CLOSE-SEARCH: ACCURATE AND SAFE EGNOS-SOL NAVIGATION FOR UAV-BASED LOW-COST SAR OPERATIONS

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BIOGRAPHY

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Dr. Ismael Colomina is the director of the IG. He holds a PhD in Mathematics from the UB. Dr. Colomina is a co-chair of the Working Group 1.5 “Integrated navigation systems for sensor georeferencing” of the International Society for Photogrammetry and Remote-sensing, and a member of the Editorial Advisory Board of “*GPS World*.”

Teo Vitoria is the head of Measurement, Communication and Control Group (MCCG) in AIN. He is an Industrial Engineer (University of Navarra) with 20 years of experience in RTD projects, leading his team in remote sensing, UAS and INS/GPS technology projects.

Pedro F. Silva received his Aerospace Engineering degree from Instituto Superior Tcnico, Portugal, in 2001 and since then has been working in receiver and navigation related applications and technology. Since 2005 he is working at DME as a Senior Engineer in the GNSS group on topics like satellite navigation systems design, aeronautics and space software systems design and management, and GPS constellation validation and health monitoring systems.

Dr. Jan Skaloud holds a Ph.D. and M.Sc. from the University of Calgary, Canada and a Diploma Engineering degree from The Czech Technical University in Prague. He is the senior scientist and lecturer at EPFL in the area of kinematic geodesy and mobile mapping. He has over 15-years experience in the airborne and terrestrial applications related to GPS and inertial technology.

Dr. Wolfgang Kornus leads the development and support team of the Geodesy Department. He has over 15-years experience in airborne and spaceborne photogrammetry and holds a PhD from the Technical University of Munich. He participated in various international projects and was secretary of ISPRS Working Group I/1 on *Sensor Parameter Standardisation and Calibration*.

Rosa Mata is the head of the Operations Support Service of the DGPC, and is responsible for the organization of support logistics in emergencies as well as in the definition of the protocols and procedures of the various civil protection action units. She graduated in Geology at the UB.

Carmen Aguilera is Market Development Officer at the European GNSS Supervisory Authority. Her current role is to manage the portfolio of R&D projects, to accelerate the adoption of the European GNSS systems, and maximize economic benefits. She holds a master engineering degree on telecommunication sciences. Prior to joining the GSA, she worked as a technology and strategy consultant on high tech innovation in aerospace, transport and ICT industry.

ABSTRACT

This paper will introduce and describe the goals, concept and overall approach of the European CLOSE-SEARCH project. CLOSE-SEARCH stands for 'Accurate and safe EGNOS-SoL Navigation for UAV-based low-cost SAR operations' and is being conducted by a consortium of a research centre (Institute of Geomatics, IG), a private for non-profit technology centre (Asociación de la Industria Navarra, AIN), the Geodetic Engineering Laboratory (TOPO) of the Ecole Polytechnique Fédérale of Lausanne (EPFL), an aerospace engineering company (DEIMOS Engenharia, DME), a public research agency and geospatial data provider (Institute of Cartography of Catalonia, ICC) and an end user, the Direcció General de Protecció Civil (DGPC, the Catalan civil protection authority).

The goal of CLOSE-SEARCH is to integrate in a small Unmanned Aircraft (UA), a thermal imaging sensor and a multi-sensor BA/RINS/GPS-EGNOS-based navigation system with an Autonomous Integrity Monitoring (AIM) capability, to support the search component of Search-And-Rescue (SAR) operations in remote, difficult-to-access areas and/or in time critical situations. The proposed integration will result in a HW/SW prototype that will demonstrate an end-to-end functionality. For reasons of manoeuvrability the proposed UA will be a helicopter. In addition, it is also the goal of CLOSE-SEARCH to demonstrate the added value of a future multi-constellation augmented GNSS configuration, like Galileo/GPS-EGNOS or Galileo/GPS-SoL. Two key target attributes of the proposed concept are ultra-safe navigation and overall low-cost, so it can be safely and massively implemented. A simple piece of equipment available in ski resorts, tourist areas, mountaineering clubs and local civil protection premises is envisioned.

The context of CLOSE-SEARCH is that of SAR operations in a number of critical circumstances ranging from "outdoor sports" to natural or man-made disasters. This context covers a broad range -if not all- situations: from position-tagged -georeferenced- distress calls, to loosely-georeferenced and non-georeferenced ones. The proposed search system can be operated day and night in rather inaccessible areas. By systematically flying over a region and through the detection of the body heat, CLOSE-SEARCH is intended to identify disaster survivors or lost people. In other words, CLOSE-SEARCH would be a low-cost and robust system to support the SAR search component in situations of just approximate knowledge of the search geographic area. Under the proposed concept, upon a loosely-georeferenced distress call, an UA integrated in an Unmanned Aerial System (UAS), will be transported to the closest possible point to the emergency area and launched to systematically scan the area with a thermal sensor following a predefined 3D flying path derived from available 3D geospatial databases. The thermal images will be transferred to the UAS' Control Station (CS) via the UAS/datalink and analyzed in search of candidate locations for the persons under search. The proposed prototype requires the integration of EGNOS and [future] Galileo/GPS SoL services, 3D geospatial databases e.g. Digital Surface Model (DSM), INS/GNSS close-coupling algorithms, as well as UAS, communications and remote-sensing technologies.

