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# High-Resolution Photogrammetric Survey of a Romanesque Mosaic Floor: A Comparative Analysis of UAS and a Custom-Built Acquisition System

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***Abstract*** **– The high-resolution survey of flat surfaces of significant historical and artistic value, such as decorated floors and mosaics, is a fundamental phase both for the documentation and the preservation of cultural heritage. Given the material and chromatic complexity of these objects, it is essential to obtain photogrammetric data that are accurate from both a geometric and radiometric point of view. This study compares two approaches to this task, both involving a typical photogrammetric workflow, but from two different point of view: firstly, an acquisition using a Unmanned Aerial System (UAS), and secondly, an acquisition very close to the object using a camera mounted on a prototype for mobile photographic acquisitions. This prototype is under development and already tested by the authors, which uses cross-polarisation with a camera and lighting integrated in an enclosed environment into a mobile cart. The aim is to evaluate and compare the effectiveness of two systems in terms of i) speed of acquisition, ii) ease of use, iii) metric quality, iv) level of detail, v) presence of reflections and vi) surface documentation capability.**

## I. INTRODUCTION

Decorated surfaces and floors of historic buildings are assets of great interest and require regular maintenance, conservation and documentation, as they are unique artefacts due to their nature and are particularly exposed to decay and degradation. Given their importance and characteristics, these artefacts are usually surveyed using photogrammetric techniques to capture colorimetric data with high accuracy [1] [2]. Photogrammetric techniques make it possible to capture high-resolution images of surfaces and create accurate three-dimensional reconstructions from which orthophotos can be derived, providing important data for their conservation. One of the most significant challenges related to this surveying technique concerns the material composition of floors and surfaces. Often, in fact, they are made up of heterogeneous materials which have specific physical characteristics, including the reflectivity which can affect the quality and accuracy of the surveys carried out. Understanding and managing these physical parameters is essential to ensure accurate surveying.

As far as geometric accuracy is concerned, the main criticality occurs when photographic acquisitions are made at inclined angles rather than in nadiral mode. In these cases, the Ground Sampling Distance (GSD) is variable according to the distance between the camera and the different points of the framed surface [3]: there will therefore be pixels with reduced dimensions in the areas close to the lens and significantly larger pixels in the more distant areas.

At the same time, the qualitative aspects concern the ability of the acquisition system to faithfully reproduce the surface characteristics of the object, regardless of environmental conditions (e.g., various light sources, reflections and shadows from external environment, people flow passing on the floor). To prevent these issues, it is essential to ensure accurate reproduction minimising the presence of external disruptive factors.

The following paper discusses the application of photogrammetry exploiting both an Unmanned Aerial System (UAS) and a ground camera (mounted on a custom-made tool) for the acquisition and measurement of horizontal surfaces, with particular attention to the documentation of floors with significant historical interest. The first acquisition was performed exploiting a camera mounted on a prototype of a mobile photographic acquisition system, developed by the authors [4], the second acquisition was carried out exploiting the camera of a commercial UAS. The two acquisition systems were compared following various criteria, to define the most suitable in various possible scenarios.

The paper is organized as follows. Section II presents related works regarding surveys of floors of historical value (including mosaic floors), and surveys of mostly flat archaeological sites. Section III presents the case study to which the methodology presented is applied and describes the methods and tools adopted during the survey conducted. Section IV describes the results obtained and discusses the differences and peculiarities of the two methods. Lastly, in Section V, the conclusions are presented, discussing the results obtained and future developments.

## II. RELATED WORKS

Several works in scientific literature addressed the topic of survey of historic floors, mainly with the use of photogrammetry techniques. Existing studies have applied various photogrammetric method (from handheld, pole, and drone-mounted cameras to integrated survey techniques) for documenting mosaic floors, prioritizing resolution and managing in various ways ambient light and reflection challenges.

Doria and Picchio [1], for example, used images taken by hand or on a pole with a camera for the Byzantine mosaic floor's survey in the Church of the Nativity in Bethlehem. Another example is what Fazio et al. [5] did to document the ancient Roman floor belonging to a temple in the archaeological park of "Lilybaeum" in Marsala, Sicily. The researchers used a pole-mounted camera with a camera-to-object distance of 3 meters, covering an area of 3x2 meters for each acquisition. Caldeira et al. [2] exploited a UAS to survey, in an archaeological area in Portugal, a Romanesque mosaic belonging to a villa. The flight altitude was about1.5 meters through all the survey. In all the presented researches, authors focused on both the accuracy of the geometric acquisition and the generation of high-resolution images to achieve a highly resolute texture, but the influence of ambient light and light reflection effects was not addressed, as the floor surveyed were mostly outdoors.

