UAV and Computer Vision in 3D Modeling of Cultural Heritage in Southern Italy

Vincenzo Barrile¹, Vincenzo Gelsomino¹, Giuliana Bilotta²
¹DICEAM Department, Mediterranea University of Reggio Calabria, 89100 Reggio Calabria, Italy
²Department of Planning, IUAV University of Venice, 30135 Venice, Italy

Abstract: On the Waterfront Italo Falcomatà of Reggio Calabria you can admire the most extensive tract of the walls of the Hellenistic period of ancient city of Rhegion. The so-called Greek Walls are one of the most significant and visible traces of the past linked to the culture of Ancient Greece in the site of Reggio Calabria territory. Over the years this stretch of wall has always been a part, to the reconstruction of Reggio after the earthquake of 1783, the outer walls at all times, restored countless times, to cope with the degradation of the time and the adjustments to the technical increasingly innovative and sophisticated siege. They were the subject of several studies on history, for the study of the construction techniques and the maintenance and restoration of the same. This note describes the methodology for the implementation of a three-dimensional model of the Greek Walls conducted by the Geomatics Laboratory, belonging to DICEAM Department of University “Mediterranea” of Reggio Calabria. 3D modeling we made is based on imaging techniques, such as Digital Photogrammetry and Computer Vision, by using a drone. The acquired digital images were then processed using commercial software Agisoft PhotoScan. The results denote the goodness of the technique used in the field of cultural heritage, attractive alternative to more expensive and demanding techniques such as laser scanning.

Keywords: Computer Vision, Cultural Heritage, Digital Photogrammetry, Reggio Calabria, Structure for Motion, Unmanned Aerial Vehicles.

1. INTRODUCTION AND HISTORICAL NOTES

There are many examples in the literature regarding the digitization of cultural heritage. The advent of the laser scanner has been an incredibly versatile solution for the acquisition of huge amounts of data with greatly reduced acquisition times guaranteeing high accuracies. This technology has been widely used in archeology [1]. Recently it has established a reconstruction of objects in the shape and size technique, which, starting from two photographic images taken from two different points of view, is able to obtain a metric 3D model of the object detected. This technique takes the name of digital stereo-photogrammetry, which in recent years was combined to the computer vision. This document describes a procedure for the acquisition and 3D modeling of the Greek walls of Reggio Calabria (Fig. 1) based on photographic images acquired by unmanned aircraft.

The city walls consisted of a wall “double curtain” (Fig. 2): only the bottom, given the chronic shortage of hard stone in Reggio, the walls are built with isodomic blocks of local sandstone,
maybe found in the Fiumara Annunziata, arranged in two rows parallel (Fig. 3), perpendicular with traits. The voids between the two curtains were filled with soil and rubble and on this solid base was raised the real wall, made of baked bricks. With regard to the structure, it must be said that the walls, built in baked bricks of which has not remained almost trace, are based on the local soft stone foundations, with many quarry marks. The preserved part is extremely interesting, because it is the point where the western walls were a corner, turning eastward, closing southern city walls of Reggio [2].

The construction technique is that typical of the core walls, masonry type used widely in the past for the construction of defensive works. It consists of two garments made in parallel and spaced stone or brick between them that have function of containment formwork and finishing superficial, and a gravel cast, between them, of a mixture of crushed stone and of the garments processing scrap, bound together by cement mortar or lime. The name derives from the fact that the two walls constitute a kind of sack in which the filling is poured. The ancient Greeks called the sack masonry *emplekton* and made use in particular in the construction of the defensive walls of their city [3].

From the historical point of view, it appears to be uncertain the date of construction. Guzzo found that the included bricks have been found fragments of pottery, but it stands as a *terminus post quem* quite wide; now the most likely hypothesis is that this is the wall built after the mid-fourth century BC, when Dionysius II rebuilt the city of Reggio with the name of Febea, the city of Phoebus Apollo. The Archaeological Office also suggested that, in Reggio circuit wall, the mud-brick walls are of the era of Anassila tyrant (V century BC), While those baked bricks are to be attributed to the tyrant Dionysius II, who remained in Reggio only between the 356 and 351 BC, when it was cast, and the freedom of Reggio inhabitants was restored. Other scholars think, however, that the walls, as we know them, are all of the last part of the fourth century BC, witnessing the actions of Dionysius II, the Reggio Republic and the king Agathocles [2].

