to carry on operational and research activities in the field of geomatics for analysis, evaluation and mitigation of natural and manmade hazards - is developing a low cost mini UAV (Unmanned Aerial Vehicle) devoted to the early impact analyses. With a view to cooperate with the WFP (World Food Programme) – the food aid arm of the United Nations and the world's largest operational humanitarian agency – the Association proposes itself as a center of applied research and for the distribution of products and services related to Information Technology in support of humanitarian activities. In particular ITHACA is devoted to scientific research, delivering methodologies, analytical services and technical tolls to improve the capacity of WFP and broader International community in early warning, early impact assessment and other related areas. The aim of the UAV project is to develop a low cost aerial platform capable of autonomous flight and equipped with a photogrammetric payload for rapid mapping purposes. The main requirements for this kind of UAV are to be easily transportable on normal aircrafts and usable on the field, autonomously, by a couple of operators. The main objective of early impact analysis after a disaster is to produce georeferenced data about the hitten area, in support of humanitarian action.

1.2 UAV definition, classification and applications

UAV is the acronym of Unmanned Aerial Vehicle and refers to a class of aircrafts that can fly without the onboard presence of pilot. They can be flown by an electronic equipment present on the vehicle and on a GCS (Ground Control Station), or directly from the ground. In this last case it is common to associate the system with the expression RPV (Remotely Piloted Vehicle), since the vehicle is remotely piloted and operated by radio-controlled devices. In literature other terms are adopted to indicate such category of vehicles, such as: Drone, ROA (Remotely Operated Aircraft), UVS (Unmanned Vehicle System).

UAVs are classified (UAV association) in three categories with respect to their possible usage. Each typology of aerial vehicle is subdivided into subcategories, according to their features and performance; particular reference is made to the vehicle range, maximum climb rate, endurance and weight. Table 1 refers to the tactic group, that encompasses ITHACA UAVs.

The development of UAVs started in the 50's for military purposes. During the cold war, different countries started projects with the aim of producing vehicles devoted to reconnaissance, surveillance and penetration of hostile territories missions, without the presence of an onboard pilot.

UAV Categories	Acronym	Range (km)	Climb rate (m)	Endurance (hours)	Mass (kg)
Tactic					
Micro	μ (Micro)	< 10	250	1	<5
Mini	Mini	< 10	150 to 300	< 2	150
Close Range	CR	10 a 30	3000	2 to 4	150
Short Range	SR	30 a 70	3000	3 to 6	200
Medium Range	MR	70 a 200	5000	6 to 10	1250
Medium Range Endurance	MRE	> 500	8000	10 to 18	1250
Low Altitude Deep Penetration	LADP	> 250	50 to 9000	0.5 to 1	350
Low Altitude Long Endurance	LALE	> 500	3000	>24	< 30
Medium Altitude Long Endurance	MALE	> 500	14000	24 to 48	1500

Table 1. UAV classification – Tactic Group (UAV association)

At present the market for UAVs has been rapidly growing both in military and civil applications. The increasing interest for these systems is due to the advantages they present in comparison to traditional aircrafts:

- flight performance. UAVs can operate in a wide range of operational altitudes (from 100 to over 30,000 m) and have an elevated range of endurance (1-48 hours); the result is the possibility of carrying out small, medium and large scale monitoring operations;
- adaptability. These systems can perform various typologies of missions, in particular for monitoring operations in remote areas;
- inexpensiveness. The possibility of designing aerial vehicles with variable dimensions, relatively reduced weight, and no onboard personnel allows to carry out flight operations at lower costs compared to the ones required by traditional aircrafts.

These features are suitable for the development of systems that allow to hold a wide range of civil applications such as:

Land Monitoring and Remote Sensing:

- meteorology and atmospheric pollution control;
- hydro geological and geophysical control;
- monitoring of areas either affected by natural disasters or contaminated;
- surveying of archaeological areas.

Agricolture:

- spraying and treatment with chemical products;
- monitoring of agricultural resources and cultivation phases.

Public security:

- borders and (road/rail) traffic surveillance;
- support to recovery/rescue operations.

Statistics (UAV association, 2005) show that only the 8% of UAVs manufactured in the world are exclusively devoted to a civil use. It has to be underlined that the use of UAV for civil purposes is slackened by several factors: insurance issues, lack of safe communication frequencies and regulatory issues.