The paper will identify some of the various technical challenges of the proposed approach, ranging from EGNOS-based UAV navigation&control to the interpretation of the thermal images for person identification, also through the system architecture, subsystem integration on the platform and the proposed flight tests. Finally, this paper will show some results obtained in the CLOSE-SEARCH project during the first test campaign performed on November, 25^{th}.

1 INTRODUCTION

1.1 Unmanned Aircrafts in Search and Rescue missions

The use of UAS/UAs for SAR operations is not new -the application is even mentioned in the English version of the Wikipedia. When a small plane crashes in a remote area, or a fishing boat is lost at sea, or a hurricane devastates a region, SAR teams must scramble every available resource to scan vast areas for evidence of victims or wreckage. For this purpose, UAs equipped with thermal sensors can be programmed to fly predefined search patterns at low altitudes (30 m to 150 m), transmitting real-time imagery back to a command post via data link. For example, UAS/UAs used in the Iraq and Afghanistan wars were deployed to find people trapped in New Orleans' buildings by Hurricane Katrina's flood waters. These UAs were equipped with thermal imaging systems to detect the body heat of storm survivors. Generally speaking, Wilderness Search and Rescue (WiSAR) entails searching over large regions in often rugged remote areas. Because of the large regions and potentially limited mobility of ground searchers, WiSAR is an ideal application where small or tactical UAS/UAs have been used to provide aerial imagery of the search region. Although less spread in Europe than in North America, it can be said, that the use of UAS/UAs for WiSAR is evolving rapidly.

Figure 1 shows a action flow diagram on a SAR chain in which the CLOSE-SEARCH system would be framed. Given a situation where a person is lost, this use case starts in (1), where an emergency call is received by the Alarm Coordination Center (ACC). The minimum input information that should be provided in that call is a loosely georeferenced area, called *incident zone*, in which a search operation must be performed. In (2), the ACC contacts the CLOSE-SEARCH operator as well as the rescue team in order to provide the incident zone specification. Then, the CLOSE-SEARCH operator initiates the mission (3), by reaching the incident zone as close as possible, planning the flight and executing it. When the person is found (4), the CLOSE-SEARCH system sends the corresponding data to the CLOSE-SEARCH operator and the latter returns the communication back to the ACC (6) to provide the so-called *rescue area*, a 10 x 10 meter region

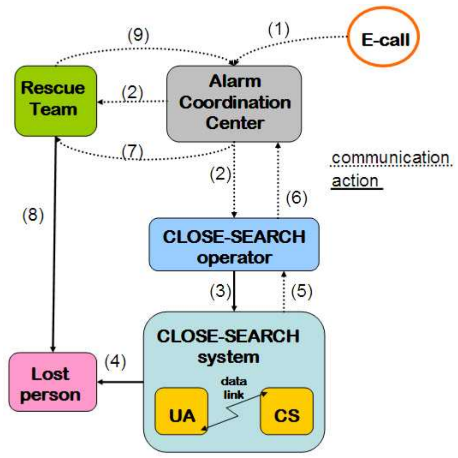

Figure 1: CLOSE-SEARCH within a SAR chain action flow

on ground. With this information, the ACC can contact the rescue team (7) to proceed with the person rescue (8). Once the whole operation is closed, a final closing message is sent to the ACC (9).

1.2 Key application enablers and the CLOSE-SEARCH state-of-the-art contributions

As discussed, the use of UAS in SAR applications may still seem very restricted to major, seldom catastrophes. However, in order to spread this application closer to the mass-market level, where local civil protection authorities, small companies, sport clubs, etc. may benefit from it, the operation -i.e., navigation- of the UAs shall be safe. For this to happen, three main conditions shall be met:

1- the predefined search path shall be followed within given accuracy and integrity levels,

2- considering the relative low flying altitude, accurate and up-to-date geospatial databases (mainly for DSM information) shall be available and integrated with the UAS, and

3- a collision avoidance system shall be in place; the so-called Sense-and-Avoid (SAA) systems.

Regarding the identified key application enablers, CLOSE-SEARCH will advance the state-of-the-art on the above points 1 and 2.

