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An Augmented Reality Application for the Visualization and the Pattern Analysis of a Roman Mosaic

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Abstract. The visualization and analysis of mosaics are often compromised by their large sizes, which do not enable the observer to perceive their whole arrangement or to focus on details placed in farthest areas from its boundaries. Moreover, the usual precarious state of conservation of these artefacts, often with damaged or missing areas, makes it difficult to perceive their original aesthetic value. To overcome these limitations, we propose an application of augmented reality able to support the observer in two ways: first, the application completes the missing surface of the mosaic by integrating the existent surface with a virtual reconstruction; second, it enables the analysis of the mosaic pattern by overlaying virtual lines and geometric shapes in order to explicit its geometric arrangements. The result is achieved via a custom Android application able to recognize and track the mosaic figures, thus obtaining a coordinate system used to perform a real-time rendering of the mosaic reconstruction. Such rendering is overlaid on the video stream of the real scene. The application runs on a standard smartphone embedded in a Google Cardboard-compatible Virtual Reality viewer and therefore is extremely affordable. As a case study, in order to reconstruct its aspects and to analyse its geometric pattern, we chose the roman mosaic re-found in Savignano sul Panaro (near Modena, Italy) in 2011, after 115 years from its first discovery, which is preserved less than half of its original 4.5 x 6.9 m surface.

Keywords. Augmented Reality, Photogrammetry, Real-time visualization, Roman mosaic, Geometric pattern, Cultural heritage.

1. Introduction

The overall perception of the whole composition of large artefacts such as floor mosaics and decorative pavements is generally limited by their size. It is not always possible to observe those artefacts from a point of view able to show them in their wholeness, nor it is possible to reach areas and details placed in farthest areas from their boundaries. Similarly, the state of conservation of artefacts, often damaged by time and by calamities, limits the observer, who cannot recognize the details, the geometric and aesthetic arrangements, the original colours, etc. These limitations are often increased by the collocation of the artefacts or by their lighting, which –far from being optimal- may limit their accessibility, visibility and therefore the possibility of perceiving their value.

The cultural heritage field recurs to technology not only in the field of materials and conservative techniques, but also as tools for visualization, analysis and study, in favour of scholars but also tourists

[1,2,3] and people with disabilities [4,5]. Among the most important applications, we can include the digitization of cultural heritage and the applications of Virtual Reality (VR) and Augmented Reality (AR), which allow a more immersive interaction between the observer and the artefact, which can go beyond its simple observation.

1.1. State of the art and research aim

The literature shows many applications of VR and AR in the field of cultural heritage, but only few of them deal with mosaics and pavement ornaments. The most of them recur to photogrammetry or image-based process in order to achieve the digital reconstruction of the artefact, which can be integrated within the VR or AR application. In [6], the close range photogrammetric survey of a roman mosaic in Palermo (Italy) is described, aiming at the production of a full-scale representation (scale 1:1) of the mosaic, useful for documentation and restoration processes. The research has allowed evaluating limit and potentiality of image-based approach using photogrammetric and computer vision (Structure for Motion) techniques in a context where the metric point of view is a very important factor. A similar photogrammetric reconstruction, but based on the use of tourist photographic images, is presented in [7], for the reconstruction of an ornamental portal covered of ceramic tiles, whose three-dimensionally arrangement in geometric patterns is then extracted and analysed. In [8], the authors propose an overview of image processing-based methods dedicated to the specificities of mosaic images for applications to restoration and cataloguing of ancient mosaics, focusing on the shape and the orientation of each “tessera”, by means of a dedicated algorithm.