The walls today are enclosed by a wrought iron gate and open to the public at fixed times. A recent restoration has not enhanced the cultural enjoyment of the Greek walls, although it has consolidated structure.

Fig. 1 – Area of the Greek Walls in the city of Reggio Calabria.
2. **Unmanned Aerial Vehicles**

Now in the common meaning Unmanned Aerial Vehicles are associated with the term UAV the multi-blade aircraft which are most commonly found on the market even if, strictly speaking, the term also extends to any means capable of moving with a high level of autonomy in the conduct of its control relation to the environmental situations in which it moves. This type of drones has been running for over 8 years on the market but at the time the news that bring them in prominence are:

- the fall of prices and the wide variety of available models;
- their greater reliability and versatility;
- their consequent far more widespread diffusion.

Currently, in fact, an UAV able to make photographic surveys useful for reconstruction goals analyzed in this article, is accessible to a growing number of professionals. Their low cost also impacts on significant cost that becomes much cheaper than those related to the use of more...
traditional engineering tools and it is desirable that the inherent said aircraft culture becomes more and more part of the university education, as are the other instruments [4].

However, it is important to emphasize that the drones are not simple aircraft and require the use of their professional preparation and maintenance. In addition, their use is regulated stringently in much of the Western world, and each survey must be done in compliance with current standards, as in the Italian case with the regulation issued by the Civil Aviation Authority and recently updated. The incompetence and negligence can lead to work so dangerous to himself and to others, risking to run into crimes both administrative and criminal type.

3. SURVEY AND RECONSTRUCTION MODELS

The principle on which the Structure from Motion technique (SFM) mirrors what happens for photogrammetry stereoscopic where the generation of the 3D structure is defined and resolved through the image overlay. Unlike for traditional photogrammetry, reconstruction of the scene with the placement and orientation of the camera is automatically resolved by the software used [5]. There is, thus, the need to specify a priori remarkable points or targets present in the acquired images. These are automatically detected and resolved by the software, based on a photographic campaign consisting of strips with overlap of images of the scene to be captured. This technique is particularly effective when the photographs are constituted by a set of images with a high degree of overlap such as to allow a full three-dimensional reconstruction of the captured scene. Developed in the 90s, it traces its origin from the computer graphics. Despite the enormous potential of the system, to date it has not found widespread use in the field of geomatics [6]. The following describes the workflow necessary for obtaining a dense cloud and the three-dimensional model.

The first step is identifying and extracting the significant points in each photograph taken. This is done by an algorithm implemented by D. Lowe in 2004 defined the SIFT (Scale Invariant Feature Transform) [7]. Thanks to this algorithm are, first, the identified homologous points present in the shots of interest by operators, subsequently, through the use of image descriptors, they will be chosen, between the homologous points identified, those that deviate less from each other. In addition to intrinsic values (such as lighting, color, rotation, etc.), homologous points are searched within particular areas of the scene: the corners or areas where you are having more elements of discontinuity. Identified the homologous points these should be coupled [8]. This is done through their matching. At this stage, it is crucial to assess the similarity between the various identified points. For this purpose, it uses the concept of Euclidean distance. Identified a point in the first scene having certain characteristics (brightness, color, etc.), the counterpart in the next scene appears to be the one that most closely matches the one in question. It is also determining the use of epi-polar geometry to define geometric constraints that bind the homologous points identified in the pictures depicting the same scene. In the next phase, the generation of the 3D model. To do that identifies the interior orientation parameters of the room used for the sockets. The identification takes place through the correspondences already identified (homologous points and epi-polar geometry). In this phase the control and limitation of the errors is through the "bundle adjustment". Last step is the generation of the model through a dense cloud. Here we are used the algorithms of dense image
matching. They are divided into two types, the area Based Matching Algorithms (AMB) that work on the statistical comparison of the intensity of gray present in the various photos and do not provide the feature extraction processing the intensity of the gray; and algorithms of Feature Based Matching (FBM) that before seeking the common feature, and then perform the extraction [9]. The combination of both ensures optimal results but considerably lengthens the processing time. It turns out to be critical of the photographs shot methodologies. It should be mentioned that the reconstruction systems from photo return a model that is proportionately correct but does not result to be to scale. The cloud of points obtained does not appear to be georeferenced but represented in a local system. Therefore, it should move from a system of spatial coordinates to an absolute coordinate system. This is possible by identifying a large number of ground control points with known coordinates and traced inside the cloud obtained through SfM reconstruction. The following will discuss the steps needed to create a cloud of dense points through SfM techniques.

