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A "LOW-TECH" APPROACH AS A STRATEGY FOR EFFECTIVE UAV SURVEYING OF LANDSCAPE AND CULTURAL HERITAGE. EXPERIENCES FROM THE LAB AND THE FIELD

From 2010 to 2015, the Geographic Research and Application Laboratory (GREAL) of the European University of Rome (UER) conducted tests to verify the applicability of low-tech/low-cost and open source micro/mini-drones to several fields in geographic research. The project included general landscape surveys and environmental, archaeological and cultural heritage prospections. The work was not primarily focused on UAV technologies *per se*; rather, it was aimed at achieving a better understanding of the potential of low-tech micro/mini-UAVs in order to improve a geographer's ability to acquire data. The research was shared by two other scientific partners: ITABC, a department of the Italian National Research Council (CNR) and the LT-TEKNEHUB centre of the University of Ferrara.

Although technical definitions may vary from one context to another, micro/mini-drones are unmanned aerial vehicles with a maximum take-off weight in the order of 25 kgs[1]. The flight of these devices is managed by a ground-based remote control station; this led to the origin of different names for the technology, depending on the conceptual emphasis on inherent features or operational criteria: "Remotely Piloted Aerial Sys-

[1] On July 16th, 2015, the Italian Civil Aviation Authority (*Ente Nazionale Aviazione Civile*, or ENAC) issued the 2nd edition of its regulation for Remotely Piloted Systems (*Regolamento Mezzi Aerei a Pilotaggio Remoto*). It defines a mass-based classification for drones: up to 0.3 kg; between 0.3 and 2 kg; over 2 kg and below 25 kg; between 25 kg and 150 kg. Technical and operational requirements, for both the pilot and the drone are incrementally defined for each class. Drones exceeding 150 kg mass are regulated by ICAO. Due to its specific regulatory classification, Italian drone users are increasingly using the term "micro-drone" in reference to the 0.3 kg category only; the term "mini-drone" should then be used to address the second higher category. This work only refers to the two lightest categories since they include most of the typical consumer-level drones used in geographic applications. As other countries in the world are developing their own regulations, mass categorization might differ in those contexts.

tems" (RPAS), "Unmanned Aerial Systems" (UAS) etc... The general concept includes several possible architectures, from blimps to small aeroplanes, to hybrid flying platforms, to helicopters and multirotors. The use of multirotors, in particular, is becoming widespread[2]. Reasons for the success of this type of machine include stability, manoeuvrability and reliability. Commonly available multirotors are generally built as symmetrical frames, with engines mounted at the vertices of a regular geometrical shape – a square, a hexagon, an octagon etc. Typical multirotors are therefore quad-copters, hexacopters (Fig. 1), octocopters etc...[3]. In most cases, micro-UAVs are fitted with cameras or other sensors for recording aerial views or collecting other data.

2 For an overview of several solutions and applications, see: Theodoridou, Tokmakidis, Scarlatos 2000; Eisenbeiss 2008; Goodrich et al., 2008; Grenzdörffer, Engel, Teichert 2008; Chiabrando et al. 2010; Chiabrando et al. 2011; Niethammer et al. 2011; Rinaudo et al. 2012; Scholtz et al. 2011; Wendel, Irschara, Bischof 2011; Caldarelli, Ceccaroni 2013. Thamm 2011 describes an interesting "paratrike" UAV. It demonstrates a kind of flyer of some complexity but featuring interesting advantages in geographic survey.

3 Generally, commercial multirotors have electric engines, powered by so-called "Lithium Polymer" ("LiPo") batteries. Unlike traditional helicopters, multirotors have fixed-pitch propellers. Stability and control are then achieved by accurately regulating the instant speed of each motor, according to specific algorithms. Motor management is performed by an onboard flight control system. This can be basic and manage only stability and remote control inputs; or it can be more sophisticated, to the point of being able to automatically navigate the aircraft. Depending on the specific implementation, automatic fight can be more or less complex. In most cases, the system is able to perform a set of standard manoeuvres such as altitude-hold, hovering, return to base and navigation through a series of GPS points. Auto take-off and landing are also frequently available.

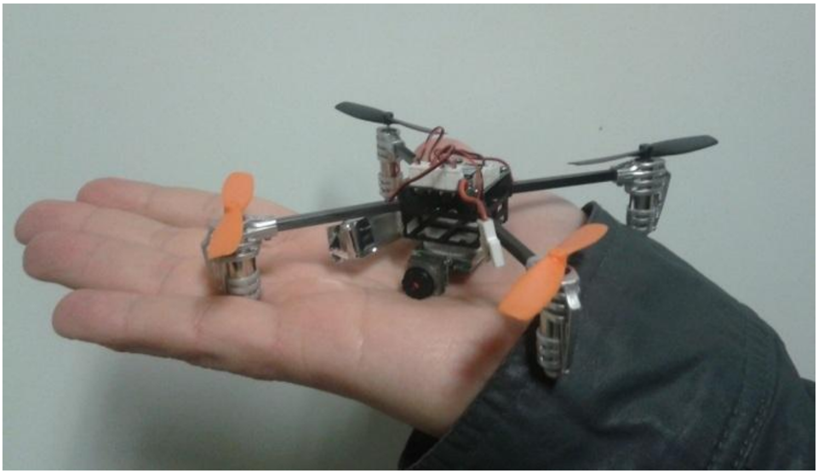
Fig. 1 – *GAUI 330XS first-generation quad in a shot taken at* UER *in 2011. This device needs constant action by a remote pilot but its light weight, good performance and reliability suggested we use it in several "real-life" applications.*