2. ITHACA UAV

2.1 From the prototype to the pre-industrial version

According to the requirements of the project, a suitable aerial platform layout was identified: fixed wing, tailless integrated wing-body configuration and tractor propeller driven. This kind of configuration has several advantages: the design is compact with an adequate aerodynamic efficiency, masses and subsystems are concentrated, structures are light and severe aeroelastic problems are rejected as no tailplane is present, stall is smooth and the configuration is spin resistant and stable in flight. Therefore it was decided to test the MH2000 version of the UAV platform developed and patented by the *department of Aerospace Engineering* (DIASP) of the Politecnico di Torino. For a long time Proff. F. Quagliotti and G. Guglieri, have been engaged in planning and implementing mini-UAV for civil applications. Since 2004, sever prototypes have been produced. ITHACA focused on the bigger model, (MicroHawk MH2000, with reference to their wingspan in millimetres), due to the payload requirements (about 1,5-2 kg). Hence, the commissioning for the realization of the prototype ITHACA 01 (Figure 1).

Figure 1. ITHACA 01 UAV prototype (2006)

The flight tests (Chapter 3) performed in the last two years using the UAV prototype, allowed to fine tune the platform and to define the technical features (Table 2) of two final layouts of the UAV.

Propulsion	DC	ICE
Wing span (m)	2	2
Wing surface (m^2)	2.1	2.1
Length (fuselage, m)	1.75	1.75
Width (fuselage, m)	1.43	1.43
Weight (body, g)	7500/8150	7500/8150
Fuel weight (g)	-	1500/1000
Payload capacity (g)	2500/2000	1500/1000
Flight envelope@sea level (m/s)	10-20	10-20
Cruise Altitude (m)	120	120
Cruise speed (m/s)	15	15
Optimum range limits	15 Km	25 Km
Optimum endurance limits (h)	0.5@15m/s	60@15m/s

Table 2. ITHACA UAV technical features (based on MH2000 UAV developed by Politecnico di Torino – DIASP)

The new platforms – ready to be delivered - are based on the MH2000 configuration, manufactured in carbon fiber and powered by a DC and an ICE engine (Figure 2).

Figure 2. ITHACA UAV - Carbon fiber, ICE engine version (2008)

2.2 Payload

The configuration of the UAV allows to carry onboard digital sensors for video and imagery acquisition. The sensors are installed in a pod (Figure 3) placed on the belly of the fuselage, that is connected to the autopilot board. A real-time video downlink of the over-passed areas is performed using the AV output signals of the camera.

Figure 3. The external payload

At the moment the Pod is equipped with the RICOCH GR camera characterised by a geometric resolution of 8 Mpixel and a focal lenght of 5.9 mm. A new pod for a semi-professional SLR digital camera (Canon Eos 5D) is in the prototyping stage. The adopted solution is to insert the camera body inside the fuselage (Figure 4) to reduce the aerodynamic drag.

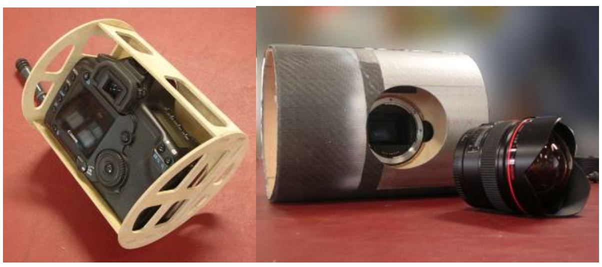

Figure 4. Internal payload prototype

2.3 Navigation system

The aircraft is equipped with the MICROPILOT MP2128^{g} autopilot that allows autonomous flights and provides a real-time attitude of flight. The MP2128g is composed by an electronic circuit board and a ground control software (HORIZON^{mp}). The navigation system includes a GPS unit, three-axis gyroscope and accelerometer (IMU), relative airspeed probe, pressure altitude transducer, AGL ultrasonic altitude sensor (optional), and external servo board. The gyroscope, accelerometer, pressure altitude transducer and airspeed probe provide telemetry at 5Hz while GPS has 4 Hz update rate. 2.4GHz radio modem (according to EU regulations) allows to transmit the flight attitude to the Ground Control Station (GCS, Figure 5).