With respect to item 1, CLOSE-SEARCH will demonstrate safe navigation with aided GPS-EGNOS and the relevance of the future Galileo and modernized GPS SoL services. Moreover, CLOSE-SEARCH will proof EGNOS-enabled INS/GNSS integration valid for UAV platform types. By combining the former concept -i.e., EGNOS-enabled INS/GNSS integrated navigation- with the use of low-cost redundant IMU configurations, baro-altimeters and magnetometers. We believe that this highly redundant configuration provides the level of precision, accuracy, and reliability for the navigation of an UAS/UA.

CLOSE-SEARCH takes a new approach to UA safe navigation. The standard line of thought is that low cost GPS/INS is not fit for the purpose of autonomous UA navigation and that, consequently, some sort of Simultaneous Localization and Mapping (SLAM) setup and algorithm are needed. SLAM relies on image matching and camera orientation techniques. However, in the context of WiSAR, the SLAM approach underestimates the possibilities of BA/RINS/GNSS and its own limitations (low texture images, operations in the darkness, operations at sea, repetitive patterns in images, etc.). In the context of civil WiSAR, that GPS and Galileo are denied is far less likely to happen than in military scenarios. On the other hand, search operations at night or at sea are frequent. In CLOSE-SEARCH, a highly redundant and reliable autonomous navigation capacity will be implemented.

To the best knowledge of the authors, INS/GNSS closely-, tightly- and deeply-integrated navigation has neither been thoroughly investigated nor applied together with EGNOS in UAV platforms, and thus the BA/RINS/GPS-EGNOS integration concept is proposed here for the first time.

Further to this, and with respect to the item 2, CLOSE-SEARCH will demonstrate how 3D geospatial information -not only Digital Elevation Models (DEMs) but also and mainly DSMs- can and must be used in combination with navigation systems. The temporal and funding limitations of the project notwithstanding, the proposed concept will demonstrate how 3D landscape models can be used to improve the search operations (identifying occlusions and other limitations of aerial imagery) and, together with AIM navigation avoid collision with the terrain or other objects. CLOSE-SEARCH may generate useful feedback to geospatial data producers on the required level of detail (electrical power lines, communication towers, etc.) of their data bases.

Last but not least, we note that condition 3 shall not be interpreted as a barrier to the practical application of the proposed concept. Certainly, as mentioned earlier, the still unregulated integration of UAS/UAs into the civil regulated airspace is a major commercial market barrier to many applications of the UAS technology. However, the CLOSE-SEARCH application will not suffer from this as, in the circumstances of WiSAR, the use of the technology is rather sought than restricted and the proposed flying altitude is low.

1.3 EGNOS added value over existing solutions and integration approach

In CLOSE-SEARCH, like in many WiSAR operations, an UAs equipped with a thermal sensor -and possibly others- will be programmed to fly a predefined search pattern at low altitude (30 m to 150 m), transmitting real-time imagery back to the command post. As mentioned above, among other conditions, the predefined search path shall be followed within given accuracy and integrity levels. Typically, so far, in GPS [and GNSS] navigation, accuracy is achieved with differential techniques; i.e., on the basis of measurements collected at well surveyed ground stations.

The method can be more or less sophisticated, ranging from just one *user established* single station and simple error modelling -i.e., Differential GPS (DGPS)- to a *multi-user* regional/global network of stations and advanced error modelling including orbit and clock errors. EGNOS belongs to the last class.

On the other side, similarly, a network of well surveyed ground stations constitutes the basis of integrity, as the incoming GNSS signals are continuously processed and their derived measurements compared against computed reference values.

From an accuracy standpoint, EGNOS based navigation has advantages over the existing, commonly used solutions like:

- non-differential GNSS,
- private and publicly available DGPS and DGNSS, and
- user established RTK setups.

Indeed, it would just too risky to fly predefined search patterns at low altitude (30 m to 150 m) with non-differential techniques. For WiSAR, we need a differential regional/global continuous service which is not always provided by local DGPS or DGNSS infrastructure. RTK solutions would be, for CLOSE-SEARCH, a waste of precision that, on the other side, require some time to be established and depend on local communication links. Clearly, a regional/global continuous DGNSS service is the ideal solution for an application like CLOSE-SEARCH that has to respond to emergency situations with a *go-and-fly* action, anywhere and anytime. From an integrity monitoring standpoint, most local DGNSS and RTK solutions do not provide integrity functions and, therefore, are not amenable for CLOSE-SEARCH.