In contrast, Conen et al. [6] worked with polarized light to reduce reflections from ambient lights and improve image matching, but the object its scale and its position were dealing with laboratory conditions. Another example of photogrammetric acquisition of an indoor floor where the ambient light was somehow taken into consideration was the photogrammetric survey of the floor of San Marco Basilica in Venice [7], which was conducted with an approach that integrated photogrammetry and topography, performed with traditional photogrammetry techniques. The researchers obtained the geometric model and orthophotos of the entire floor using a camera mounted on a trestle with nadiral shot distance from the object of about 2 meters. Floor acquisition was performed during the night, the general light settings, provided by artificial devices put in place by the authors, were sufficiently homogeneous and working by night ensured that the images acquired by the camera were not altered by sunlight.

These contributions showed how the research carried out on the acquisition of horizontal surfaces has focused on obtaining high-resolution images without being always able to control the reflection of indoor or outdoor environment light. In this paper we want to test and compare the two acquisition systems, UAS and prototype of mobile photographic acquisition system made by the authors, pointing out the qualitative differences in image acquisition.

## III. MATERIALS AND METHODS

### *A. Case study description*

The Basilica of San Michele Maggiore in Pavia is one of the most important examples of Romanesque architecture in Northern Italy. It was built between the end of the Eleventh and the beginning of the Twelfth century. The basilica underwent an important stylistic restoration in the Nineteenth century by engineers Carlo and Siro Dell'Acqua. During this period, a mosaic from the Romanesque era came to light, of which some portions remain today. The floor mosaic is located in the presbytery and depicts the themes of the "Months" of the year and the "Labyrinth". Opicino de Canistris from Pavia (c. 1296 - 1336) in the "*Liber de laudibus Civitatis Ticinensis*" attests to its presence in 1330, defining it as "*incredibili et admirabili pulchritudine decoratur*" (it is adorned with incredible and admirable beauty) and considering it one of the major attractions of Pavia.

This polychrome historiated floor mosaic, which originally occupied the entire presbytery, has come down to us in fragmentary form at two different times in 1863 and 1972 on restorations. The entire presbytery measures approximately 11x9 metres, with a paved surface area of approximately 99 square metres. The precious floor mosaic has been damaged since before 1580-1590, that is, since the marble altar of 1383 was moved from its original location (further back towards the apse) forward, coming to cover part of the floor lithostratum, some "Months" and a portion of the "Labyrinth". In 1967 Adriano Peroni, professor of History of Medieval and Modern Art in Pavia, studied and restored the design of the original mosaic. During the nineteenth-century restorations, tiles were built to keep that presbytery floor distinct from the ancient rest of the presbytery [8].

Nowadays, it is possible to see portions of the mosaic on the floor of the presbytery, surrounded by tiled flooring on which the possible continuation of the mosaic labyrinth design has been engraved, as can be seen in Figure 1.

*Fig.1. Portion of the floor, where it is possible to see a fragment of the remaining of the mosaic floor (the "Labyrinth" theme in this image) surrounded by the more recent tile floor. Note the engravings on the tiles (on the lower part of the image), that mimic the continuation of the mosaic floor.*

### *B. Survey tools and survey phases*

This article aims to compare the results of two photogrammetric acquisitions carried out using different methods and tools (i.e. UAS and ground camera on the prototype of a mobile acquisition system). In order to support both the photogrammetric surveys, a total of 27 markers were placed on the floor, forming a grid, and their coordinates were obtained from measures taken with a total station (Leica TS30).

The first survey conducted was completed exploiting the terrestrial acquisition with the camera mounted on a prototype of mobile photographic acquisition system. This prototype (fig.2), which was previously developed by the authors [4] and is still under study, allows photographic images to be captured in controlled, uniform lighting conditions without reflections or external interference in every shot; it also allows colours in images to be controlled, shots to be taken at the same height from the ground and with the same coverage, and orthogonal to the floor surface. The system consists of a wheeled cart that can be moved across the floor surface; the trolley is enclosed by blackout curtains, lighting is provided by spotlights, the camera can be positioned orthogonally and the height of the system is adjustable. The colour of each shot can be controlled by correcting the colour of the images using a ColorChecker system applied to the first shot. Since the lighting conditions are consistent across all shots, the colour correction applied to the first shot can be considered valid for all the others. Reflections can be minimised as the use of polarised filters on both the lights and the camera ensures cross-polarisation.

