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UAV-BASED PHOTOGRAMMETRY AS AN INTEGRATION IN MULTI-SENSOR ARCHITECTURAL SURVEY

USO DE LA FOTOGRAMETRÍA CON UAV PARA INTEGRAR LEVANTAMIENTOS ARQUITECTÓNICOS CON MULTISENSORES

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ABSTRACT

Current methodologies used in architectural surveys allow to obtain 3-D models featuring high precision for geometry and shape and good quality for chromatic data. Several researches are available in bibliography, showing how easily high-precision models, with high-quality photorealistic textures, can be obtained by using and combining laser scanning and terrestrial photogrammetry.

Anyway, there are some contexts in which achieving good quality surveys with these techniques is logistically complex, such in the case of areas with difficult or no access (roofing, high façades, etc.). In many of these cases, a solution can be found in an innovative survey methodology, which is becoming more and more popular: Unmanned Airborne Vehicle (UAV)-based photogrammetry, with processing of data via Structure from Motion (SfM) procedures.

The present paper describes a study of the integration of different survey methodologies (laser scanning, ground- and UAV-based photogrammetry, total station) in order to obtain a full featured 3-D model, whose accuracy has been checked.

Keywords

UAV, laser scanner, structure from motion (SFM), aerial photogrammetry, architectural survey.

1. INTRODUCTION

In order to correctly plan a restoration intervention a good survey is mandatory in the preliminary study. The methodologies currently used in the architectural survey allow to obtain highly accurate three-dimensional models, in both geometric and morphologic viewpoints, and a good quality color information. In literature (e.g. Guidi, G., Russo, M. y Beraldin, J.A., 2010, Koska, B. y Křemen, T., 2013, Wenzel, K., Rothermel, M., Fritsch, D., Haala, N., 2013), descriptions of numerous investigations are found, showing that, using and combining terrestrial laser scanning and photogrammetry, the achievement of highly accurate models with photorealistic textures is relatively easy.

Figure 1. UAV capturing the façade of the church.

However, using such techniques a still unresolved issue is presented: the areas not accessible, either for elevations greater than those achievable with the survey instruments, or simply impassable. In this case, both terrestrial photogrammetry and laser scanning are not an option. In many cases, sloping roofs, domes, façades located in areas near ravines, or simply areas with very little space between façades, prevent correct photo shooting and/or laser scanning which would allow for a complete survey, able to generate three-dimensional models. A solution to this problem is sought in the introduction of a new surveying methodology: UAV (Unmanned Air Vehicle)-based photogrammetry and SfM (Structure from Motion) techniques for post-processing of the data.

UAVs are a new support medium for photogrammetric data acquisition, which in recent years is going through a phase of great development (Bendea, H., et al., 2008; Friedli, E., Theiler, P.W., 2014; Gruen, A., et al, 2012; Lingua, A., et al., 2009; Uribe, P., et al., 2015). Until now, aerial photogrammetry has been limited to small scales inherent in the average aircrafts flight height, while terrestrial photogrammetry had the problem of not being able to meet the requirements mentioned in the previous paragraph. UAVs are presented as an intermediate solution that allows greater flexibility in the network for taking photographs. On these premises, the integrated survey of the Romanesque church of San Miniato in Marciana, in the Province of Pisa (Italy), is presented.

The goal is to perform the mapping of the church, including the roof plan, not easily obtainable by other high precision methods. For these purposes, a high number of photos of the roof has been collected by a UAV-borne camera; subsequent use of automated and semi-automated methods allows to obtain a model of the roof. In addition, a UAV-borne photogrammetric survey is performed on the main façade, which has also been surveyed by laser scanning. This allows a comparison between these two survey methods performed on the same object.

2. SURVEY METHODOLOGY AND DATA PROCESSING

The church of San Miniato is quite simple, featuring a single nave, a single level and two doors. It is located in the center of a plot devoid of any attached building. Therefore its survey does not introduce any difficulty, save for two façades (North and East) with a rather narrow passageway. In order to achieve a complete model of the church, it was decided to use different survey techniques. These include laser scanning for surveying the inside and outside of the church (with the exception of the extrados roof, not accessible), aerial photogrammetry for surveying the main façade and roof, terrestrial photogrammetry for the application of photorealistic texture to the laser scanning model and total station to bind laser scanning and photogrammetry data with high precision. The survey of the same area (the main façade) with both methodologies, allows in turn the control of the UAV-borne photogrammetry methodology, in which the achievable accuracy is not repeatable nor homogeneous. A total station survey is used to measure the position of 67 Ground Control Points and Control points useful to scale the model and to performed comparison and accuracy analysis of UAV photogrammetry.

2.1 Laser scanning

For the design of the church plan the survey conducted by laser scanner is used as a base. Four scans have been performed inside the church, and seven more outside.

In the post-processing phase all scans are imported into the processing software and oriented in the same reference system. From the oriented point clouds, a three-dimensional high precision model is generated (3.73 million polygons mesh). Starting from this model it has been possible to obtain horizontal sections to define plans and transversal and longitudinal vertical sections to define the orthographic projections of the ancient walls.