Source: GREAL

Fig. 2 - *A custom-assembled DJI F550 hexa-copter. This model, like most others in the same class, is able to autonomously hold its position in flight, return to base and land. It can also be upgraded to follow a pre-programmed flight path*

Source: GREAL

Fig. 3 – A *"dwarf". A modified Walkera Ladybird is a 70 gram quad-copter featuring a 640 x 480 live broadcasting video-camera. This minimal micro-drone can be used for indoor and outdoor inspections and its analog TV signal can be picked up by recording systems on the ground up to a distance of 20-30 metres*



Source: GREAL

Fig. 4 – *A "giant". The SKYJIB 8A is a professional custom mini-drone assembled by Hely-GO. It features 8 engines, fully retractable landing gear and gyro-stabilized camera gimbal. Drones of such large size are generally built on demand by specialized workshops*

Source: Hely-GO

Images or data can often be downlinked to receivers on the ground for display or processing. The effectiveness and potential of this type of tool in several applications, whether related to general geography, environment, land-use monitoring, civil protection or public safety, are evident. Compared with traditional scientific survey methods, the use of micro-drones can provide a significant amount of information in a very short time. Furthermore, these devices could theoretically be operated with minimal logistic overheads and by non-specialized users.

In high-profile applications, such as sophisticated photogrammetry or multispectral remote sensing, correspondingly high-level technology is obviously required. Our experience, however, suggests that for most general applications low-tech equipment is sufficient to provide researchers with good working data. Low-tech allows for inexpensive data acquisition. Open source or low-cost solutions would do just as well in supporting the processing, analysis and publication of data.

Open source is obviously not merely a set of software and hardware tools: rather, it is a workflow concept. It means opening access to more or less advanced tools, so that more operators can participate in their use and development. Merging low-cost technology with "open" systems can foster "distributed" development of integrated solutions. This will exponentially increase application potentials by "putting more brains" to work. Typical "target customers" of this formula are small-budget scientific teams whose excellence is somewhat hampered by the difficulty of acquiring access to technological opportunities. As regards geography in particular, when technologies become more affordable and even *expendable*, it becomes possible to extend their use for investigation and other processes to "minor" contexts. As far as cultural heritage and historical sites are concerned, it is worth noting that the bulk of cultural heritage buildings in Europe, for example, is certainly made up of "minor" landmarks and monuments. For many of them, commonly available research budgets do not allow much more than a quick status survey, let alone in-depth studies and recovery programs. The development and safe use of low-cost survey technologies allow us to hope that some significant knowledge concerning these fragments of our history may be acquired before they are lost.

This paper summarizes the results obtained by the authors during a five-year test of the concept in real-life applications. The research included surveys of minor and partially neglected monuments, the identification of undocumented archaeological sites, and surveys of the damage caused to historical buildings by earthquakes.

Testing on a worst-case scenario: the origin of the research. – In order to verify the above concept, the authors considered the problem of assessing the actual survey capabilities of a "worst-case" micro/mini-UAV system. The specifications were that it be:

-Mobile.

-Lightweight.

-Easily portable.

-Easily manageable.

-Operable by general, non highly-specialized users.

-Scientifically and technically adequate for the investigation, monitoring and protection of cultural heritage.

-Specifically suitable for deployment and data acquisition on "minor" landmarks and sites.

The above features can be practically implemented by adopting the following three criteria:

1. Immediate availability.

This criterion involves:

a. using general market products.
b. using open source hardware and software.
c. avoiding restricted proprietary solutions.
d. keeping systems design as simple as possible.

2. Portability.

This criterion involves:

a. using as much as possible *de facto* standard solutions.
b. preferring widespread commonly used formats for data and information.

3. Extensibility

This criterion involves:

a. designing configurations with modularity in mind.
b. keeping systems and operational profiles (if possible) open to change.

As stated earlier, a successful merging of "low-cost" with "open-source" means that more workgroups can access the technology and therefore it is possible to acquire more knowledge. This greater operational efficiency is obviously fostered by the fact that cheaper systems are more easily expendable if necessary. For instance, micro/mini-drones, regardless of their sophistication, are machines sensitive to weather and context. Their use may sometimes prove a risk to their very survival, yet it may be appropriate to take that risk for the sake of knowledge, once safety of people and properties is ensured. On the other hand, a "precious" device, too expensive to be replaced in case of loss, would simply be "grounded", and the survey would be cancelled or postponed. Research workgroups may have difficulty in rapidly reaching the survey site, or the site itself may not be easily accessible. A possible consequence, therefore, can be that an excessively timid approach to operating a costly UAV would hamper the research instead of supporting it.

For these reasons, our work focused on testing towards the cheapest and most lightweight solutions available.

Fig. 5 – *In field operations, pilots can take care of many procedures on their own.*

Source: GREAL.