The Structure from Motion technique is used in various applications related to the environment UAV (Unmanned Aerial Vehicle). The software used for this study is produced by PhotoScan Agisoft LLC of St. Petersburg (Russia); it allows the generation of dense clouds, meshes and textures. Agisoft PhotoScan is a low-cost commercial software that allows you to get a high-quality 3D model. The workflow is fully automated both with regard to the orientation of the images for both the generation and reconstruction of the model. The generated model can be exported to be managed and possibly treated with external software. All processes can be performed with various levels of precision and different parameters can be set in order to improve the result. For the work in question has been used PhotoScan installed on an HP Z800 Workstation. The workflow is fully automated both with regard to the orientation of the images for both the generation and reconstruction of the model. This condition has led to an optimization of the processing time guaranteeing good performance of the machine/software complex.

For the acquisition of the photo to use in the 3D reconstruction was used the drone of the DJI Phantom 2 equipped with a digital camera GoPro HERO3+ Silver Edition which, thanks to its technical and handling characteristics in use, is well suited to use of this type. The flights for several surveys have been set in automatic mode thanks to the preparation of flight plans, set by inserting waypoints with known coordinates obtained from ground surveys with GNSS RTK rover kinematic mode made at earlier stages (also useful in being processed for scaling the
The possibility of real-time control of the drone through a ground station allowed to have detailed and accurate shooting of the investigated works by monitoring the position, the altitude and the device status.

The processing steps were as follows:

1. **Align photos** (photo array) consisting in identifying the binding sites using interest operators. The points selected in the various photos must have common characteristics in order to be properly overlapped. For a good result the image quality to be high, you have to have a few gray areas and adequate lighting;

2. **Build Dense Cloud** (heavy cloud). Through this phase, it is built a dense cloud using the algorithms of dense image matching. These are divided into algorithms that use a stereo pair to find matches (stereo matching) and those that identify them in multiple images (multi-view stereo);

3. **Build mesh**, that is to generate a polygon model based on the newly created dense cloud. The mesh is a subdivision of a solid into smaller solids of polyhedral shape;

4. **Build texture**, allows instead to obtain the 3D representation of the work under investigation.

Table I – Summary of processing data

| No. Photo | No. Sparse Cloud Points | No. Dense Cloud Points | No. Sides | No. Vertices | Survey Time | Processing Time |
|-----------|------------------------|------------------------|-----------|--------------|-------------|-----------------|
| 124       | 75472                  | 2844896                | 189659    | 96275        | 0,5 h       | 12,00 h         |

Fig. 5 – UAV ground station screen with flight waypoints.
4. COMPARISON OF RESULTS AND CONCLUSIONS

To see what has been achieved by the combination UAV and PhotoScan, the use of the proven laser scanning technique allowed to rebuild in another way a 3D model of the Greek walls using point cloud, and make a comparison in terms of accuracy, time and cost of modeling between the two methodologies image-based and range-based. For the work scanning, a laser scanner RIEGL LMS-Z420i has been used.

The survey was structured with the choice of the instrument position, its set-up, and its calibration. Following the acquisition of the data and the step of processing data with
registration of point clouds, filtration, cleaning data, modeling and creation of three-dimensional mesh [10].

The evaluation of the accuracy is based on the finding of 5 target points placed on the walls and materialized on the comparison of the results obtained compared to traditional surveying with total station High-precision automated Leica TCRA 1201.

Fig. 9 – Greek Walls: Laser Scanner survey.

Fig. 10 – Comparison of errors (cm) in the two systems.

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