These highly detailed horizontal and vertical sections will in future phases allow the pathological study of the church, allowing to submit drafts for restoration or rehabilitation and maintenance.

A new model optimized for rendering was obtained by a "decimation" (reduction of the details) of laser scanning model. On this lighter and more manageable 3D model a photo-realistic texture derived from high-resolution photographs has been applied and then exported into an entertainment-grade modeler, enabling different renders, for display as synthetic image, and possibly for the production of a model of the church.

Figure 2. Transversal and longitudinal section of the church.

2.2 Aerial photogrammetry from UAV

Photographic shootings of roof and principal façade have been performed by an UAV-borne camera. The aircraft used is a yet unmarketed prototype UAV, manufactured by Pisa-based CAM (Costruzioni Aero Meccaniche - Air Mechanical Manufacturing), an industrial partner of the ASTRO Laboratory (Applicazioni Scientifiche Topografiche per il Rilievo Operativo - Scientific topographic applications for field survey - of the Department of Civil and Industrial Engineering, University of Pisa). The camera used is a full frame Nikon D600 with fix 50mm focal length lens. The camera shoots a photograph every second. The flight's altitude and speed are planned to obtain a Ground Sampling Distance (GSD) of about 2 mm and a minimum image overlapping of 70%. In the case of the UAV used in the survey, the maximum duration of each flight ensured by the onboard batteries is about 10 minutes. The UAV was remotely piloted by a specialist that performed three flights (each one of about 4 minutes): one for the principal façade only, and two including the area of the main façade and the roof. For the survey of the roof the flight's altitude is approximately 30 meters and for the survey of the facade the UAV flew along a vertical path at a distance of 15 meters from the building.

Data are processed with SfM techniques, using Agisoft's PhotoScan software. Two separate models are obtained, one of the roof and one of the façade.

The first one is generated by processing of a set of 36 pictures and allows completion of the model obtained by laser scanning. The second one is generated by processing of a set of 18 pictures and allows to compare the results of laser scanning and SfM from UAV-borne photogrammetry models.

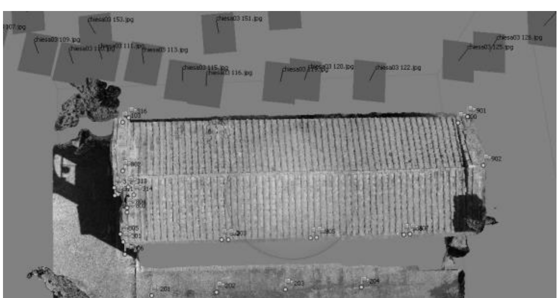

Figure 3. SfM model of roof from UAV-borne survey

The comparison of these models yields an average deviation of 12 mm. This average can be considered an acceptable value for a representation at architectural scale of the model. It should be noted that the geometric resolution of the model is less than the one given by image resolution that allows reading details which have a size close to the millimeter. Furthermore the homogeneity of precision of models obtained by laser scanning is greater than that of SFM-derived models. It can be concluded that SFM-derived models can be used with advantage in those cases in which a higher radiometric resolution is required rather than a high geometric detail.

3. RESULTS

The result of this study is a complete three dimensional model. From this model, several orthophotos of the various exterior façades and sections of the interior of the church have been obtained. The representations obtained in this model yield a detail with good accuracy for typical architecture scales ranging from 1:20 to 1:50.

The geometrical precision obtained from terrestrial laser scanner is the order of 1cm. On the other hand, the graphic resolution of the applied texture is higher and coincides with the linear dimension of the pixel, in the order of 1 mm. This allows reading of very small elements (e.g. rifts, cracks, deformations, etc.). This statement is confirmed by the orthophotos generated from ground-based surveys.

In the parts where laser scanning surveys were not practicable (e.g. Roof), SfM methodology has been very helpful. The accuracy, as commented in previous paragraphs, is not homogeneous but is, however, comparable to that obtained by laser scanning. Also in this case, the photographs used in SfM generate high resolution textures.

From plans obtained, it is possible to generate a complete restoration project. The resulting sections can be used to analyze small displacements, either vertical (due to subsidence for changing of water table, nearby excavations...) or horizontal (due for example to push from the cover), wall thickness, presence of voids (windows, doors, etc), current status of the wood trusses of the cover, and, thanks to the introduction of the UAV-survey, the status of the roof tiles and the roof in general (e.g. areas with missing tiles, not noticeable from the ground).

The roof model, and the plan generated from this, has allowed to detect several points where the replacement / integration of some tiles is needed. With this intervention it is possible to eliminate the presence of water leaks due to a badly preserved roof.

This type of survey also allows regular monitoring that would eliminate the high costs connected with water leaking in the interior of a church, with all that entails.

A further advantage of the integrated survey is having a single reference system for all data. This allows to build an information system of the architectural object, to which all documentation and georeferenced elaborations can be referred.