Fig. 6 – *When flying the device in operational contexts, the pilot should be assisted by one or more observers*

Source: GREAL

In the initial phase of the research, the system tested by GREAL included a low-tech commercial GAUI 330XS quad-copter[4], fitted with a 2 axis pan/tilt camera mount. The remote control was operated by a standard type Aurora 9 2.4 GHz, 9 channel transmitter. Typically flown cameras were a 640x480 FlyCamOne FCO III and a Hewlett Packard HP 540. Both of them were generally used to take videoclips. Occasional tests were also conducted with alternative devices such as the FlyCamOne 720p or a SAMSUNG S10 videocamera for oblique aerial views. On one occasion, a heavier mirrorless Canon PowerShot G-15 camera was also flown to take photogrammetric shots; although the test revealed the excellent quality of the images taken, the drone was found to be overweight and therefore its operation was considered to be dangerous. Consequently, this solution was abandoned. During this phase of the research, the aim was to test the capabilities of simple systems in geographic survey. In theory, the overall UAV system (quad-copter + cam-

[4] An interesting application scenario for this very type of quadcopter in landscape archaeology is described in Degrassi et al. 2012.

eras + remote control + equipment) would not exceed a total budget of 1,200 Euros (in 2012) and could be technically operated by a pilot with modest training experience (about 50 hrs with the type). In our case, a typical field operation was conducted by a crew of two – a pilot[5] and a "spotter"[6]. Operations were performed in daylight, maintaining the visual line of sight between the pilot and the UAV, which was generally kept below a height of 200 ft (60 m). There was no need of a separate system operator since images and procedures could be handled by the pilot alone or later in the lab. No FPV[7] piloting took place. When a live-downlink camera was used (FCO III and FCO 720p) the signal was displayed on a receiver on the ground. However, the receiver was only used by the spotter, or some other qualified person, to monitor the progress of each survey.

Testing the system in its general geographic and environmental application is discussed in Casagrande, Salvatori 2011, pp. 9-24.

Aerial-view survey of archaeological sites. A test at the catacombe di Callisto complex (Rome). – In order to verify the system's capabilities with regard to archaeological survey, a significant site was selected in Rome in early 2011. It is located between the Via Ardeatina and the Via Appia Antica, at about the "*Terzo Miglio*" (3rd Roman mile from the Aurelian Wall, outbound). The area was not particularly large (180 m by 85 m) and it had been partially investigated through excavations in the early 1930s. Those excavations had made it possible to prepare planimetric documentation of the site.

Archaeological data and maps were available for the south-eastern margin of the area. Therefore images taken from the UAV could be compared with documented evidence (Reekmans, 1964). It was possible to recognize in the sector a large circular trace on the ground, associated

[5] Although it was not a legal requirement at the time of the research (2011-2012), the pilot had an Italian "Attestato VDS" (microlight aircraft pilot license) and over 50 hrs of previous training with the GAUI 330XS in the described configurations. As of 2015, Italian ENAC regulations involving drones prescribe detailed official qualifications for the crew, as well as formal validation and identification for each drone operated in professional applications.

[6] The "spotter" is an observer whose role is to keep a careful watch over the flight area and surrounding airspace to ensure the safety of third parties.

[7] FPV (First person view) is a technique which allows a pilot to fly a UAV by simply observing its aerial view as transmitted live to an appropriate device (goggles, computer screen etc.).

with a large tumulus-mausoleum dating back to the time of the Roman Republic. When flights were made (in February-March 2011 and in February 2012) only a few marks could be related to the aforementioned excavations. On the other hand, it was possible to recognize numerous other traces which could be related to undocumented remains. Some of the marks suggested the presence of at least three quadrangular structures, very similar to those documented by Josi (Josi 1935) but not coincident with any of them. They were located a few metres south of a pit (Fig. 7 P1) dug in the Modern Age in order to allow access to the Hypogee III tunnels of the archaeological complex (Fig. 7 A1). Additional marks, probably related to a much larger structure (10 m by 13 m approximately) can be seen in the central sector of the survey area, close to the Via Appia (Fig. 7 A2). The images acquired by the UAV show a quadrangular structure with an apse at the northern end. Its shape, its fairly large dimensions and its location suggest it was a funerary building, probably from a chronological phase different from that of the previously documented mausolea. Particularly interesting are some images taken of the north-western sector of the area, which was never previously mentioned in the literature. In that sector, surveyed by nadiral and oblique views both in the 2011 and 2012 flights, it is possible to recognize consistently reappearing marks which probably relate to undocumented archaeological elements. It can be hypothesized that the marks belong to a single, very large structural complex. This seems to be indicated by evident NE/SW and NW/SE alignments (Fig. 9).

The presented findings suggest the considerable potential of applying micro-UAVs to this kind of survey. It is worth noting, however, that the applicability of the technology goes beyond preliminary investigations. It is also possible to use UAVs for data acquisition and documentation during excavations, for photogrammetric and 3-D rendering of both the individual monument and its immediate surroundings.

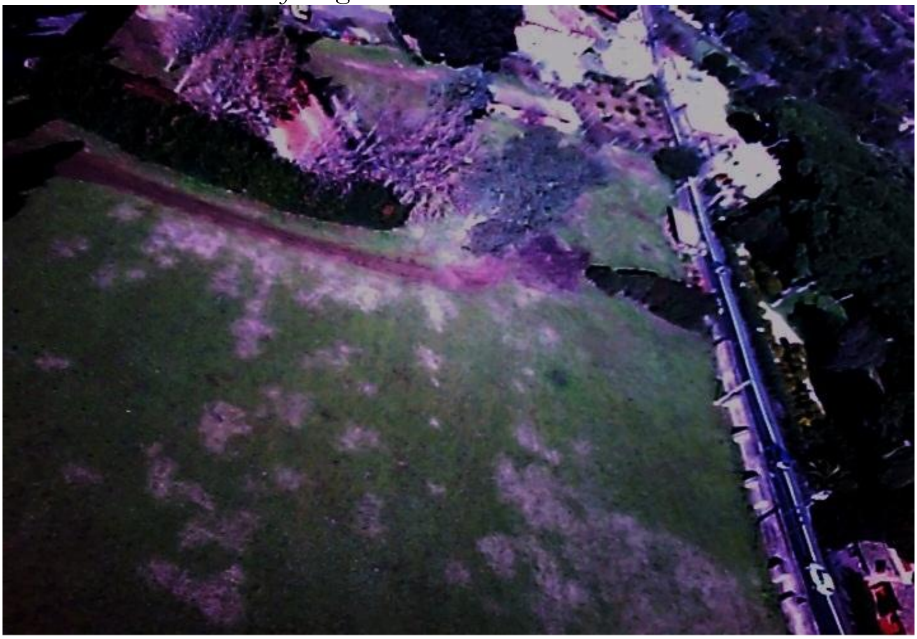
Fig. 7 – *Marks on the grass in the survey test area at Catacombe di Callisto complex, Via Appia Antica, Rome*

