MICRO UAV FOR POST SEISMIC HAZARDS SURVEYING IN OLD CITY CENTER OF L'AQUILA

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KEY WORDS: UAV, Photogrammetry, GNSS, Earthquake, Surveying.

ABSTRACT:

Almost three years ago a disastrous earthquake hits the old city of L'Aquila, hundreds of victims, thousands of collapses. The post emergency and very crucial phase regarding surveys, structure controls and investigations till now is fully underway. Conventional surveying techniques using high precision total stations, GNSS and laser scanners for investigations on damaged buildings are always becoming more automated, accurate and operative in always shorter time manners. Even if these techniques represent instruments of extreme operability there are still many evident limits on their use especially regarding the survey of both the roofs and the facades of tall buildings or dangerous places, typical on post earthquake situations. For example, the details of a bell set at 40 m height are always hidden for most of the instruments such as laser scanners or total stations, certainly, the non optimal capturing angle and the bad visual would represent considerable limits for the identification of potential damages. The present work aims on experimenting an innovative surveying methodology using multirotor UAVs (Unmanned Aerial Vehicles), fully remote controlled, that will allow high quality image capturing on roofs and facades of structures in the old city center of L'Aquila. These data will be elaborated with photogrammetric software suits to create digital models of the building and databases with its detailed characteristics. The field of application can be the concept of photogrammetry of proximity as the flights are carried out at altitudes much lower than an aerial photogrammetry, moreover, as the flight is operated in a fully automated way, extended areas can be surveyed in a fat and economic way. This paper highlights the reasons that led to explore the use of a Micro UAV in the relief of an old city center through a real case application. Each step of photogrammetry is described, from the planning software of the flight plan and gripping points to ensure the coverage required to the execution of the flight and the data processing. The experiments were performed using an IPT Mikrokopter (Rome - Italy), in octo-configuration (8 engines) in order to have better flight stability and raise the needed payload for an SLR digital camera; the flight was also performed in fully automatic way at the height of 80m. The results presented in this study highlight the excellent integration of these surveys with those made by conventional instruments and propose this methodology as an effective documentation necessary for a recovery of an old city in a post natural disaster.

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1. INTRODUCTION

On April 6, 2009, a devastating earthquake hits the city of L'Aquila and all surrounding villages in the Abruzzi Region (Italy). The earthquake causes more than 300 fatalities, thousands of injuries, extensive and severe damage to buildings, structures and lifelines. About 16.000 buildings are completely or partially destroyed: about 80,000 residents must be evacuated and more than 25,000 remain homeless. The earthquake's magnitude is initially estimated to 5.8 degrees of the Richter scale while a long-lasting seismic sequence that including more than 30 minor earthquakes with magnitude 3.5<MI<5.0 continues shaking the whole region for many months creating an extremely dangerous environment for surveys of any type. Overall, the region affected by the seismic activity covers an ellipse-shaped area measuring about 15 km in length (parallel to the Apennines mountain chain) and 5 km in wideness. According to the INGV this seismic activity is the result of a normal fault movement on a NW-SE oriented structure which is part of the 800 km long segmented normal fault system running all along the Apennines mountain chain and covering great number of Italy's most important monumental cities. Thus, not only a continuous seismic activity of the whole last mentioned area exists but also can became very dangerous, especially for partially or even totally destroyed cities. Within this urban setting, the seismic event caused serious damage to numerous important buildings, mainly including a valuable real estate heritage stemming from the Baroque and Renaissance periods, and also including eminent churches, important palaces, and other monumental buildings and structures.All the masonry buildings including the traditional palaces and high-density residential quarters in the old city centre suffered severe damage and many partial collapses. Many of these buildings survived anyhow, their general collapse being in most cases avoided by tie, rods, anchor plates and other simple but effective earthquake-resistant presidium schooled by the historical seismic nature of the land. During some weeks after the quake fire fighters and civil protection teams arrived to L'Aquila from all over Italy to create emergency shoring for as many damaged buildings as possible. The first emergency shoring takes months and even when is completely done only a small step of the whole operation is cleared. Certainly, the first thing to do in these cases is a detailed documentation of all structures in order to gather all the vital information for a correct projection of the next procedures. Moreover, during the emergency shoring a continuous monitoring of all building is crucial in order to guarantee that each structure at least will not worsen until the final reconstruction is completed. To do so, detailed surveying of all building is performed using geomatic means like total stations, land photogrammetry, laser scanners and deformation monitoring. Even if all these techniques can perfectly respond to many crucial post hazard situations, there are still many cases that are not enough. All these difficulties are mostly related to the morphology and the architectural particularities typical to medieval cities like L’Aquila. In fact, the whole town is created of relatively tall buildings among very narrow streets that in most cases are completely covered by arcs that at their time reinforce the masonry surrounding constructions. As anyone can imagine, during a post-seismic period, surveying in such conditions is not only difficult but also extremely dangerous for workers, instrument operators and surveyors. Typical examples are the bell towers, old tall castles, multistory museums, churches, schools and finally roofs of any type. Using traditional surveying means on post seismic situations apart from being extremely dangerous is also a week method as a great part of the architectural and structural information remains unable to be surveyed or hidden by other buildings or parts of the same construction. Other methodologies like aerial photogrammetry can certainly help but also would create additional huge expenses to the already red balance of the reconstruction while would not in any case produce detailed and accurate information for the damaged structures.