With respect to the integration approach, the navigation solution of CLOSE-SEARCH will be computed in a Kalman filter navigation loop where the IMUs will play the role of primary navigation sensors whose drifts will be removed by EGNOS-GNSS update measurements in a close-coupling INS/GNSS integration scheme. In other words, the INS mechanization differential equations will be numerically integrated and the result updated in the Kalman filter with the EGNOS-healthy (integrity functionality) and EGNOS-corrected (accuracy functionality) pseudoranges. We note, that the CLOSE-SEARCH highly redundant navigation sensor configuration allows for a navigation Autonomous Integrity Monitoring (AIM) function; that is, not just redundant pseudorange measurements are used like in standard Receiver Autonomous Integrity Monitoring (RAIM) techniques, but *every sensor* measurement is used in the least-squares component (or Kalman filter) enabling an enhanced RAIM version by which faults can be detected at *every sensor*. Finally, classical system availability (computation of Protection Levels and checking against Alert Levels) will be performed and, in an advanced phase of the project, extended to the full *time-position-velocity-attitude* (tPVA) domain.

2 THE CLOSE-SEARCH SYSTEM

2.1 State of the technology in the CLOSE-SEARCH consortium and evolution during the project

The main components of the CLOSE-SEARCH system are the Navigation System (NS) of the Institute of Geomatics, the UAS (including the UA, the CS and the data link) of AIN, the thermal camera of AIN, the GNSS receiver simulator of DME, the redundant IMU (RIMU) system of EPFL and the 3D countrywide LiDAR-based DSM of the ICC.

The Institute of Geomatics NS is a real-time tPVA server. For the acquisition component, several sensors are integrated (JAVAD TR-G3T GNSS receiver with GPS L1, L2, L2C, L5, Galileo E1, E5A, GLONASS L1, L2, WAAS and EGNOS capability, a Leica magnetometer, a Honeywell Barometric Altimeter (BA), Northrop-Grumann LN-200 IMU) and for the processing component, the IG's NAVEGA real-time generic Kalman filter is used.

AIN counts with three UAS/UA of the helicopter type, among which the UAR35 (Maximum Take-Off Weight (MTOW) is 75kg) is its contribution to CLOSE-SEARCH. The UAS/CS is an in-house development of AIN. The thermal camera (Raytheon 2000B) is sensitive in the 8-12 μ m spectral range and is equipped with two lenses (25 mm f/1.0 and 100 mm f/1.0).

DME contributes to CLOSE-SEARCH with the GRANADA GNSS receiver simulator in two versions: the GRANADA FCM Blockset (fast simulator) and the GRANADA Bit-True Simulator.

The RIMU system of EPFL consists of four Xsens low-cost IMUs (three IMUs of the type MTx-i and one of the MTi-g type) and their acquisition SW.

2.2 Architectural overview of the whole system

Figure 2 shows the CLOSE-SEARCH system architecture, described twofold: the *air* and the *ground* segments.

On the *air* segment, the UA is depicted including the EGNOS-based navigation system (IG's mTAG) and RTK-based navigation system (AIN's actual system, back-up in CLOSE-SEARCH). These two subsystems provide a navigation solution to the Flight Control System (FCS), which is in charge to perform the platform control and interact with the communication unit on-board. Another important piece on board is the Imaging Subsystem (IS), composed by the thermal camera, video encoders and Personal Video Recorder (PVR) to eventually store images on-board. An optional optical camera is also envisioned.

On the *ground* segment, three main pieces are implemented: the *Commander* is an AIN's SW development to perform the command-and-control of the UA (monitoring the mission, managing the route,...); the *Mission Plan* is a genuine CLOSE-SEARCH work based on a GIS-platform to design the mission in terms of flying path, scanning patterns, image overlaps...; and finally, the *Search Manager* is a SW tool to interact with the IS outcome. It is very important that the user can visualize and [eventually] pin-point any object in the image to geo-reference it and input it to the mission information as a *target candidate*.

3 FIRST TEST CAMPAIGN

Due to its iterative-incremental character nature, there are two defined test phases at the middle and end of the project. The first test campaign (scheduled for the second half of November, 2010) was devoted to test the mechanical, electrical and SW interfaces of the system and to demonstrate preliminary end-to-end capabilities. It is intended that, for the second test campaign (to be collocated in 2011, probably on September), a mature CLOSE-SEARCH prototype is presented fulfilling the user requirements and demonstrating advanced end-to-end functionalities.

The first test campaign included laboratory and pre-field tests on controlled scenarios to verify and validate those system components needing a higher level of validation within the project. The fact that previous R&D work has been brought together in the project inherently brings along different levels of maturity. Fro example, the AIN's UAS/UA and UAS/CS have been widely used in several projects and thus require few test items. Finally, the first test campaign concluded on the so-called field test. The chosen scenario for those field test was the town of Copons, Catalunya (figure 3). This location was suitable for many reasons: it is an easy accessible area but far away from big urban areas, local permissions were obtained, and the area presented different land features (smooth and rough terrain, vegetation...)