Source: GREAL

Fig. 8 – *Marks on the grass in the survey test area at Catacombe di Callisto complex, Via Appia Antica, Rome*

Source: GREAL

Fig. 9 – *Evident marks on the northwestern side of the survey test area at the complex, as they appeared during the February 2011 UAV survey. The traces disappeared a few weeks later and reappeared, identical in shape, in February 2012, due to the seasonal conditions of the grass*



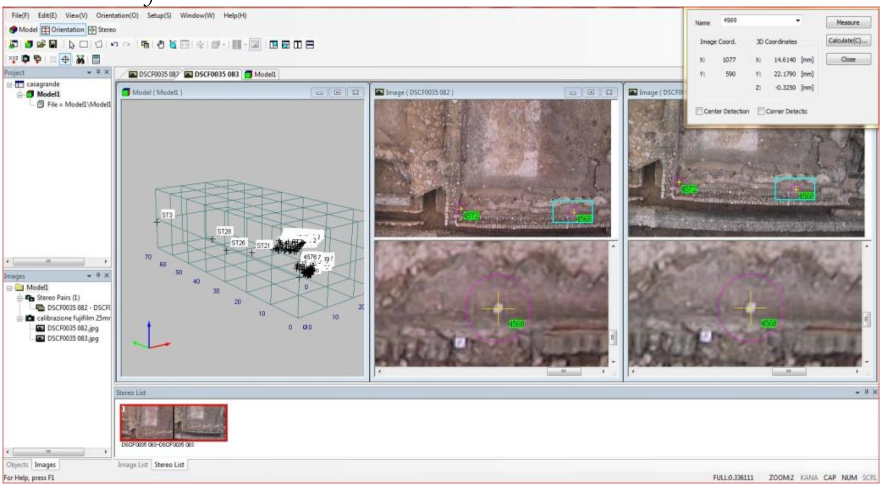
Source: GREAL

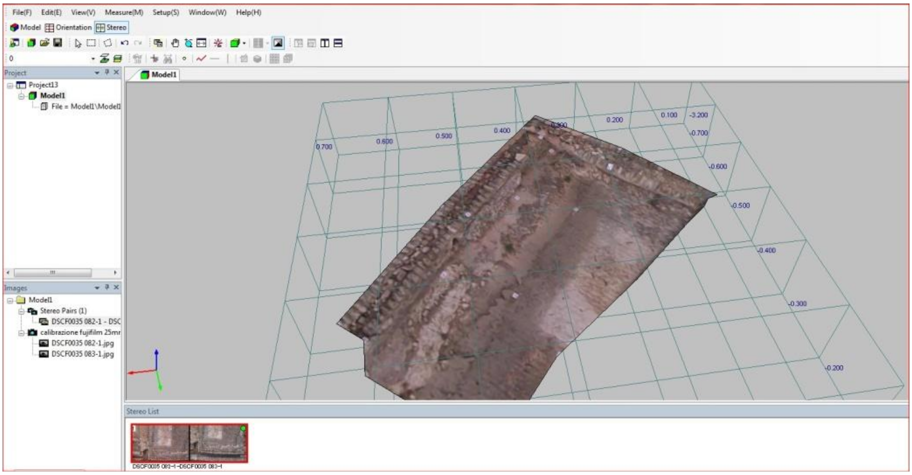
Fig. 10 – *A shot of the same area in an oblique view from a lower height*

Source: GREAL

Basic archaeological photogrammetry. Tests at Domitian's villa, Parco Nazionale del Circeo and Lucilius Paetus' mausoleum, Rome. – One of the most promising applications for the use of UAVs in the investigation of cultural heritage is certainly aerophotogrammetry (Remondino, 2012). Currently available software, along with the technical progress of digital imagery, makes it possible to work on quite complex types of rendering. As a matter of fact, 3-D modeling for both architectural and archaeological applications can be obtained by having a UAV collect images, which can later be processed. Results are compatible with those achieved by more traditional and expensive methods. This kind of application was also tested during our "worst case scenario" experiment. The test was conducted in a real archaeological context, i.e. a section of Domitian's villa at Circeo, in October 2011, under the direction of a professional archeologist and topographer, Diego Ronchi. The UAV was flown in slow loitering mode between 5 and 15 metres over an original Roman pavement area. Control points had been previously defined, well scattered, on the target surface and accurate trigonometrical measures had been taken to establish a reliable network of ground control points. During the flight, the UAV camera was shooting a nadiral 640 x 480 frame video which was then downloaded and sectioned into single frames. Frames were then associated to define pseudo stereographic pairs. Such pairs were then processed through a standard professional photogrammetric software (ImageMasterPhoto™). The output was a mesh elaborated from the images. The process was conducted by taking into account, as a reference, the previously fixed control points. The output mesh was then covered with the RGB texture as acquired in the images. The final result was a basic 3-D model of the surveyed area (Fig. 11), whose accuracy was found acceptable for the needs of a rapid, provisional survey. The second, more advanced**,** survey was conducted – with a similar profile – at another site, the Lucilius Paetus' Mausoleum (July 2013) This monument, from the early Roman Empire, is located at Via Salaria 125, Rome. In this case the survey yielded a 3-D model which was later used to obtain a 3-D print.