1.1 CASE OF STUDY

Since April 2009 earthquake, about 90 % of the University’ strategic buildings remained out of service and plans for their rehabilitation are complex to be defined in an integrated view with the future of the town. The need for innovative techniques integrating different methodologies both to gather all necessary structural and architectonical information and to monitor the destroyed buildings immediately raised. Scientists decide to find an alternative, fast, economic, reliable the most important safe method to continue surveying on such difficult situations. Less than two years after the terrible earthquake of L’Aquila in the Laboratory of Geomatics some experiments begin projecting an innovative versatile and safe surveying instrument able to work under any environment without any kind of risk for the operator’s life. The project aims on integrating a series of sensors to a flying micro UAV to be used for survey and documentation on the old city center of L’Aquila. (Figures 1-2)

Figures 1 - 2
The UAV used for this case study on the left and the test area (piazza Palazzo) on the right

The instrument will be able to gather detailed accurate information of high quality for any kind of structure at any height under any circumstances in a way that till now was at least difficult and extremely dangerous. In this paper all steps as well as the first experimentation of a flying drone used for post seismic surveying in the old city center of L'Aquila are presented. The prototype as will be described is made by a Microkopter platform in OCTO configuration created by the Italian IPT^{TM} and the project and data elaboration made by the Geomatica Lab in the university of L'Aquila. The test area was the Palazzo square of the old city center of L'Aquila and especially the Marguerite Palace that features a 40m tall bell tower. All experiments started on march 2011 and are still going.

1.2 ADVANTAGES USING UAVS

Conventional techniques of geomatic surveying in post hazard situations are until now in wide use mainly employing laser scanners, motorized total stations, digital aerial and terrestrial photogrammetry. Even if these methodologies can certainly provide results of high precision, accuracy and quality there are still limits for their use especially when employed in complicated sites like the old city centre of L'Aquila for post hazard surveying. As an example, one of the most important bounders for conventional methodologies is the need for access to all points of the structure. Thinking of a forty meter tall, baroque monumental building anyone can imagine how many important details can remain hidden among the architectural particularities of such rich structures. Moreover, even if an aerial photogrammetric survey could provide all necessary architectonical details of the building, the cost of such massive survey and the quality of the final data would be prohibitive. Another possible solution to achieve details of high architectonical interest could be given using a mechanical robotic arm, in this case certainly many of the structure's points could be revealed but there are still some limits regarding both the maximum height of the arm and the difficulties of accessing the narrow streets of the old city centre, certainly, also this solution most of the times can be economically inconvenient. Another very important disadvantage of the traditional surveying especially during the post seismic periods regards the overall safety for both the instruments, operators and workers. In particular, the seismic sham that continues for months after the main shock continued causing collapses and ulterior damages that in most cases could close a whole road also creating important problems to all instruments settled in that area and definitely giving an ulterior serious risk for all operators. the difficult reputability of all surveys when using traditional means is also an great issue. In particular, there are frequent cases that a survey has to be repeated periodically in order to achieve a final result, using traditional means such an operation not only can be impossible because of the sites accessing difficulties but also would cause ulterior expenses. moreover, the flight height of an aerial photogrammetric survey apart of the prohibitive cost can only provide data of relatively low quality making this type of survey less convenient. On the other hand, using micro UAVs for surveying in such particular cases many of these problems can easily bypassed. For example there is no matter talking about accessibility for an UAV mainly because of the extreme flying capabilities of these instruments that can really permit the access of any place, then regarding the security as these instruments are fully remotely controlled they do not involve any risk for the operator simply because he is not in the dangerous area. Another significant advantages are the time and cost effective use of Drones. In fact, these instruments are able to clear a whole survey flying only some minutes and spending almost nothing as they only use rechargeable batteries for their need in energy. The extreme versatility of these instruments has also to be mentioned as permits a wide range of sensors integrated to the main platform creating in this way many kind of different data but always using the same Drone. Also the possibility of flying in that low altitudes with such fast and easy repeatability of any survey provides very accurate results of high quality always in very economically convenient way. Finally the low aeroacustic impact of these drones is important in this sensitive post seismic contest as any vibration can cause serious damages to the already devastated buildings.