A survey of digital technologies in cultural heritage is presented in [9]: the authors investigate the potential of those technologies for providing instruments for sharing information about cultural heritage, which museums and institutions are called to preserve and promote. Their project aims to find the most suitable procedure to acquire archaeological artefacts, build their digital replica together with 3D printed prototypes, and derive simplified models to be visualized through stereoscopic devices, allowing the simultaneous viewing of real and digital 3D data through an AR environment, portable to mobile devices as well. With the aim of promoting the territory and its heritage, in [10] the authors recur to technologies (as 3D scanning, 3D printing and AR) for cultural tourism. Their aim is to document current and past historical ages and integrate 3D visualizations with renders capable of returning an immersive VR for a successful enhancement of the heritage. The case study is the archaeological complex of Massaciuccoli, one of the best preserved Roman site of the Versilia Area (Tuscany, Italy). As results, the project develop the 3D virtual reconstructions through the main historical periods on the basis of historical investigation and the analysis of the data acquired. Similarly, [11] presents a detailed account of the construction of a computerized model of the Roman theatre of Byblos, one of oldest continuously inhabited cities in the world. The starting point is a historical study, which yielded the formation of a hypothesis on the original shape and details of the theatre, which today retains very little of its original structure. Their final aim is the creation of both a VR and AR application of the Roman theatre, focusing also on the description of the floor ornaments and geometry.

The Literature review highlights that the development of novel integration between VR/AR technologies and cultural heritage are continuously developed, aiming at promoting the accessibility and the knowledge of artefacts. In this paper, our contribution will focus on 2D damaged artefacts, as mosaics and frescos, for completing their missing surface by a virtual reconstruction through AR techniques.

The paper is structured as follows. Section 2 describes the general method, Section 3 presents the case study and the method applied to a Roman mosaic, and finally Section 4 draws some final remarks.

2. Method

The proposed method is based on the application of AR to support the observer in two ways: first, the application completes the missing surface of ancient and damaged mosaics or, more generally, pavement or wall ornaments (e.g. frescos) by integrating the existent surface with a virtual reconstruction; second, it enables the analysis of the geometric pattern of the 2D ornaments by overlaying virtual lines and geometric shapes in order to explicit its geometric arrangements. Therefore, the method follows the steps listed below.

1) Digital reconstruction of the original artefact:

1.a) The first sub-step is the development of a digital model of the whole surface, which is –in the case of a floor mosaic– a 2D model. The 2D model can be achieved by means of an orthophoto, which is a parallel projection of the view of a photogrammetric textured model taken along a predetermined plan, or a photoplan, which is a photographic image corrected and rectified so that the image plane represents the plan of the real object in scale and metrically measurably [12]. A digital model of the artefact is required to implement the AR application.

1.b) In case of damaged or missing parts of the artefact, the missing areas may be reconstructed on the basis of the adjacent ones by directly modelling or reshaping them by an image editing software, according to archaeological studies. A high-resolution image of the ornament before damage (if available) may act in the same way in case of 2D artefacts.

2) Analysis of the artefact: the geometric pattern of the artefact is required to be analysed and highlighted by means of auxiliary geometric elements. This analysis is aimed at supporting the observer in understanding the whole pattern and its repetition of elements (e.g. if the missing element is identical with another one, etc.). Therefore, the auxiliary elements consist of virtual lines and geometric shapes that will be overlaid to the real artefact. By means of colours, each element may be identified and highlighted, and identical elements in the pattern may be represented with the same colour in order to help the observer in understanding the pattern.

3) Augmented Reality implementation: the AR application is implemented first by filling the missing parts of the real mosaic with the reconstructed parts and, once it is completed, by overlaying the virtual lines and the geometric shapes in order to explicit the geometric arrangements. Such rendering is overlaid to the video stream of the real scene. The application may run on a standard smartphone embedded in a VR viewer (e.g. a Google Cardboard-compatible viewer) and so is extremely affordable.

3. Case study: The Roman mosaic of Savignano sul Panaro

The ruins of a large late Roman structure were discovered for the first time in Savignano sul Panaro (near Modena, Italy) in the farm of Melda di Sotto, in compliance with via Magazzino (near the ancient via Claudia), in 1897. In that period, the director of the Civic Museum of Modena was Arsenio Crespellani, who was attracted by the exceptional floor mosaics. He promoted an archaeological excavation during which the mosaics have been documented with polychrome watercolours paintings and drawings by the young artist Giuseppe Graziosi [13]. At the end of the 19th-century the mosaics were covered in the same place of their discovery, up to a new excavation between 2010 and 2011, during the construction of a roundabout, which represented a new recovery opportunity. Thanks to the Graziosi’s watercolour (see next paragraph) documenting the mosaic existence, the Archaeological Superintendence of Emilia-Romagna identified the ruins of the architectural complex, and the archaeological investigations was completed, allowing at the same time the separation of the mosaic of one of the rooms. The rooms currently investigated are four, but only the one described by Crespellani with the letter A (called room 1 in the last archaeological investigation), is completely discovered. All the found structures are very damaged by interventions of different ages: the scarce or absent indication of the walls makes it difficult to define exactly the size of the rooms. The room A is rectangular, approximately long m. 6.90 with a hypothetical width in m. 4.80 [14]. It seems to be the most important room, at least in this sector of the building.