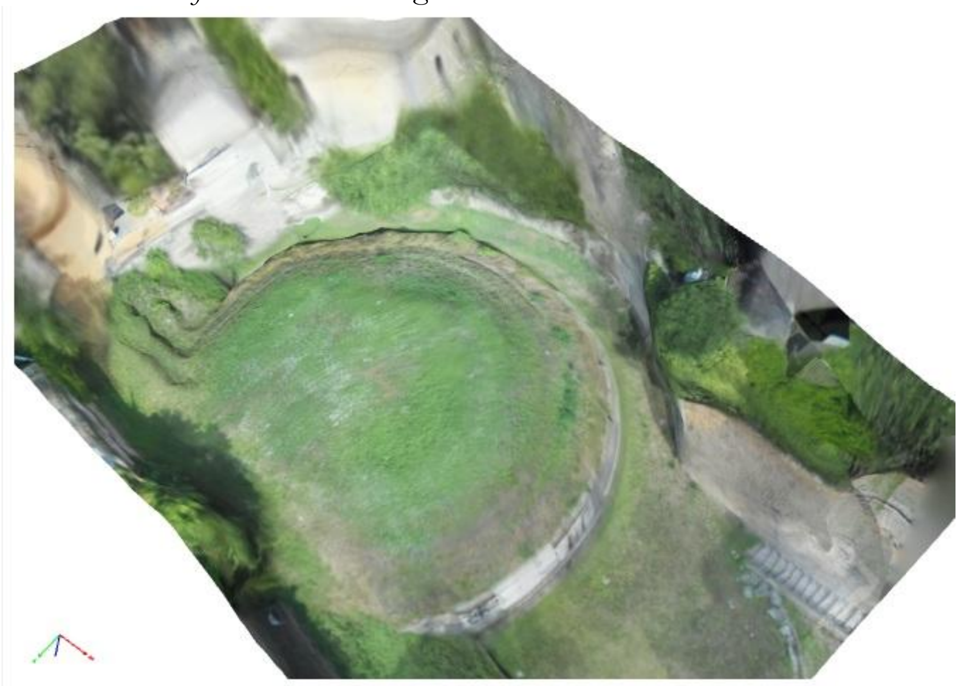
Fig. 11 – *Two screenshots, taken from the initial and the final steps of a photogrammetry-based 3-D rendering of an archaeological site. The model is based on nadiral views from the UAV.*





Source: Diego Ronchi

Fig. 12 – *A 3-D aerophotogrammetric model of the Lucilius Paetus' Mausoleum as obtained from the aerial images.*



Source: GREAL

Fig. 13 – *Physical 3-D print crafted in gypsum from the digital model. Colors are reproduced from the original image textures.*

Source: GREAL

Documenting minor landmarks. A case study at Torre Flavia, Ladispoli. – Specific attention was paid to minor landmarks and cultural heritage. A low-tech approach is obviously strategic in this type of survey. In January 2013, GREAL performed a series of flights related to this field. The purpose was to obtain a basic documentation of a typical "minor" landmark: Torre Flavia, a 16th century watchtower on the Tyrrhenian coast, close to the town of Ladispoli (Rome). The rectangular-shaped tower was bombed during World War II. It remained damaged and exposed to the sea for many years. It is now broken into four low, ruined sections, which appear to be increasingly dis-aligned from one another. A three hour survey with the aid of GREAL's GAUI 330XS UAV enabled us to collect far-ranging and useful data about the monument's current material status (Figs. 17-18).

Fig. 14 – *An oblique view of Torre Flavia shows two separate sections of the building, clearly leaning on diverging axes. A brick stair is visible, descending from the left section to the right one.*

Source: GREAL

Fig. 15 – *A closer view of the top of the eastern section of the building allows us to better observe the structure of a doorway. The same feature would be difficult to document from the ground.*

Source: GREAL

Fig. 16 – *A nadiral view of Torre Flavia shows a clear dis-alignment of the four surviving elements of the structure. Detailed information about the current status of the materials on top of each element can also be seen. This suggests the possibility of a periodical monitoring of conditions and decay. It can also provide data towards restoration or protection.*

Source: GREAL

Surveying in emergency. Post-earthquake damage assessment of relevant buildings. – A basic UAV system can provide very useful information in emergency contexts. A major application field is post-earthquake damage assessment of buildings and infrastructures. The system described in these pages was operationally tested in a real emergency context during the Emilia Romagna 2012 seismic sequence. Several surveys were conducted in two different sites of the province of Modena (Figs. 17-19). Damage to minor landmarks and historic buildings was inspected in support of surveys conducted by emergency operators. The system's ability to acquire close-up views around single architectural elements allows for an effective documentation of post-earthquake damage. This type of qualitative survey has two main advantages: first of all, it makes it possible to inspect structures whose current status might be dangerous for human operators; in the second place, the "freedom" and mobility of a UAV system is likely to provide a more detailed and complete description of the ongoing phenomena.