3.1 Description of the test flights

On November, 25^{th} 2010 three flight tests were executed by the UA to test different features. On the first flight, different height and speed profiles were proposed (see figure 6) and an active thermal target was used. The intention of this test was to assess the optimal height and speed UA profiles in relation to the thermal target perception; that is,

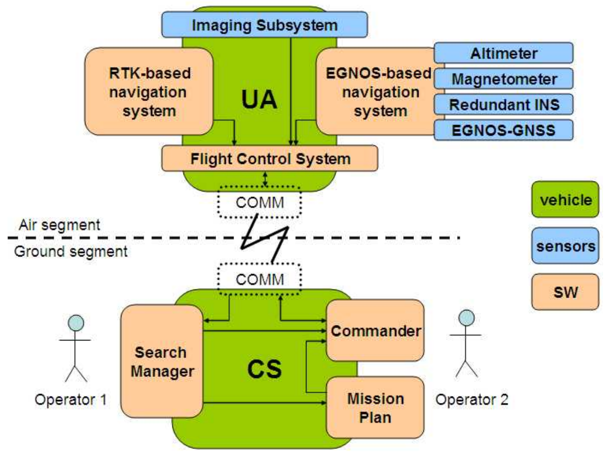

Figure 2: Architectural overview of the system

Figure 3: Unmanned Aircraft and Control Station on November, 25^{th} -the first CLOSE-SEARCH test campaign

how high and fast should we fly in order to ensure recognition of targets in ground. In order to simplify target recognition, a well-surveyed target was used (see Figure 7): a 2 m^2 metal and polystyrene chess-type layer. Underneath the layer, a thermal blanket was used in order to create intense thermal emission and enable a clear target recognition.

On the second and third flights, a strip-based scanning pattern was proposed at constant 4 m/s horizontal speed but different height profiles: 50 meters and 30 meters respectively. On both tests, several active/passive thermal targets of different nature were used (2 m^2 metal and polystyrene layers, different persons...) and spread over a 100 m^2 area. Each target location was previously surveyed with precision GPS for a posteriori validation matters. The aim of these tests was to demonstrate end-to-end capabilities in search missions: on the air segment, to demonstrate the capacity of flying and thermally scanning a given area, and at the ground segment, to control the mission both for the UA performance and for the thermal vision subsystems. Several attendees to the test were able to tell when a body was displayed on the image.

For all flights, the 3D geospatial information extracted from LiDAR-based DSMs provided by ICC was used for planning the missions *a priori* (that is, not on site). UA waypoints and actions were derived from the three flight specifications.

3.2 Results

In general terms, the three tests were successfully executed -just few events happened along the test execution (problems on the GNSS acquisition during the second flight, poor target reflectance due to the used materials...) Therefore the main objective of this test, which was to proof the mechanical, electrical and SW interfaces of the system and to demonstrate preliminary end-to-end capabilities, was achieved. This supposes the achievement of a major project milestone: the *the built of the prototype* and *the use of 3D spatial databases* as fundamental goals of the project.

With respect to the navigational aspect, the NS acquired data from the BA, magnetometer, LN200 IMU (RINS system was not integrated at the time of the tests) and EGNOS-GNSS sensors, providing a loosely-coupled magnetometer/INS/GPS (GPS stand-alone, EGNOS capability were switched off) real-time solution. This solution was degraded by the several satellite in-and-out's (provoked by the antenna placement) which is well-known to have a severe impact on loosely-coupled schemes. Nonetheless, data can be reprocessed in a closely-coupled, EGNOS-enabled BA/magnetometer/INS/GPS scheme, with the expectancy of improving the navigation results. On the second test campaign, a full-fledged navigation approach will be brought to the system, aiming to be suitable for UA control. The AIM approach is also envisioned for the seconds test campaign. Finally, no target georeferencing has been done so far, and will be done once the closely-coupled scheme is used.

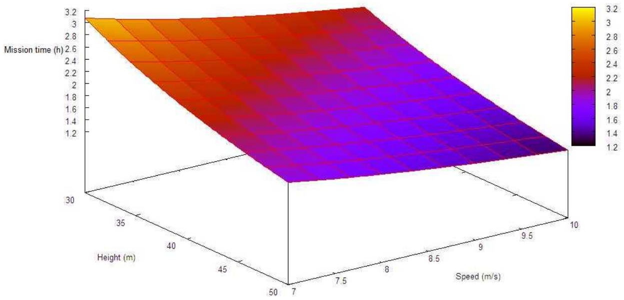

Figure 4: Relation between flying height, flying speed and mission performance in CLOSE-SEARCH

With respect to the imaging results, the three tests showed a good performance of the subsystem. On the first test, the theoretical Ground Sampling Distance (GSD) provided by the sensor was validated and no major image deformations were observed -thus no geometric or thermal calibration is needed (figures 8, 9 and 10). When analyzing the target recognition at different speed profiles, it can be seen that a fading effect is observed at all speeds ranging from 4 to 8 meters per second.