Figure 4. Render of the church from integrated surveys

4. ANALYSIS OF PATHOLOGIES FOR FURTHER INTERVENTION

From the three-dimensional model of the church, orthophotos are generated, in order to conveniently investigate the pathologies found in the building. Results of these investigations are subsequently analyzed and the necessary solutions to intervene in the process of restoration are presented.

Two examples are presented in the orthophotos generated of the roof and facade. The resolution of textures obtained from models developed with SfM allows to detect the pathologies present in the church. In the detail below (Figure 5) two pathologies can be identified: one consists in missing or broken tiles (detectable by the naked eye), and the other is biodeterioration (pathology more widely present in the church), consisting of yellow patches in most of the tiles, masking their original red color.

Broken or missing tiles, besides aesthetic issues that can be neglected due to their location, can lead to water flowing along the façades, and water leaks inside the church. Flowing of water along the façade leads to biodeterioration, due to the porosity of stones, in which it is retained, leading to germination of spores and seeds and ultimately to presence of microorganisms, lichens, etc. Leaks, on the other hand, can cause well-known damage to the interior due to introduction of water.

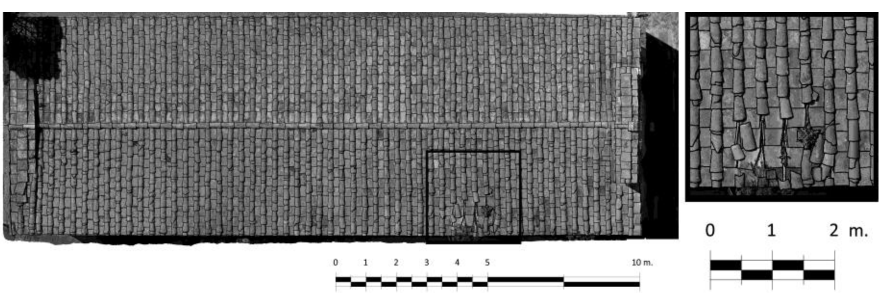

Figure 5. Ortophoto of roof (left) and detail (right).

Moreover, a detail of the façade (Figure 6) reveals pathologies such as vegetation, due to the presence of water along with spores and seeds, and black crusts. These are an evolution of biodeterioration, i.e. while in the latter attacking microorganisms are active, in black crusts involved microorganisms are no longer active and concur to the creation of a layer of dead material that hardens and thickens over time, due to the adhesion of dirt and other particles.

Another noticeable pathology is alveolization or disintegration. Higher humidity levels in north facing façades, with scarce – if any – exposure to direct sunlight, cause partial dissolution of stones due to flowing water.

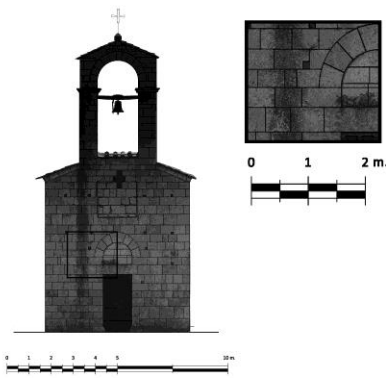

Figure 6. Ortophoto of main façade (left) and detail (right).

5. CONCLUSIONS

The proposed methodology allows to obtain a three-dimensional model which can generate a complete survey. So far in historic buildings, whenever preliminary study were required for any further intervention, the survey of roofs involved high difficulty levels in both operative and economic terms. The problem of access, to damaged or complicated accessibility areas, are always one of the most conflictive for this survey.

The introduction of UAVs for the survey of roofs and areas with accessibility issues has been a major advancement in jobsite safety also allowing major reductions in costs.

The difference between models based on SfM techniques and on laser scanning has been substantially reduced, since the reliability of the models of the first type is closely linked to the ability of the operator to appropriately structure the network (the position of the different cameras relative to the object). From this point of view, UAVs have been a major advance, allowing to eliminate one of the most common problems in photogrammetric surveys of closely placed elements, i.e. vertical plane shootings.

An example can be provided by standard building, where a camera can capture essentially the lower levels. Although it is possible to capture wider areas using the zoom, ultimately the object is developed mostly horizontally and therefore the reliability of such a survey will be very high at the bottom and much lower on higher levels. The uses of UAVs allows for a vertical development of network enabling documentation of the objects from many viewpoints. This in turn allows to approximate the precision of photogrammetric surveys to that based on laser scanning.

Models obtained with photogrammetric techniques have variable accuracy (depending on acquisition method, type of camera, medium - i.e. airborne or terrestrial photogrammetry - and software used in the process of elaboration), but, by using appropriate methodologies and by controlling the generating processes, may be suitable to integrate data collected with different instrumentation such as terrestrial laser scanners, Total Stations, GPS, etc. Therefore, SfM techniques can be considered a good method for integration with other methodologies. Integration of models, and consequently of modelling techniques, is essential, and therefore important for analysis both architectural and related to interventional techniques.

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