Fig. 17 – *Flying inside an unusable warehouse, the drone took a video of the collapsed shelves. About 2/3 of the stored goods had been thrown to the floor by the seismic shocks on May 29th, 2012. When the survey was performed, no person could access the building. The flight was thus conducted by the pilot from the outside, observing the UAV through an open secondary door. Meanwhile the images captured by the drone were recorded and shown live on a display for technical operators on the site*

Source: G. Casagrande

Fig. 18 – *Post-earthquake damage assessment on the 18th century bell-tower of the San Nicola di Bari church in Camposanto (Modena). A typical X-shaped rupture separated the top of the arc of the belfry's eastern window and a full section of the northeastern corner. The close-up view was achieved by flying the UAV at a height of about 30 metres above the evacuated "red zone". The remote control station was safely on the nearby bank of the river Panaro, about 60 metres from the belltower*

Source: G. Casagrande

Fig. 19 – *Invisible from the ground, a large crack had appeared at the foot of the 18th century Torre Ferraresi, Camposanto (Modena). Due to its particular position, it was initially unnoticed*

Source: G. Casagrande

Indoor inspection and survey. – Indoor survey is a specific field of UAV applications, often requiring "specialized" hardware and procedures. Inspection of indoor spaces can involve both the general structure of enclosed volumes and specific elements of the objects within it. This type of operation can therefore take place in either natural or artificial environments and can range from simple visual observation of the context to photogrammetric three-dimensional measurement and modelling; from proximity and close-up views of details to multispectral remote sensing and – last but not least – measurement of atmospheric conditions or other environmental parameters.

Fig. 20 – *In 2014, GREAL developed the iMAVS-1 prototype (indoor Multirotor Aerial Video Surveyor) to test basic solutions for indoor inspections. The drone could sustain small collisions with typical obstacles without alteration to its flying and manoeuvering capabilities; it also featured powerful LED illuminators, real-time video link and a gyrostabilized HD camera. The prototype was successfully used for surveying the Ciota Ciara cave, Piedmont, Italy. It was also tested in several enclosed spaces. The drone was lost during outdoor validation tests in May 2015, owing to a propulsion failure.*

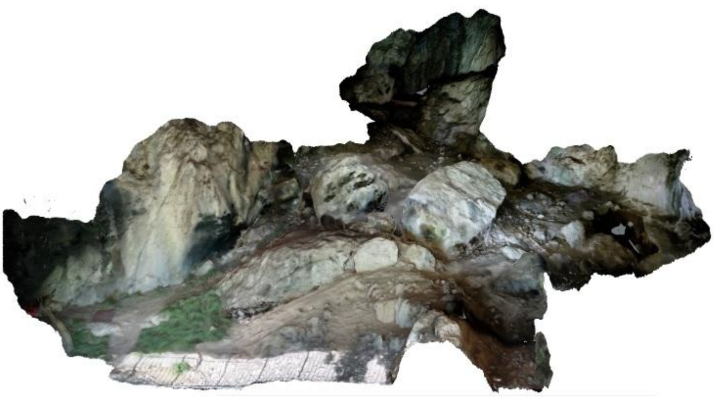
Source: GREAL

Fig. 21 – *The experience gained during testing of the iMAVS-1 allowed for tdesign of a multipurpose, pre-series UAV, iMAVS-2 "Hornet"*

Source: GREAL

At the time of writing, indoor UAVs are a specialized minority of the drones available on the market, due to the particular features they must have in order to accomplish their tasks. Major issues involve pilot handling of the drone, automatic orientation and navigation inside enclosed spaces and, obviously, interactions between the drone and the indoor context. As far as pilot handling is concerned, it must first be said that flying inside a natural or artificial structure should take into account the fact that the physical presence of the pilot inside the space may be impossible. Therefore the drone must be configured so as to allow for FPV (First-Person-View) flight. The pilot conducts the drone without any direct visual contact with it: all operations are carried out through the monitor (or FPV goggles). The pilot flies the drone by watching the real-time image broadcast by the drone camera(s) and may get additional information about the situation through telemetry. Indoor FPV may turn out to be far more difficult than outdoor operations, since camera views from the drone may be limited and so may the pilot's ability to keep fully aware of the situation. Automatic flight inside enclosed volumes requires different hardware from that used in corresponding manoeuvres in the open air: GPS does not work inside a building or a cave, and the drone must be fitted with sensors to detect its position relative to indoor obstacles. Sensors of this category are, typically, sonars, optical and barometric sensors. Others are being developed as technology progresses. Moreover, the flight control system must be able to process the overall information in a rapid and logical way, and to manage the drone accordingly. In most cases, indoor volumes prove relatively "narrow" for an average-size micro-drone. This makes indoor operation a demanding task for current UAV technologies. Nevertheless, the reward is worth the effort, since UAV survey has considerable scientific and practical value in many peculiar enclosed contexts, as in the case of unusable and inaccessible spaces (damaged or dangerous buildings, tunnels, caves, contaminated environments...), as well as in particular architectures (under-construction buildings, cultural heritage, etc...).

Fig. 22 – *Aerophotogrammetric 3-D model acquired by iMAVS-1 in July 2014 inside the Ciota Ciara prehistoric cave. The model was obtained from 1080 × 720 pixel frames. The purpose of the survey, requested by the University of Ferrara's LT-TEKNEHUB, was to acquire information about the overall shape of the cave floor in order to better understand the possible effects of water-debris interactions*



Source: GREAL. Processing: D. Plasmati.