Figure 5. UAV Ground Control Station and navigation software

The control software HORIZON^{mp} provides flight path and current sensor values in real-time. The operator can also insert a flight plan (up to 1000 waypoints) on a preloaded map and upload it during the flight. Besides the system can be connected with the payload cameras, so it is possible to schedule an automatic shooting time. Therefore it is possible to carry out automated photogrammetric flights at half of the optimum range limits. The operations of take-off and landing must be accomplished manually due to the insufficient GPS in-flight accuracy.

3. FLIGTH TESTS

During the last two years two flights specifically aimed at testing the photogrammetric performances of the system were carried out: the main aims were to validate the stereoscopic coverage of the acquired images and to estimate the triangulation accuracy. Furthermore several test flights were performed in order to evaluate the autonomous flight performances of the platform and to check the link between the autopilot board and the payload (needed to trigger the acquisitions).

The photogrammetric flights require flight plans to be defined, according to RICOH GR digital camera technical specifications (Figure 6). The first test was carried out in the Villareggia RC flight center (Turin - Italy) in November 2006. The area of interest was covered by a block of 2 strips with 3 frames. (flight altitude: 100 m, overlap: 60%). The second test was carried out in an archaeological area (Bendea et al, 2007) located in Piedmont (Italy). Two photogrammetric flights were performed over the theatre and the amphitheatre areas at a flight altitude of 60 m. The coverage of the theatre area is assured by 2 strips with 4 frames (overlap: 60%).

The two photogrammetric test flights were done by ground manual radio control due to safety issues. Since the link between autopilot board and payload wasn't yet operational, images were acquired through a remote radio controlled system based on a twin microswitch card interfaced with the digital camera, allowing the user to set a shooting time interval.

Figure 6. Photogrammetric test - Example of flight plan

The triangulation operations were carried out with a bundle block adjustment using different commercial software. The best results have been obtained with LPS Leica photogrammetry suite software following a self-calibration approach. The obtained 3D accuracy ($10^{-3}\cdot d$) is suitable for rapid map production (Figure 7).

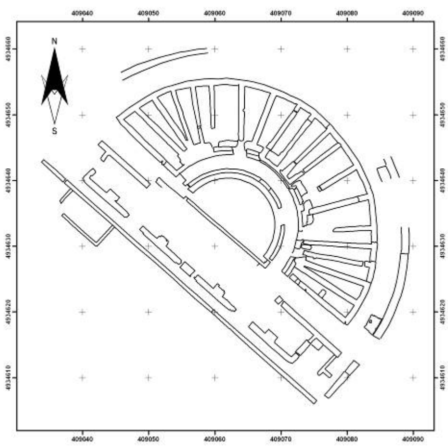

Figure 7. Photogrammetric test - Example of stereo-plotted map

More than 10 test flights have been performed in order to check the performances of the MP2128g autopilot (using both the standard GPS receiver at 1Hz and the UBLOX upgrade to 4 Hz) and to plan the required improvements. Test flights have been accomplished in the flight fields of Villareggia and Santena (Turin - Italy). In order to validate the autonomous flight capability of the UAV and to minitor the platform attitude during the flight, a flight plan has to be pre-defined. Telemetry data processing allows to analyse the flight dynamics: the platform is rather stable, the altitude, speed and attitude angles are steady and near to the target parameters. Nevertheless the system has main difficulties to follow the target trajectory. This problem is probably due to the low accuracy of the pseudo-range 1 Hz GPS positioning.

The link between MP2128g board and camera suffers for unreliability, since the number of shooting signals sent by the autopilot and the number of acquired images are not equal. This issue may be due to the low speed of the camera memory buffer, and it should be solved using the Canon EOS 5D semi-professional SLR camera.

4. ONGOING DEVELOPMENTS

At the present the research group is working on two main planned developments of the UAV system. The first one is devoted to the improvement of the in-flight positiong accuracy, in order to have better navigation performances (attainment to the flight-plan) and based on a differential GPS approach. The second topic is related to the development of an automated procedure aimed at performing a photogrammetric processing of the acquired data.

4.1 Navigation sytem improvements

Differential GPS positioning is a technique were two (or more) receivers are used. A GPS receiver is placed on a known point (master station) and another one is on moving (rover). The master station is able to estimate the pseudorange correction (PRC) or differential correction and their range rate corrections (RRC). These data are transmitted to rover receiver, using different devices such as radio modem, GSM modem and internet services.