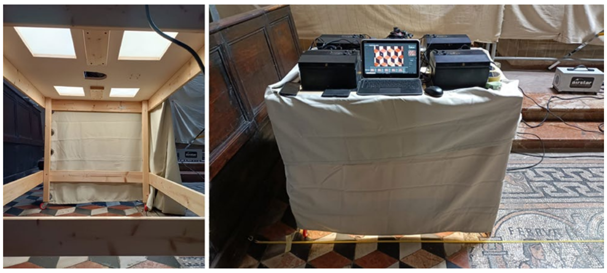

*Fig.2. Picture of the prototype of the mobile photographic acquisition system developed by the authors and used in this study. Left: view of the prototype from the inside. Right: view of the prototype in use on the mosaic floor; note how the blackout curtains ensure that there are no external influences.*

A Canon 5DSR camera with 35 mm lenses (sensor size 36x24 mm, image size 8688x5792 pixels) was mounted on the mobile photographic acquisition system, the height respect the floor was set to 0.85 meters, covering a photographic area of 0.9x0.6 meters with a GSD of approximately 0.2 mm. The acquisition was performed following a set of strips, having an overlap between the various acquisition sequences of 70-80% longitudinal and 30-40% transverse. 772 photos have been produced in a time of 3.5 hours.

The second survey was performed exploiting the UAS DJI Mavic 3 Cine, which mount a Hasselblad L2D-20C camera with a 24 mm equivalent focal length and 17.3x13 mm sensor size (image size 5280x3956 pixels). The flight altitude was of 1.80 meters above the floor for a GSD of approximately 0.5 mm. The flight altitude of the drone has been defined to allow safe flight avoiding obstacles and ensuring adequate ground coverage. An excessive proximity to the floor would have also led to a greater influence of reflections from external lights and a greater presence of shadows brought by the UAS itself on the floor. The acquisition was performed following strips and ensuring overlapping both longitudinal and transverse, as for the previous case. The survey was conducted in 15 minutes producing 356 photos.

### *C. Data processing*

The data from both surveys were processed using the Structure From Motion (SFM) approach, as it allows the photogrammetric model to be calculated more automatically and efficiently than more traditional techniques, taking into account both flat and curved surfaces [9]. Agisoft Metashape was used for the photogrammetric calculation.

Prior to performing the computation, the images captured with the camera mounted on the mobile prototype were colour-corrected with Adobe Lightroom software using a colour-profile obtained exploiting the ColorChecker. Considering the strong variations in environmental condition of the images acquired with the

UAS, and due to the impossibility of maintaining the same lighting conditions for each shot, the use of ColorChecker for colour calibration in images with UAS was not considered, and the images were used as captured without colour correction.

In both cases, processing with Agisoft Metashape was carried out using the typical workflow for this software: image orientation (key point limit 40,000, tie point limit 8,000), model georeferencing, dense point cloud generation (depth maps computed in high quality), mesh and orthophoto generation (Fig. 3). Both photogrammetric models were georeferenced and scaled using the GCPs coordinates previously measured with the total station. For the generation of the orthophotos, we kept the highest quality, in order to evaluate the best results in terms of quality.

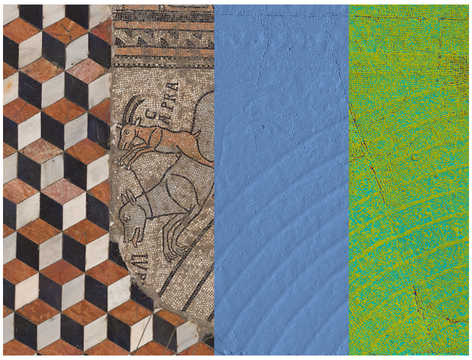

*Fig. 3. Portion of the floor acquired with the prototype of the mobile photographic acquisition system in three display modes. From the left: true colour orthophoto; mesh model; coloured 3D mesh highlighting the differences in heights.*

## IV. RESULTS AND DISCUSSION

Two types of comparisons were conducted: i) geometric analysis by comparing the number of polygons of the mesh, Ground Control Points (GCP) and Check Points (CP) errors, point cloud deviations, and ii) visual analysis, by comparing orthophotos, degree of influence of external lights, absence of reflection, pixel size.