Finally, on the second and third flight, the person recognition was feasible at both flying heights. When comparing a given target on images taken at different heights (figure 11 vs figure 14, figure 12 vs figure 15 and figure 13 vs figure 16) it is clear that at a lower altitude a better recognition can be done, which is quite an obvious statement.

From both flights, a conclusion arises: on one hand, the lower altitude and the lower speed we fly, the better recognition can be done. But on the other hand, low height and speed mission profiles require more mission time as less area is scanned per time unit. Thus, the relation between flying height, flying speed and mission performance needs to be established. This relation, depicted as a 3D surface, can be seen in figure 4 for an area of 1 km^2. As a CLOSE-SEARCH objective is to scan a 1 km^2 in a single flight and the UA platform endurance is of 90 minutes, high height and speed values need to be achieved.

4 ACKNOWLEDGMENTS

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REFERENCES

[1] Colomina,I., Gimnez,M., Rosales,J.J., Wis,M., 2004. On the use of redundant inertial data for geodetic applications. ION GNSS 2004, 2004-09-21-24, Long Beach, CA.

[2] Colomina,I., Aigner,E., Agea,A., Pereira,M., Vitoria,T., Jarauta,R., Pascual,J., Ventura,J., Sastre,J., Brechbhler de Pinho,G., Derani,A., Hasegawa,J., 2007. The uVISION project for helicopter-UAV photogrammetry and remote-sensing. VII International Geomatic Week, 2007.2.20-23, Barcelona.

[3] Colomina,I., Blzquez,M., Molina,P., Pars, M.E., Wis,M., 2008. Towards a new paradigm for high-resolution low-cost photogrammetry and remote sensing. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, Beijing, China.

[4] Rudol,P., Doherty,P., 2008. Human Body Detection and Geolocalization for UAV Search and Rescue Missions Using Color and Thermal Imagery. Aerospace Conference, 2008 IEEE, 1-8 March, Big Sky, Montana.

[5] Molina,P., Wis,M., Pars,M.E., Blzquez,M., Tatjer,J.C., Colomina,I., 2008. New approaches to IMU modelling and INS/GPS integration for UAV-based Earth-observation. ION GNSS 2008, 2008-09-16-19, Savannah, GA.

[6] Silva,P.F., Silva,J.S., Caramagno,A., Wis,M., Pars,E., Colomina,I., Fernndez,A., Dez,J., Gabaglio,V., 2007. Inertial-aided GNSS receiver. Inside GNSS, Vol. 2, No. 2, march-april 2007, pp. 58-63.

[7] Skaloud,J., 2007. Reliability of Direct Georeferencing - Beyond the Achilles' Heel of Modern Airborne Mapping. 51st Photogrammetric Week, Stuttgart.

[8] Waegli,A., Skaloud,J., Guerrie, S., Pars, M.E., Colomina, I., 2010. Noise reduction and estimation in multiple micro-elecrto-mechanical inertial systems. Measurement Science and Technology, vol. 21, 2010, p. 065201 (11 p.)

5 ANEX I: PICTURES, PLOTS AND THERMAL IMAGES

Figure 5: AIN's UAR35, the Unmanned Aerial Vehicle (UAV) used in CLOSE-SEARCH

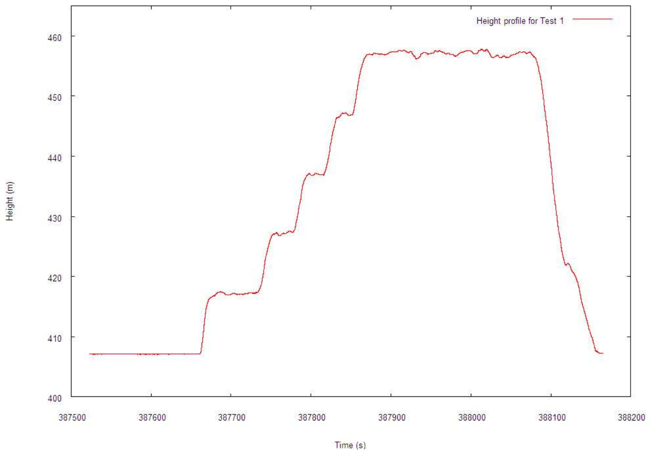

Figure 6: Height profile for test 1 during the Test Campaign for CLOSE-SEARCH

Figure 7: The thermal passive target used during the Test Campaign in CLOSE-SEARCH