This approach allows to increase the accuracy of the UAV positioning, because the autopilot GPS estimates its position through the PRC, allowing bias error to be decreased or eliminated. Differential positioning is available both using pseudorange and carrier phase measurements. The first case, which is the one used by the Micropilot autopilot, is called DGPS (differential GPS), while the second one is called RTK (real time kinematic). The ongoing tests of the UAV are based on both DGPS and SBAS (Satellite Based Augmentation Systems) techniques.

4.1.1 DGPS positioning

The range between receiver and a satellite (j) could be modelled using:

$$R_A^j(t_o) = \rho_A^j(t_o) + \Delta\rho_A^j(t_o) + c\delta^j(t_o) - c\delta_A(t_o) \quad (1)$$

Where pedicel A= receiver
apex j = satellite
R= receiver – satellite pseudodistance;
ρ = receiver – satellite distance;
Δρ = radial orbital error;
cδ = clock error (satellite and receiver)

PRC is estimated as:

$$PRC_A^j(t_o) = -R_A^j(t_o) + \rho_A^j(t_o) = -\Delta\rho_A^j(t_o) + \\ -c\delta^j(t_o) + c\delta_A(t_o) \quad (2)$$

At the epoch t, PRC can be approximated as:

$$PRC_A^j(t) = PRC_A^j(t_0) + (RRC_A^j(t_o) * (t - t_0) \qquad (3)$$

Where $(t\text{-}t_0)$ is the latency.

Latency is defined as the difference between the epoch when the correction is calculated and when it is applied.
PRC is applied in the rover receiver, using the follow equation:

$$R_B^j(t\ )_{corr} = R_B^j(t\ ) + PRC^j(t) \qquad (4)$$

PRC is transmitted using different devices mainly using 2 data formats: owner format (where only same receivers can work together) or standard format (RTCM) that allow interoperability between different GPS receivers.
RTCM is a standard format, composed by different types. Each type contents a different information. For example, PRC is usually included in the type 1 and 2 (in the RTK positioning, type 18 and 19 content the carrier phase corrections). The DGPS plugin provided by Micropilot is based on the RTCM 2.0 format.

4.1.2 Network of permanent stations

Nowadays the differential corrections can be received from a permanent station, that is a master station working in continuous and able to send the differential corrections. The increase of the number of permanent stations in the last years allowed a new type of DGPS-RTK positioning to be developed. It is therefore possible to process differential corrections coming from different permanent stations in order to estimate a more precise model of bias on a large area. This approach allows to apply the surface model on the pseudorange measures to increase the DGPS accuracy.

The ongoing tests are validating the usage of corrections coming from:
- a permantent station (or a network of permanent stations), sent through GSM or Internet services.
- a base GPS receiver, sent through a serial port.

The expected accuracy in real time positioning is about 1m (respect to about 10 m).

4.1.3 Satellite Based Augmentation Systems (SBAS)

Another approach that is being tested to enhance the navigation performances of the UAV is based on the SBAS capability of the Ublox GPS installed on the Micropilot autopilot.

SBAS (i.e:WAAS, EGNOSS, MSAS, GAGAN) is a satellite based DGPS system. The main difference respect to DGPS is that no additional long-wave receiver is necessary to receive the correction data and there is no need for an endless number of DGPS beacons that transmit these correction data. The SBAS shall provide additional accuracy and reliability for the GPS system. To achieve this aim, a number of GPS receiving stations are required. In the US, 25 stations are used, Europe uses 10 stations during the test operation and will have 34 when EGNOS will be fully operational. The position of these RIMS (Ranging and Integrity Monitor Stations) needs to be know exactly (up to a few centimetres). The RIMS station receives the standard GPS signal (and also the signal from the Russian GLONASS system and the GALILEO system in future). It is therefore possible to calculate the difference between the known position of the station and the position calculated by the GPS receiver. And since the RIMS uses receivers that use both GPS frequencies (L1 and L2), the signal delay through the ionosphere can be calculated for every single satellite. Additionally, if the signals from more than four satellites are received, more information needed for a position determination are available and these information may be used to check for possible problems with the satellites or deviations in their orbits or time.