1.3 INTRODUCING THE TEST AREA

To curry this experiment a typical italian square features historic-monumental buildings of an important architectonical merit was chosen. Its dimensions are 60 meters long to 38 meters wide covering a total area of 2500 square meters and surrounded by the public library, the city hall "palazzo Margherita" with its 40m height bell tower. (Figures 3-4) To carry this experiment the whole survey was separated in three principal phases, firstly the preparation of the test area and the flight planning, then the execution of the surveying flight and finally the acquired data elaboration. each step is described in the following paragraphs.

Figures 3 - 4
The 40m S. Marguerite tower on the left and the test area, piazza Palazzo on the right.

1.4 THE UAV PLATFORM

All experiments in the historic center of L'Aquila for this project are fruits of a collaboration between the Laboratory of Geomatics, Faculty of Engineering, and the IPT^{TM} of Rome, that gently provided a Mikrokopter platform in Okto configuration, including all on board sensors like Reflex photogrammetric cameras and GNSS navigation receivers to enable the automatic flight mode also with the necessary transmitters able to send all telemetry data in real time to the ground control station. The choice of this platform was made trying to achieve excellent flying characteristics that can allow an optimum stability even in presence of wind or other non optimal climatic conditions and according to the payload specified by the manufacturer, which allows to carry a reflex digital camera without problems. In particular, a Canon EOS 550D also equipped with a wireless video transmission to the ground was chosen to allow a better control both the whole platform and the state of the flight in real time.

1.5 TEST AREA PREPARATION

The preparation phase consists on making all the necessary preliminary operations to the test area in order to permit a correct application of the methodology created. Firstly a detailed topography of the whole area is important in order to evidence and materialize the so called Ground Control Points (GCP) that are used in order to geo-reference the photograms surveyed by the UAV. For each control point the coordinates in the geo-centered WGS84 reference system are determined using GNSS techniques in real time (RTK) calculating the differential corrections received by a permanent station's network, formed with baselines of some kilometers. In this way the precision of some millimeters was achieved creating accurate input for further elaboration of the whole network. Certainly, each one of these points was surveyed using all principles of the GNSS techniques paying attention on the quality of the survey for example guarantying good satellite distribution, signal quality and high data accuracy. (Figures 5-6)

Figures 5 - 6
The materialisation of each point and the wooden target for the point's individuation in the photogram.

The main characteristic of the GCP is the fact that they has to be easily visible and homogeneous in all frames applying the same principles also used by the traditional aerial photogrammetry. In the test area for example a number of 18 GCP were chosen and materialized creating a well distributed polygonal network of points extended to the whole square (Figure 7). To better observe all ground control points both by the local surveying topographic instrumentation and by the aerial means wooden targets with dimensions 30x30 cm were positioned in each points. Finally the maximum distance between each couple of points was up to 15 meters creating a steady network of control points to reference and correctly orientate all frames.

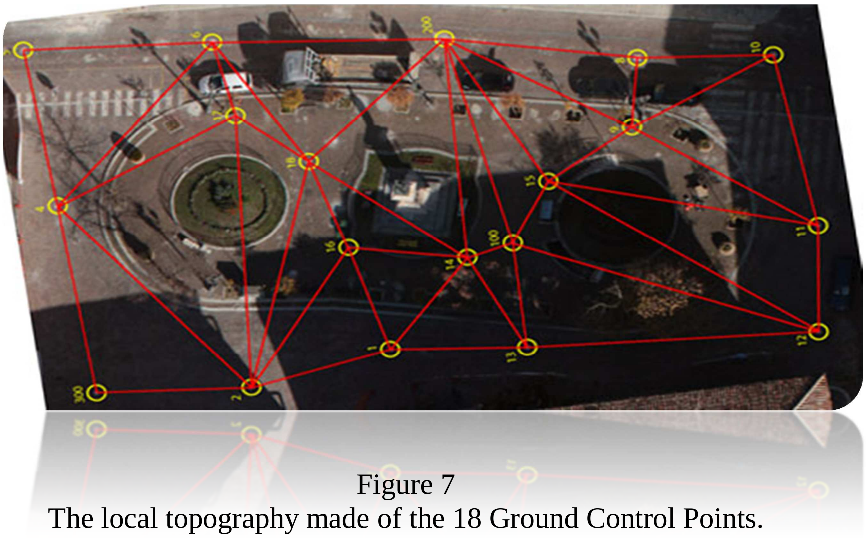
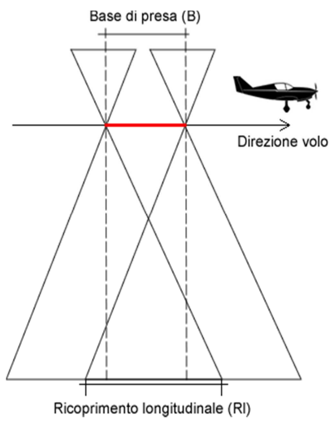
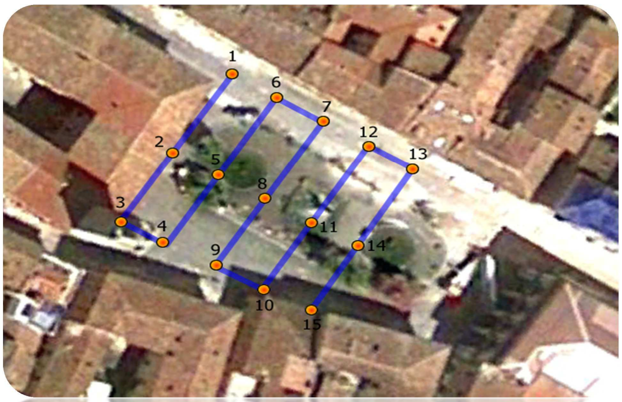