Survey of (fairly) large areas by means of (fairly) small drones in (fairly) bad weather. An experience in the Philippines. – In winter 2014, a survey mission in the Cagayan valley (Philippines) was planned and jointly conducted by the University of Ferrara and the University of the Philippines Diliman. The Cagayan valley, in northern Luzon, is a crucial site for the re-definition of the prehistoric occupation of the Philippines, given that some lithic artifacts were found in association with elephant remains (Dizon and Pawlik, 2010). The aerophotogrammetric survey aimed at better documenting the correlation between several excavations, dating from the 1930s to 2014, and the geomorphology of the area. A general localization of the archaeological levels was also among the goals (Figs. 23-24).

The survey was performed by the use of a DJI F-450 quadcopter equipped with a compact mirrorless Canon Power Shot G15 camera. The survey covered an area of about 4 km^2. The outcome of the survey, in terms of data, was excellent and functional to the intended scientific purposes. Nevertheless, the operation proved challenging for the work-group and several modifications to the initial survey protocol were necessary. First of all, international shipping of some pieces of the equipment (especially the flammable LiPo batteries) was not accepted by several carriers; this turned out to be time-consuming and required the "risky" choice of having other batteries purchased in the Philippines for the workgroup to find ready upon arrival. These batteries were known to be theoretically compatible but no test was possible before the field-deployment. The overall setting of the survey area and its typical weather also influenced the protocol by affecting both the hardware and the procedures. Furthermore, the absence of electric supply in the valley forced the workgroup to rely only on an old generator for all their needs. This entailed longer time for battery recharging and longer intervals between flights. Due to uncertainties about the batteries' performance, the work-group decided to shorten the flight time down to 7 minutes (the originally planned flight-time was 10 minutes).

On the first day of the campaign, the drone gyrostabilized camera gimbal got damaged. The rest of the survey had therefore to be flown without camera stabilization. As the lab analysis showed, however, this problem had no ill consequences and the images (1080x720 pixel) were perfectly within the quality requirements.

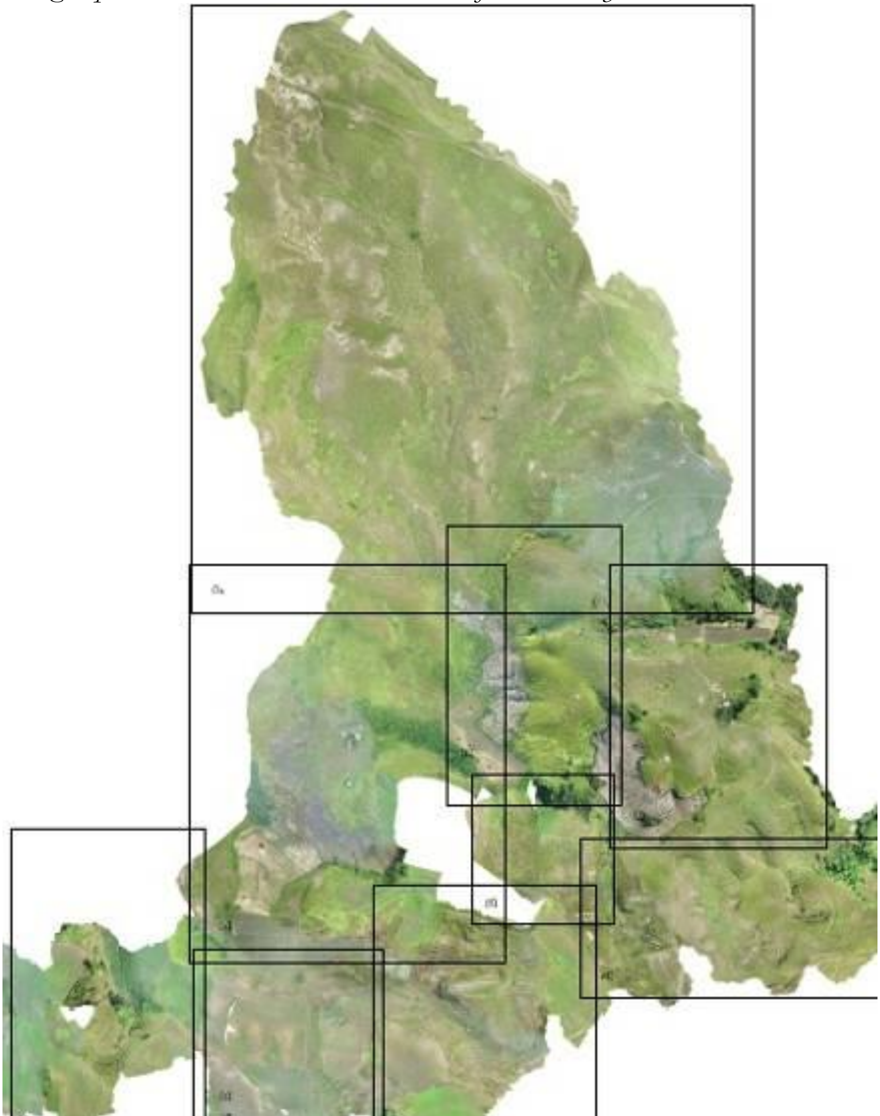
The survey area was divided into nine sectors (Pic. 24), based on the landscape morphology. Each sector was surveyed in 3-4 flights, lasting no more than 7 minutes. A photogrammetric 3D model was directly obtained on the site by processing the images through Agisoft Photoscan(TM) software. Models were then connected in order to verify the correct superposition of sectors and the overall quality of the data. Due to sudden weather changes and to the short time available, most survey flights were performed in light-to-moderate rain. Since the DJI F-450 is not designed to fly in such conditions, a provisional rain protection was built and applied to the drone in the field. The electronics and the engines were covered by plastic sheets and those were partially sealed by tape. This provisional solution succeeded in preventing water from reaching the components. An expected possible problem, on the other hand, was hardware overheating. However, protections were applied so as to allow some degree of air circulation. Other flights had to be performed in relatively strong wind. This affected the survey navigation paths because of the major difference in the "groundspeed" reached as the drone was alternately flying in tailwind or headwind.