During the survey phase, a total of 27 markers were placed on the ground in an almost regular grid. Within the photogrammetric process, 14 of them were used as GCPs, while 13 were used as CP (fig.4). As regards the survey carried out exploiting the camera mounted on the prototype of mobile acquisition system, an average error in the GCPs of 0.0012 m was identified, with a maximum of 0.0016 m and a minimum of 0.0005 m; the average error in the CPs was 0.0018 m, with a maximum of 0.0027 m and a minimum of 0.0006 m. As regards the survey with UAS, on the other hand, an average error in the GCPs of 0.0076 m was identified, with a maximum of 0.0199 m and a minimum of 0.0004 m; the average error in CPs is 0.0068 m, with a maximum of 0.0147 m and a minimum of 0.0017 m. GCPs and CPs average, minimum and maximum values are also reported in Table 1. It can be observed that the accuracy reached by the prototype system was greater.

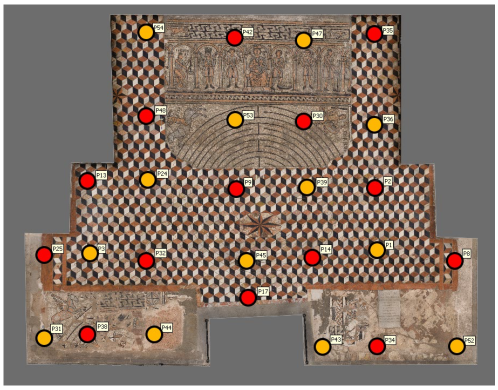

*Fig. 4. Top view of the survey area with depicted the position of 14 Ground Control Points (in red) and 13 Check Points (in yellow).*

*Table 1. GCPs and CPs average, minimum and maximum values for both the photogrammetric processes of UAS survey and camera on mobile prototype survey*

| | **Camera on prototype** | **UAS** |
|---|---|---|
| *GCP average* | 0.0012 m | 0.0076 m |
| *GCP max* | 0.0016 m | 0.0199 m |
| *GCP min* | 0.0005 m | 0.0004 m |
| *CP average* | 0.0018 m | 0.0068 m |
| *CP max* | 0.0027 m | 0.0147 m |
| *CP min* | 0.0006 m | 0.0017 m |

A second analysis involved a direct geometric comparison between the two point clouds obtained from the photogrammetric process. The two point clouds were oriented in the same reference system as they were produced after entering exactly the same GCPs for georeferencing and scaling both photogrammetric models. The two point clouds obtained were then compared in CloudCompare using the C2C algorithm, which calculates the absolute distance between neighbouring points belonging to two different clouds (fig.5). The result shows that, with the exception of a greater deviation between the two point clouds (around 2 cm, in red) in the lower left corner, there are areas with a distance very close to zero (in blue) and areas with distances around 5 mm (in green). The distribution of distances shows an average distance of 0.0023 m with a standard deviation of 0.0025 m. Based on this, it can be inferred that there are minimal deviations between the two systems, with the exception of the lower left corner, which can be attributed to possible errors due to less photographic coverage in that area in the UAS survey.

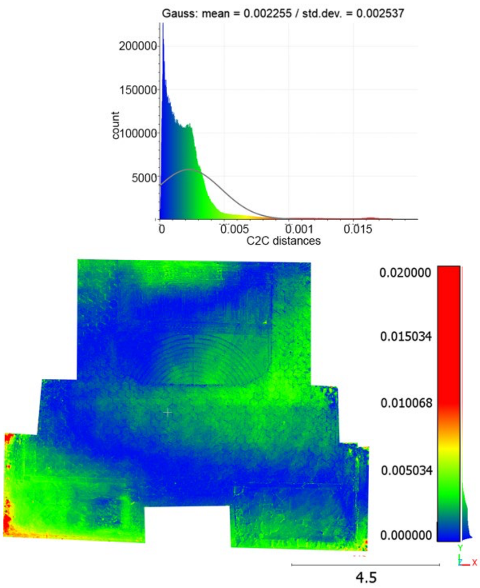


*Fig. 5. Comparison between the two point clouds obtained through photogrammetric workflow. The comparison was made in CloudCompare using the C2C algorithm. Top: graph showing the Gaussian distribution of distances. Bottom: top view of the point cloud with a colour scale in accordance to the distances computed. Values in meters.*