Figure 7
The local topography made of the 18 Ground Control Points.

1.6 FLIGHT PLANNING

Flight planning is a rather delicate part of the project. The whole importance of this part regards the fact that a correct photogrammetric survey begins with suitable for post elaboration number of frames of high quality. To guarantee this quality the whole flight and thus the capturing points have to be spatially distributed maintaining certain metric characteristics, equal and correct capturing baselines and correct interaxes. The importance of all these, prior to take off planning operations, is evidenced by the fact that once the flight plan is correctly created will be automatically cleared by the drone using a waypoint navigation system and in this way creating accurate and correct data. Returning in the test area of Piazza Palazzo the first flight plan was created researching an adequate number of waypoints to guarantee enough overlaps and correct flying vector distances. At this point some important photogrammetric aspects can be mentioned as they remain exactly same also when used by a drone platform. Considering any kind of photogrammetric survey, the flight has to be cleared in a predetermined way creating parallel and linear routes. (Figure 8) To determine the density and the number of the needed waypoints some metric information are necessary. Firstly the flying altitude and the flying speed to simulate the temporal intervals needed to clear all distances between each couple of waypoints. Then, the geometric characteristics of the reflex camera, as the focal length, internal orientation, pixel dimensions and the frame format in order to correctly determine the physical area covered by each capture. Having all these information and using a flight planning software each waypoint is calculated in order to guarantee a minimum of 60% overlap between each couple of photograms in the longitudinal direction ensuring in this way also a stereoscopic vision, thus the three-dimensionality of all objects. (Figure 9) In addition to these parameters, another characteristic for the planning is the average scale of the photogram. This scale expresses the relation between the dimension of an element in the photogram and the dimension of the same element in the physical earth surface. Due to the fact that the terrain cannot be completely flat the distance between each pixel and the capturing point is not the same, thus an average value of this distance is used instead.





Figures 8 and 9
The waypoints of the flight plan for the test area (Right) and the flying altitude and capturing parameters determination scheme (Left).

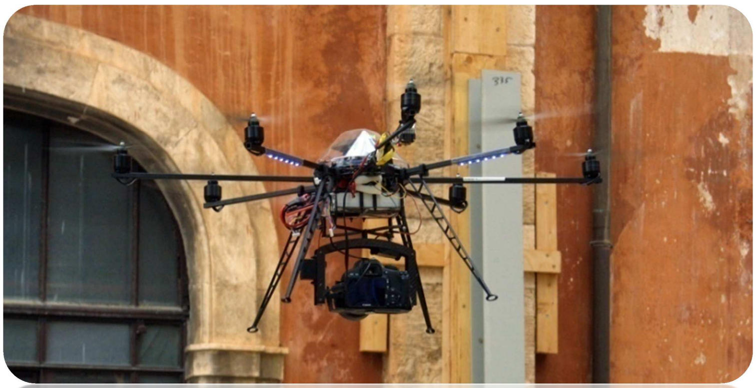
The importance of this average scale is crucial to correctly generate maps or to create printed copies of these frames with a known aspect ratio and a fixed scale. Moreover, a preliminary determination of these parameters can evidence an optimal flight altitude that will permit the generation of photograms able to maintain correct all the metric characteristics projected for each photogrammetric survey. With these parameters, (fling altitude, focal length and frame dimensions) used with an amateur digital camera the nominal scale for the final result can also be generated. Summing up, all formulation guided to the conventional rule that an optimal flight altitude has to be approximately equal to four times the length of the desired photogram length in order to obtain an ideal overlap between the photograms. Applying all these characteristics for each flight planning the stereoscopy of each object is proven permitting the generation of digital elevation models also known as DSMs. The same methodology is also used to plan a flight with a drone, the only difference is the fact that multirotor UAVs are able to clear the whole flight plan also making instant stops of about 10 seconds to capture the photo permitting in this way an even more steady capturing that can improve the overall photogram's quality.