The relatively unusual climatic conditions of the research site allowed the performance of the DJI F450 to be tested. The machine proved extremely versatile and capable of successfully operating as an aerophotogrammetric surveyor even in marginal conditions.

Fig. 23 – *Two images of the Cagayan valley (Philippines). A prevailingly natural environment, it proves a challenging site for the field-deployment of a basic UAV system. A major difficulty, from a practical point of view, is that in this kind of operational scenario the workgroup must rely on very limited technical support if any problem occurs. However, a thoroughly planned survey program can be successfully conducted even with basic equipment if it is supported by some technical skill and a sufficient degree of adaptivity*

Source: M. Arzarello

Fig. 24 – *A general view of the aerophotogrammetric model acquired by the workgroup. The view includes the indication of the 9 survey areas.*



Source: M. Arzarello, J. Arnaud.

Conclusions. – The experiences described in this paper led the authors to the conclusion that low-tech and open source UAV systems have enormous potential in many applications to landscape and cultural heritage survey. In numerous operational scenarios, simple UAV platforms can prove effective and provide private and public users with plenty of data. Important services can be effected by the use of low-tech and open source solutions. Merging these two components would allow for a larger number of workgroups to operate. Furthermore, the inherent simplicity, safety and ease of use of small UAVs allow crew specialization and training requirements to be reduced, as compared with traditional aircraft management.

Notice. – This paper is the result of a joint research project by all the authors. However, contributions should be specifically attributed as follows: Gianluca Casagrande authored the following sections: "Testing on a worst-case scenario: the origin of the research"; "Basic archaeological photogrammetry. Tests at Domitian's villa, Parco Nazionale del Circeo and Lucilius Paetus' Mausoleum, Rome"; "Documenting minor landmarks. A case study at Torre Flavia, Ladispoli"; "Surveying in emergency. Post-earthquake damage assessment of relevant buildings"; "Indoor inspections and survey". Flavia Salvatori authored the section "Aerial-view survey of archaeological sites. A test at the Catacombe di Callisto complex (Rome)". Marta Arzarello and Julie Arnaud jointly authored the section "Survey of (fairly) large areas by means of (fairly) small drones in (fairly) bad weather. An experience in the Philippines". The introduction and the conclusions were shared by all of the authors.
The paper derives from a previous work (limited to Casagrande's and Salvatori's sections) presented to the 1st International Conference RICH 2012 "Robotic innovation for Cultural Heritage", Venice, 3-4 December 2012. To the best of the authors' knowledge, prior to May 2015 neither the conference proceedings nor the aforementioned paper had been published. Hence the research was revised and updated to reflect the state-of-the-art of the described technologies and methods. It was also extended to include the most recent results of the authors' laboratory experiences. It was then submitted for publication in this Journal.

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Abstract. – I droni si stanno diffondendo rapidamente sul mercato generalista. Gli hardware e i software attualmente disponibili divengono sempre più economici e questo accresce le potenzialità applicative di questi strumenti. Parallelamente al numero degli operatori commerciali, cresce anche quello dei gruppi di lavoro scientifici interessati all'uso di questi mezzi per lo studio delle condizioni materiali e dello *status* complessivo del paesaggio, del territorio e dei suoi beni storici e culturali. La tecnologia si adegua rapidamente a diverse necessità operative; nel frattempo, in vari paesi europei iniziano a svilupparsi normative sull'impiego di questa nuova peculiare tipologia di aeromobile. Se è vero che sistemi e sensori di alta sofisticazione si rendono necessari in alcuni casi, l'esperienza tuttavia insegna che, in altre circostanze, anche prodotti meno avanzati forniscono una grande quantità di dati e contribuiscono all'acquisizione di conoscenza significativa sui fenomeni osservati. La possibilità, per un maggior numero di gruppi di lavoro, di avere accesso a queste tecnologie innovative grazie ad un'opportuna convergenza di approcci "open" e "low-tech" permetterà nei prossimi anni un più completo ed utile studio dei beni materiali del nostro "cultural heritage". Tale concetto generale è stato sottoposto a verifica, fra il 2010 e il 2015 dal Geographic Research and Application Laboratory (GREAL) dell'Università Europea di Roma, in collaborazione con altri partner di rilievo fra cui l'Istituto per le Tecnologie Applicate ai Beni Culturali (ITABC-CNR) e l'LT-TEKNEHUB dell'Università di Ferrara. Questo lavoro presenta alcune delle più significative applicazioni sottoposte a verifica e riassume le conclusioni tratte da tali esperienze.

Keywords. – UAVs, drones, aerophotogrammetry, landscape

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