The data from all RIMS are sent to a Central Processing Centre. For the EGNOS test bed (ESTB) this centre is in Toulouse (France) and a backup system is located in Hønefoss (Norway). At these stations, the data will be collected and the following data will be calculated:
- Long term errors of the satellite orbits
- Short term and Long term errors of the satellite clocks
- IONO correction grids
- Integrity information

By use of the integrity information, it is possible to inform the users within 6 seconds on problems that occur with the GPS system.

The most important feature of the SBAS for common GPS users is the IONO correction grid. Since SA (selective availability) is deactivated, the largest single source of error in GPS position determination is the signal delay in the ionosphere. Being able to correct these errors significantly increases the accuracy of every GPS receiver is able to process WAAS/EGNOS data. From the measured data of the RIMS, a ‘map’ of the Total Electron Content (TEC) in the ionosphere for the area covered by the RIMS station is calculated (Figure 8).

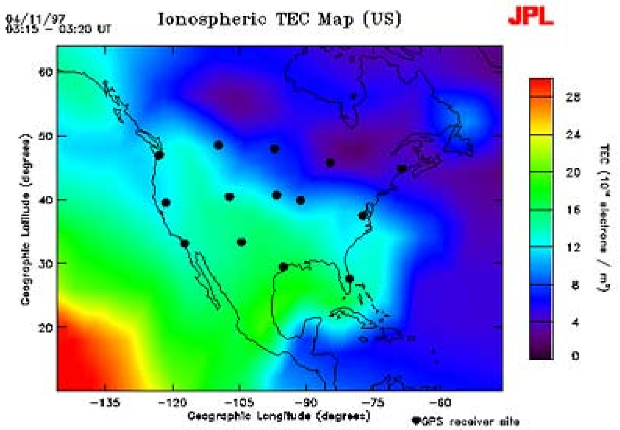

Figure 8. Example of Ionospheric Total Electron Content (TEC)

With decreased accuracy the area where the TEC map is calculated can even be expanded further. This TEC map is now transmitted to a geostationary satellite that itself acts like a GPS satellite, that means that can be used for position determination but also provides the receiver with the information it needs for the correction of the ionospheric effects.

The geostationary satellites provide a signal very similar to that of the GPS-satellites and on the same frequency. Therefore these satellites may be used for position calculation and additionally, the correction data sent out can be used to improve accuracy for position calculation with all GPS satellites.

Using the TEC map transmitted by the geostationary satellites, the GPS receiver can now calculate the 'pierce point' and signal delay of the signal of each satellite used for position calculation and then correct the data for higher accuracy in position determination.

Other interesting functions provided by SBAS are the integrity check of the GPS system and the transmission of warnings in case of problems with the system.

4.1.4 Differences between SBAS and DGPS

For land-based people, the main difference between DGPS and the SBAS systems is the calculation of the TEC map for ionospheric corrections. This brings some of the benefits of an expensive dual frequency receiver to a cheap single frequency receiver.

With DGPS, every single reference station compares its own precisely known position with the position calculated from the GPS signals. The station then transmits this information on a certain long wave band as correction data. A DGPS receiver receives the correction information and applies this correction to the signals received from the GPS satellites. With increasing distance of the receiver to the DGPS reference station, the atmospheric influences on the signals get more and more different and the correction get less and less accurate.
SBAS systems (WAAS, EGNOS, MSAS), respect to DGPS, provide correction for a wide area and are not limited to isolated corrections. Every single receiver then corrects its own position itself by use of this data. In this way, the accuracy that can be achieved is even better than with DGPS.

4.2 Automated photogrammetric processing

The research group is working on the definition and implementation of an automated procedure for image data processing. The main goal is to implement a software devoted to the automatic production of orthoimages and other added-value products such as the STOP (Solid True OrthoPhoto). This product allows to merge 3D information (coming from a DTM), with an orthoimage generated through a rigorous approach.

The input data are the images acquired during the flight and the corresponding IMU/GPS data recorded by the autopilot board. Their integration allows to use a direct georeferencing (DG) approach that cuts drastically the GCP survey operations. Using DG the calibration topics are fundamental: both single-step and two-step calibrations are investigated. Sperimental tests with DGPS data will be performed in order to define the best calibration approach.