1.7 EXPERIMENTS IN THE TEST AREA

As described above the total dimensions of the test area were about 60x38 meters, moreover the initial project aimed not only to cover the square's surface but also part of the surrounding structures. To do so, the extension of each photogram was decided to 100 meters while the planning software (MK tools) using the camera and flight parameters calculated the flight altitude, the average photogram scale, the restitution scale and the overlap between each couple of photograms. in particular, the overlap was decided to 80%, the semi-length of the photogram was 11.49mm, the value of the capturing angle for this photogram was 32.55 and finally the flight height was 78.30m. using these information the final average scale for the photograms was 1:4444. In this way clearing a flight routine at 80 meters with the Eos 550D focal length the element's scale eas 1:4444. Moreover, considering the nominal scale of the digital sensor of 18 Megapixels the real dimension of each pixel in the terrain was 1.97cm. (Figure 10)

1.8 FIRST FLIGHT EXECUTION

When an accurate flight planning is cleared, the flight can be executed to collect all data for further elaboration. In case of the survey in "Piazza Palazzo" (Figure 11) the flight was executed both in auto mode, so following automatically the pre-determined flight plan and in manually capturing



Figures 10 and 11
The Canon Eos 550 camera (Left) and a photo of the first flight in piazza Palazzo (right)

many pictures by different heights to retrieve a variety of information regarding the structures particularities. Focalising to the automatic mode some important aspects have to be mentioned. First of all the possibility to perform the whole flight automatically can easily let us undervalue important factors that can compromise the whole success of the survey. To avoid these problems flying with good climatic conditions is crucial as even some light wind can compromise the drone's stability affecting the quality of all photograms and creating undesirable results. Moreover, the correct calibration of the camera before surveying is important to maintain valid all internal orientation of each photogram also the necessity to always verify the correct function of all rotors and to control the charge of each battery is crucial to correctly finish the desired flight. Returning to the flight in the test area, the first test was made on November 15th at 11:30 with excellent climate conditions. Immediately after the take off the automatic function was enabled capturing 15 photograms exactly as projected in the flight plan. The whole flight was also monitored by the radio transmitted video to the ground that made possible the evaluation of each frame in real time. In the following figures, the integrated frame of all these captures is visible also evidencing one of the targets positioned in the ground to geo-reference the photogram. Another helpful fact is that the system also captures a series of information regarding each capture like the geographic coordinates deriving from the internal GPS sensor, the flight altitude, the flying speed, the

GPS signal's quality, some information regarding the traceable satellites and the distances from the last and the next waypoint. All these information can be used to correctly understand and evaluate each frame alone or together with the other captured photograms.

2. DATA ELABORATION

2.1 Preliminary operations and hardware calibration

Even before elaborating the first data, some important preliminary operations are needed in order to guarantee the correctness both of the elaboration procedures and of the final data. The first task regards the camera calibration. This operation is needed as permits the determination of the internal orientation for the whole optical lens system, which is the one that generates the photogrammetric data. (Figure 12)

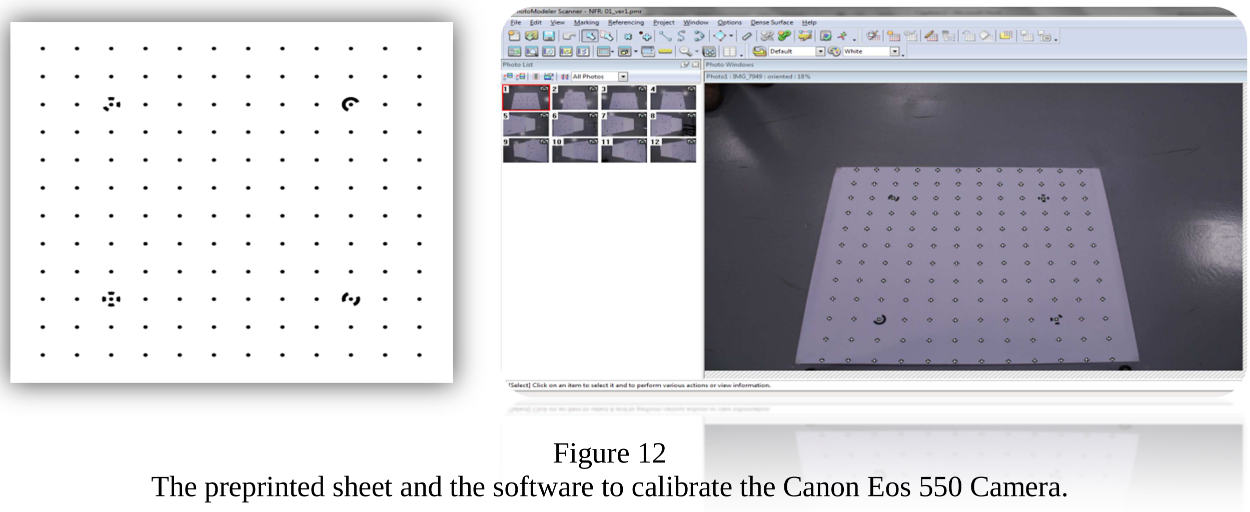


Figure 12
The preprinted sheet and the software to calibrate the Canon Eos 550 Camera.