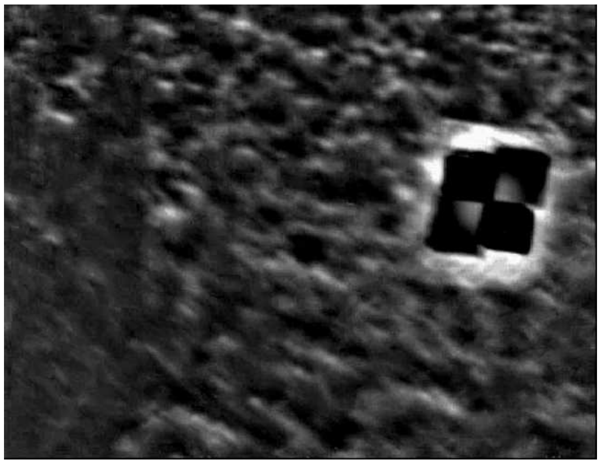

Figure 8: Thermal image of the passive target at 10 meters height

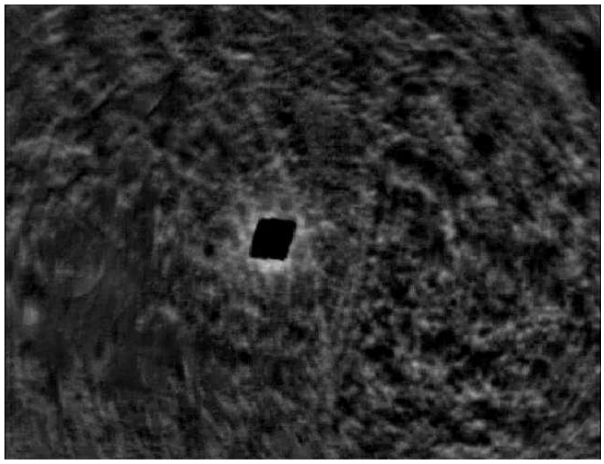

Figure 9: Thermal image of the passive target at 30 meters height

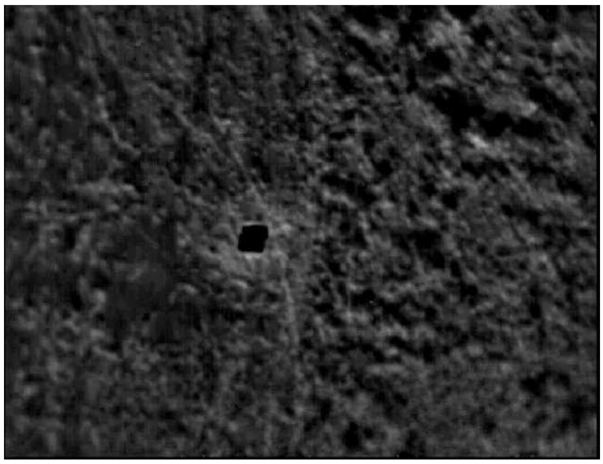

Figure 10: Thermal image of the passive target at 50 meters height

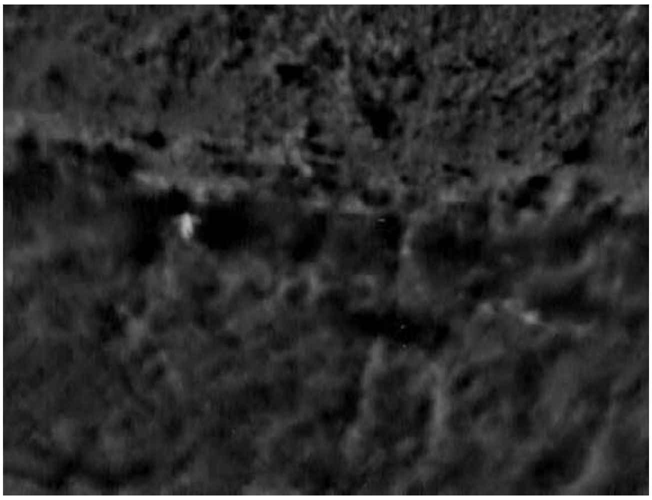

Figure 11: Thermal image of Target Person 1 at 50 meters height

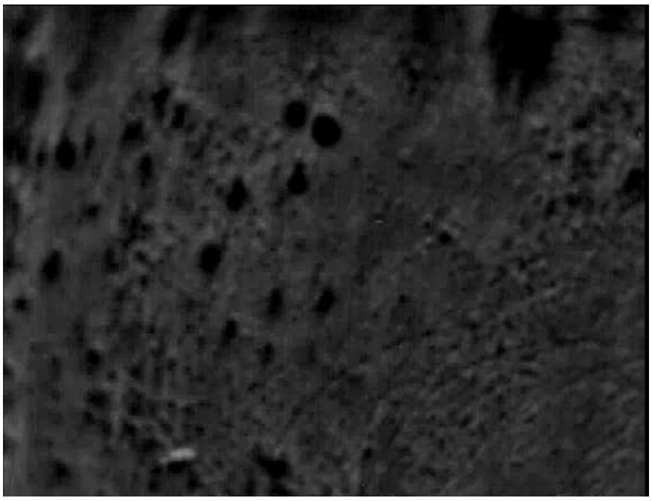