The first step in the processing workflow (Figure 9) is the automatic tie point extraction. The chosen approach is the feature based matching known as Scale Invariant Feature Transform (SIFT). This approach supplies a large number of features invariant to scale and orientation which are detected using a difference of Gaussian function for each image. Each key point is associated with a "descriptor" that computes the radiometric arrangement in a region around that. The matching between two homologous points is computed by similar descriptors.

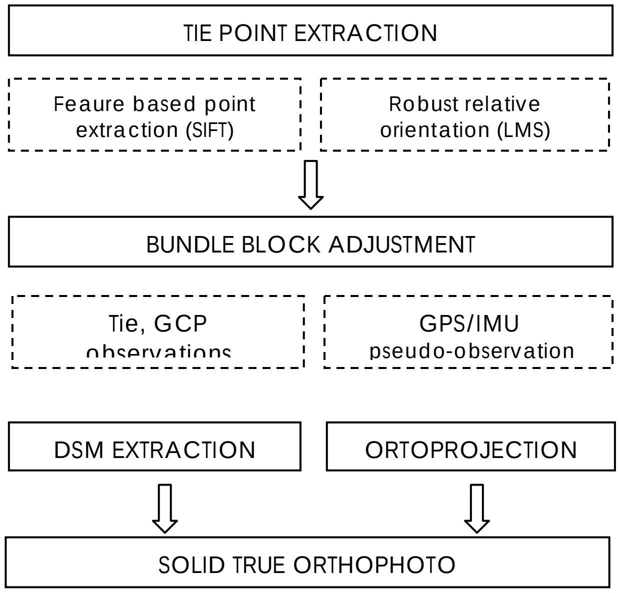

Figure 9 – Automated image processing work-flow

For each image pair a relative orientation based on a robust approach (LMS, Least Median Square) is performed to select the correct homologous pair.

Subsequentially the aerial triangulation is performed: the mathematical model used is the bundle block adjustment based on collinearity equations. Tie points and GCPs observations are integrated with the pseudo-observation equations of the GPS/IMU data corresponding to each image. Pseudo-observations will be weighted according to the DGPS/IMU measures accuracy.

The last two steps are the automatic DSM extraction and the orthoimage generation, which allow to obtain the afore described STOP. DSM extraction techniques based both on single and multi-images approach are investigated.

REFERENCES

Capello, E., Guglieri, G., Quaglotti,F., 2008. A Software Tool for Mission Design and Autopilot Integration: an Application to Micro Aerial Vehicles. 2008 *Internation Simulation Multi-Conference*, Edinburgh, Scotland (in press)

Bendea, H., Boccardo, P., Dequal, S., Giulio Tonolo, F., Marenchino, D., 2007. New technologies for mobile mapping. *The 5th international symposium in Mobile Mapping Technology.* Padova, Italy, 28-31 May 2007

Bendea, H., Chiabrando, F., Giulio Tonolo, F., Marenchino, D., 2007. Mapping of archaeological areas using a low-cost uav. The augusta bagiennorum test site. *XXI CIPA International symposium.* Athens, Greece, 1-6 October 2007.

Vedaldi, A., 2006 An open implementation of the SIFT detector and descriptor, UCLA CSD Tech. Report 070012, University of California at Los Angeles, USA.

Franzini, M., 2005. Indipendent and rigorous assessment of standard and refined methodologies for GPS/IMU system calibration in aerial photogrammetry, Final dissertation, *Research Doctorate Course in Geodesy and Geomatics*. Politecnico di Milano, Italy

Lowe, D., 2004. Distinctive image Features from Scale-Invariant Keypoints. *International Journal of Computer Vision.*

V.A., 2004. Guidelines for the regulation of light UAV systems", Annex 1

Jacobsen, K., 2002. Calibration aspects in direct georeferencing of frame imagery. In: *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. 34, Part 1, pp. 82-89, XIXth ISPRS Congress, Denver, USA

Cina, A., 2002. *GPS: principi, modalità e tecniche di posizionamento*. CELID, Torinohttp://www.kowoma.de/ (accessed on April 2008)www.esa.eu (accessed on April 2008)

ACKNOWLEDGMENTS

Authors would like to thank the Aerospace Department (DIASP) of Politecnico di Torino for the support in the flight test operations.