In this phase parameters like the principal lent distance, the exact focal point's coordinates and the distortion curve of the photogram are precisely determined. Moreover, when working with a digital amateur camera, the so-called camera calibration, done by specific software (figure 12) is an operation during which all internal parameters for the camera can be determined to be used during the further elaboration of all photograms. On the contrary, when using metric professional cameras, all the internal orientation parameters can be found in the so-called camera calibration certificate.

2.2 ELABORATING THE CAPTURED DATA

The data elaboration was carried using the OrthoEngine software by PCI. The first step was choosing the best photograms to use controlling their correct focus, the dimensions of the covered surface and the quality of the details presented in each photogram. The main information to be set in the software are the desired mathematic model for the elaboration, the camera type used to capture the photograms and the external orientation. Regarding the last, permits the survey of the ground control points and their association with the corresponding pixels in the photograms to generate the so called tie points or homologue points. Another two important settings are about the output projection type, which fixes the type of the final result, for example an orthophoto, a Digital Surface Model (DSM) or a Digital Elevation Model (DEM) and the Output Pixel Spacing that determines the final pixel's dimensions in the elaborated result. Finally, the software has to set all the camera calibration information such as focal length, radial distortion of the lent and distortion of the decentration of the lent parameters obtained by the calibration of the camera.

2.3 GENERATING THE DIGITAL SURFACE MODEL (DSM)

To create the information about the Digital Surface Model at least a couple of photograms with optimal characteristics is needed. These two photograms, as described above have to maintain an overlap of at least 60% of their surface, finally a stereoscopy, that is a three dimensional information can be generated to that overlapping zone. In the figure 13 a couple of photograms with an overlapping of 60 % is visible used to generate the stereoscopy of Piazza Palazzo for this case study. After identifying the frames to be used their external orientation has to be made.

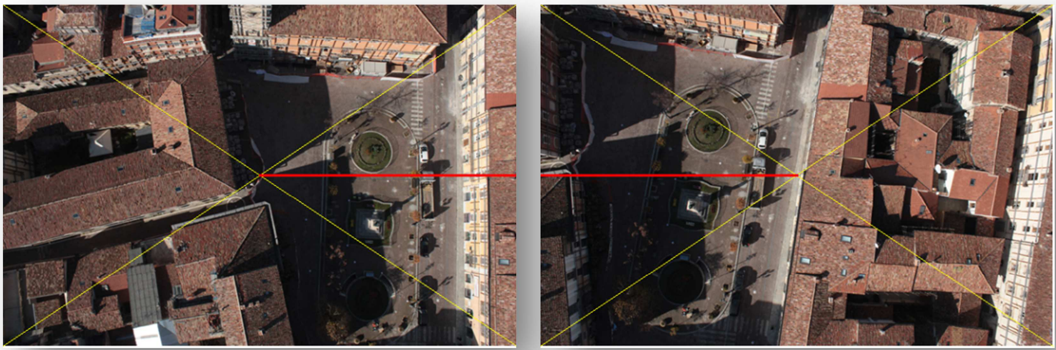


Figure 13
Using at least a couple of photograms with good overlapping to create a stereoscopy.

This operation is separated in two steps. The first one called relative orientation and consists in introducing the tie points to generate a numerical layer in each photogram; moreover, using the epipolar images principle both photograms are being orientated in the same way so that each couple of homologue points are traces under the same axis. The absolute orientation then, reconstructs the geometry of each photogram in relation to the physical ground surface also calculating the position of the camera in relation to the terrain at the moment of the photo capture. During the absolute orientation, the ground control points have also to be introduced and indentified by evidencing their targets optically in the photogram and introducing their coordinates. Regarding the coordinates, attention should be paid in adding the correct coordinate types; wrong orthometric heights for example would create malfunctions in the correct DSM extracting. In relation with the quantity and distribution quality of the GCP the mathematic model of the software can calculate the residual quantities (Root Mean Square) also estimating an average displacement between each control point and its actual physical positions. (Figure 14)