Figure 12: Thermal image of Target Person 2 at 50 meters height

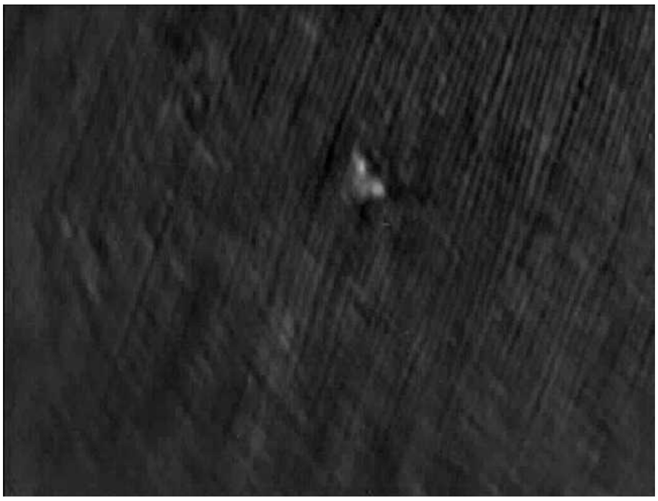

Figure 13: Thermal image of Target Person 3 at 50 meters height

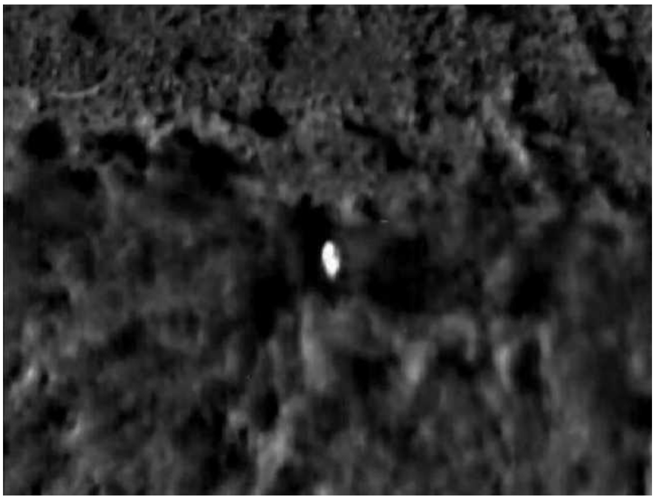

Figure 14: Thermal image of Target Person 1 at 30 meters height

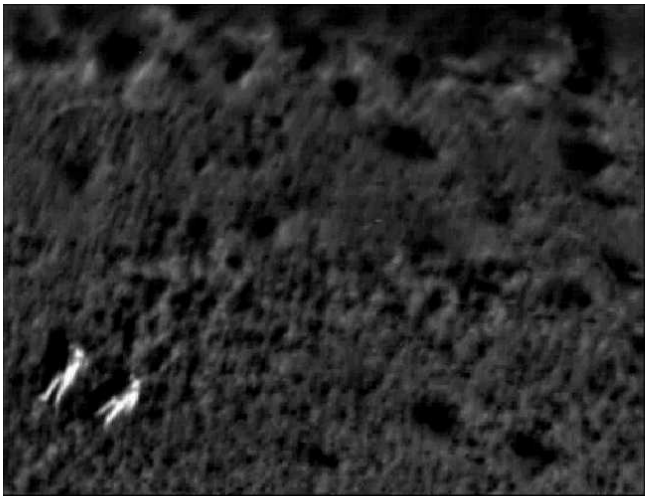

Figure 15: Thermal image of Target Person 2 at 30 meters height

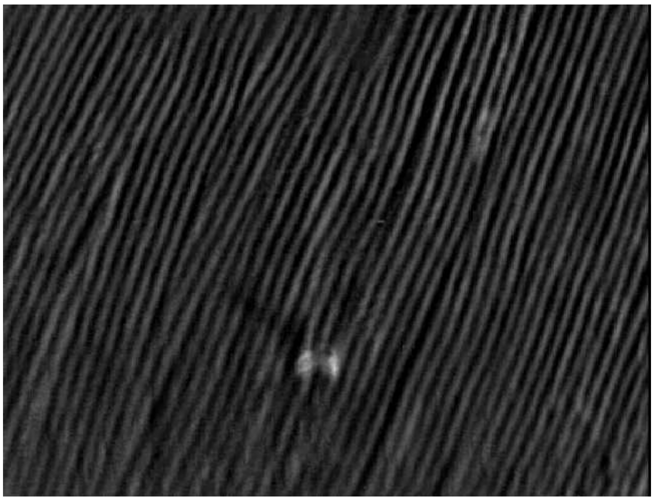

Figure 16: Thermal image of Target Person 3 at 30 meters height