Regarding the visual analysis, the orthophotos generated by the two systems had substantial differences. The image quality obtained using the camera mounted on the mobile acquisition system was better: by inspecting the orthophoto it was possible to observe that the result was not affected by ambient lights and reflections, which were clearly visible in the orthophoto generated by the UAS survey (fig.6). Then, considering the difference in GSD, the pixel resolution of the image obtained by the camera on the prototype was much better and more refined (fig.7). In the same Figure it could also be noted the difference in colors; As already mentioned, given the impossibility of maintaining consistent conditions in all the shots taken by the UAS, these images have not undergone colour correction, which was instead performed on the images obtained from the camera on the prototype. It is therefore not meaningful to compare colour rendering, as one system appears to be at an advantage due to the use of the ColorChecker.

Then, assessing the mesh models, it could be better observed the differences in elevation between the various floor elements, cracks, and incisions on the model generated by the camera on the prototype.

*Fig. 6. Orthophotos of the surveyed Romanesque mosaic floor. Top: generated by the UAS images; Bottom: generated by the camera mounted on the prototype.*

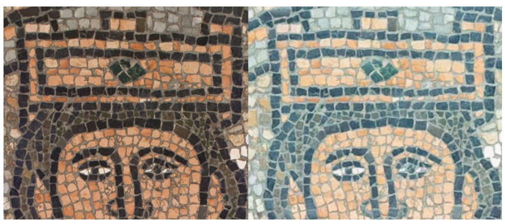

*Fig. 7. Comparison of a detail of the orthophotos. Left: generated by the camera mounted on the prototype. Right: generated by the UAS images*

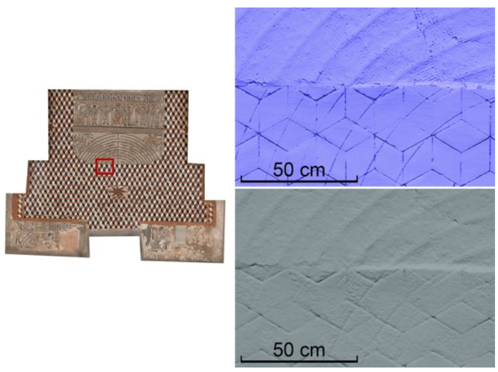


*Fig. 8. Comparison of two portion of mesh models obtained from the two acquisition systems. In purple the result from the camera on the prototype (engravings more visible) and in grey the result from the UAS.*

From the results obtained, it could be observed that the engravings were more visible from the acquisition obtained with the prototype (fig.8). This may be due to the fact that there was a slight variation in GSD between the two instruments, smaller in the prototype and slightly larger in the UAS. Furthermore with the prototype of mobile acquisition system, it could be possible to be closer to the object to be detected than the UAS, even better reconstructing the shape of the engravings.

Further discussion could take place regarding the acquisition times of the two methods: lower with the UAS, longer with the camera mounted on the prototype of the mobile acquisition system. UAS surveying allows for rapid coverage of large surfaces, making it particularly effective in spatially large contexts; while the use of the prototype system allows for more detailed and color and reflection-controlled results.

*Table 2. Main parameters compared to the two acquisition methods tested.*

| **Parameters** | **Prototype** | **Drone** |
|---|---|---|
| *Acquisition time* | 3.5 hours | 15 minutes |
| *No. of images* | 772 | 356 |
| *Image size* | 8688x5792 px | 5280x3956 px |
| *Camera-to-object distance* | 0.85 m | 1.80 m |
| *GSD* | ~0.2mm/px | ~0.5mm/px |
| *Reflections* | Highly reduced | yes |
| *No. polygons (high quality)* | 32350173 faces | 3031619 faces |

## V. CONCLUSIONS

The results highlighted the strengths and weaknesses of each approach, suggesting that a conscious choice of technique must be guided by the specific needs of the survey and the final data to be obtained: extension of the area, timing of the survey, required quality and environmental conditions. UAS surveying has limitations in the management of lighting and reflections, especially indoors or in uncontrolled light conditions. On the contrary, the ground-based camera mounted on the prototype of mobile acquisition system, allowed greater control of the ambient conditions. The two tested methodologies were effective in obtaining complete and accurate documentation of historic floors. For an acquisition that requires more detail and precision, the camera on the prototype proved to be more efficient. A future work on the photogrammetric data of the floor will be used to implement the documentation and knowledge of basilica of San Michele Maggiore through HBIM.

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