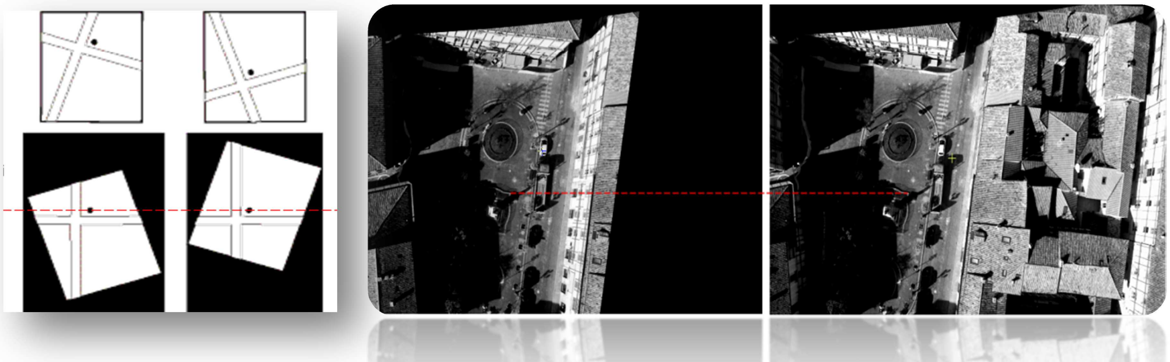


Figure 14
Using epipolar images to evidence all tie points and continue with the DSM creation.

In this way also an intrinsic quality control of all measurements and of the distribution and quality of control points, is cleared by the software. When all these settings are set the software can generate automatically a DSM by overlapping the two-epipolar images and using the stereoscopy between them also calculating the average characteristics of the studied area such as min and max elevation, failure and background values, DSM details and pixel sampling intervals. The last step regards the DSM extraction which has to be georeferenced using an opportune codification. The final result is a DSM re-projected to the ground coordinates system. (Figure 15)

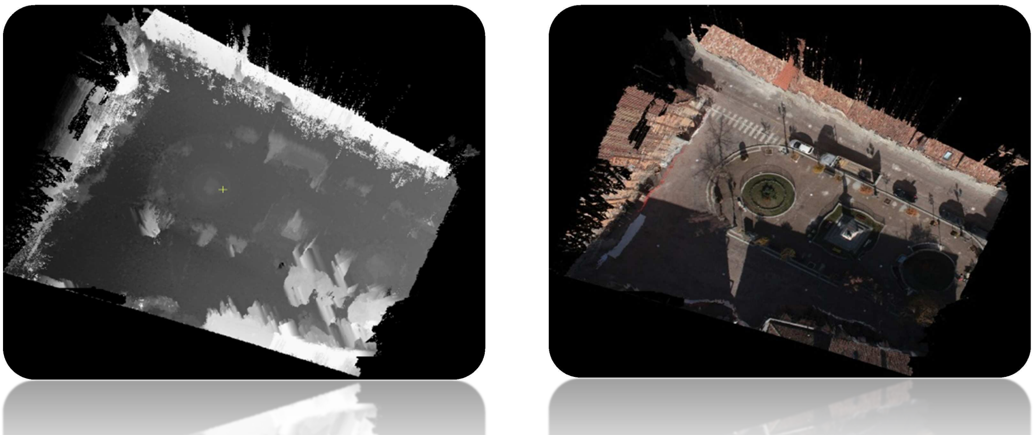


Figure 15
The DSM created for the Piazza Palazzo (on the left) and the final orthophoto
of the test area created using this DSM (right)

Having a DSM and using appropriate software orthophotos of the same area can also be generated. In figure 16 two detailed exports with resolution of 2 cm and 10 cm are shown respectively.

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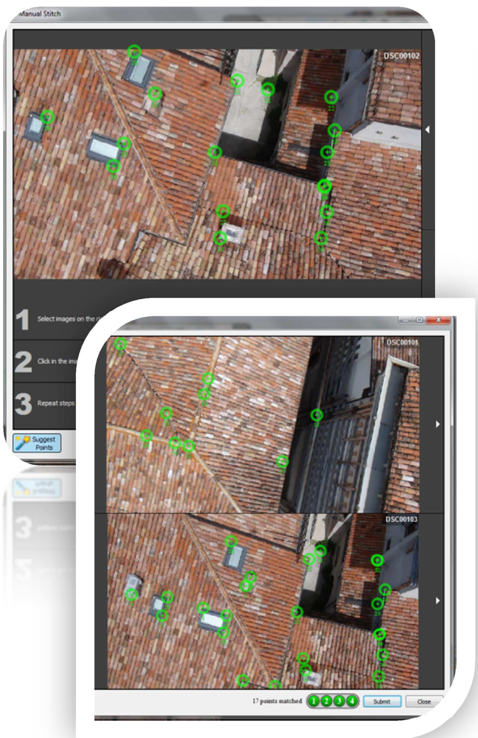
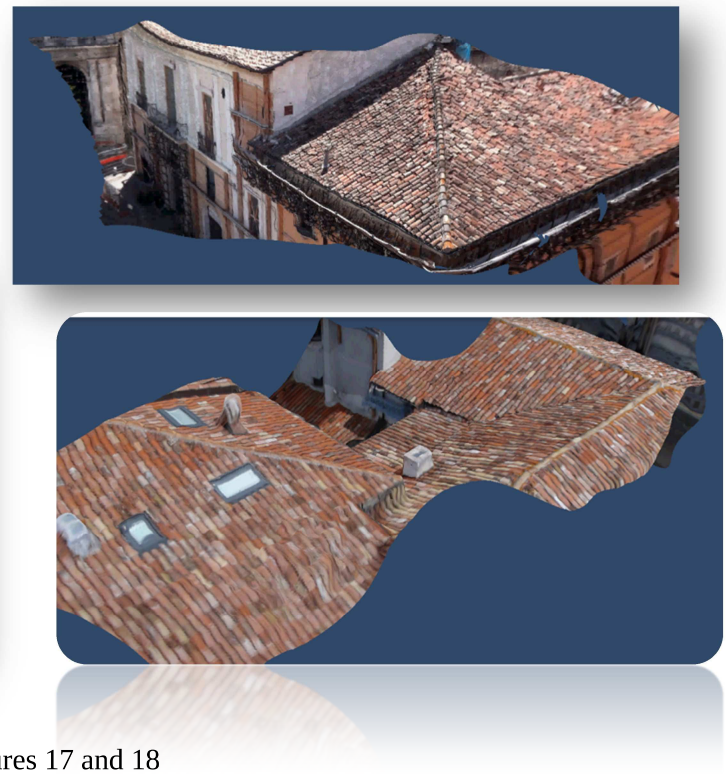
Figure 16
Exports of the same project using pixels with dimension of 2 cm (left) and 10 cm (right)

2.4 3D MODELS

With all the surveyed data, apart from creating DSMs and orthophotos was also thought to experiment the creation of three dimensional models by only using the initial photograms or even integrating them with photos taken manually by an operator.





Figures 17 and 18
Generating three-dimensional models for the building in the test area (left) using photograms surveyed by the micro Uav.

In fact, using appropriate software the creation of the 3D model was possible. Images 17 and 18 show the preliminary models created using photograms surveyed by the micro Uavs in Piazza Palazzo.

3. CONCLUSIONS

This experience demonstrated that surveying with micro Uavs can be a valid tool during emergency and post hazard situations. This study aims to continue researching for a better choice of the GCPs for a more equilibrated georeference of the 3D models. Thus, algorithms for an even more accurate DSM extraction have to be created. Moreover, other sensors and cameras have to be experimented, for example thermal cameras or possible SAR, to enrich all information regarding the construction materials and the structure itself.

Biographic notes

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Donatella Dominici is an associate professor in Engineering's Faculty - University of L'Aquila where teachs Surveying, Satellite Geodesy and Remote Sensing. She obtained a Ph.D.in Geodesy and Surveying in 1991 from Bologna University. Her areas of expertise are GPS analysis data and design network The latter includes design and materialization of GPS permanent network for Abruzzo Regional Council , monitoring with high resolution satellite images Abruzzo's coastline. She is the coordinator of Laboratory of Geomatics in Faculty of Engineering of L'Aquila, member of editorial board of Applied Geomatics and member of AFCEA 's council.

Valerio Baiocchi*

Valerio Baiocchi , graduated with full marks in Geological sciences at "La Sapienza" University of Rome during 1993. In 1999 he obtained his first PhD degrees in Geodesy and Cartography and in 2010 he obtained his second PhD in Infrastructure and Roads at "La Sapienza" University . From 2008 to 1992 he is Researcher- Adjointed professor at "La Sapienza" University , Department of Civil, Environmental and Building Engineeringg. He is the author of more than 150 scientific papers, published on specialized scientific journals and in the proceedings of national and international conferences.

Alessandro Zavino **

Alessandro Zavino graduated in Computer engineering in 2012. His thesis point of interest was the realisation of a WebGIS for the post seismic management of the emergency including a wide range of data received by geomatic surveys, space born technologies and Flying UAVs.

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Maria Alicandro graduated in Civil and Environmental engineering with full Marks in University of L'Aquila. At the moments she works at Geomatica_LAB as a a research associate in the fields of Geomatics and space born technologies.

Michail Elaiopoulos **
Michail Elaiopoulos is a graduating student in civil engineering under Prof Dominici. During the last months deals with structural monitoring of masonry monumental building using geomatic techniques for his thesis in Geomatica_LAB - University of L'Aquila.

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