The Roman mosaic originally measured about 6.90 x 4.50 meters, but it is preserved less than half of its original surface (Fig. 1), and is dated around the 5th century CE [14]. The combination of polychrome stone and terracotta tiles with emerald green and ruby red glass tiles shows the importance of the environment and the wealth of the commitment. It is decorated with intertwined elements, geometric and stylized plants that alternate with the knot of Solomon, with a central element framed by a laurel wreath that delimits a figurative decoration perhaps of a symbolic nature.

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Figure 1. The Roman mosaic as permanently installed at the "Casa Natale Giuseppe Graziosi" (Savignano sul Panaro (Modena, Italy)). Photo credit: Marianna Grandi.

3.1. Digital reconstruction of the original artefact

This first step consists of two sub-steps:

a. Development of a digital model of the real artefacts: The difficulties in obtaining a photographic image of the whole mosaic, due to the small room in which the mosaic is preserved that causes a strong distortion in the photographs, and the non-optimal lighting condition, we decide to achieve the digital model from an orthophoto. A photogrammetric model of the Roman mosaic of Savignano sul Panaro is therefore achieved by means of 115 photos (Standard compact camera Nikon P310, 16.1MP CMOS Sensor, Sensor size: 1/2.3" (~ 6.16 x 4.62 mm), Max. image resolution: 4608 x 3456). The photogrammetric reconstruction is performed with the software PhotoScan (Agisoft) and consists of a textured detailed model of the mosaic. The final result, shown in Fig. 2 (Left), is an orthophoto of the mosaic (dimensions: 3982x3625 300 DPI).

Figure 2. Left: The orthophoto developed from the textured photogrammetric model. Right: The original watercolour by Giuseppe Graziosi (1897, Archive of Civic Museums of Modena. Photo credit: Paolo Terzi).

b. Integration of the damaged or missing part: The Roman mosaic of Savignano sul Panaro is strongly damaged, because more than a half of its original surface is missing and, similarly, also the remaining one is incomplete. Even if the missing areas may be supposed by the symmetrical repetition of the decorative elements within the pattern, a further contribution to the whole reconstruction of the mosaic is determined by the original Graziosi's watercolour painting conserved in the archive of Civic Museums of Modena (Fig. 2, Right). This painting represents an original source in order to integrate the missing parts of the mosaic.

Starting from a high-resolution photographic image (dimensions: 4164x3688, 300 DPI) of the painting, first we mirrored the painting image, then we superimposed the orthophoto on it, and finally we extract the boundary lines of the real mosaic and we use them for cutting the painting image: in this way, we extract from the painting only the complementary part with respect to the real mosaic (Fig. 3). This "cut" image will be used in the AR application.

Figure 3. Mirrored and cut image of the Graziosi's painting.

3.2. Analysis of the artefact: pattern analysis

In order to create the auxiliary geometric elements for the AR application, we propose the analysis of the mosaic pattern according to [14,15], as shown in Fig. 4.

The mosaic shows a rotational symmetry with eight elements arranged around a central one of greater dimensions (Fig. 4a). The central element consists of an eight-pointed star, formed by two superimposed squares in order to form a central octagon with irregular sides (in purple, in Fig. 4b). The vertices of the star originate eight octagons, smaller in size, arranged in pairs of two on each side (in red, blue, and yellow, in Fig. 4b); the space between the octagons and the side walls is filled with different shapes, depending on the resulting space, which are trapezoidal and triangular (in red, in Fig. 4c).

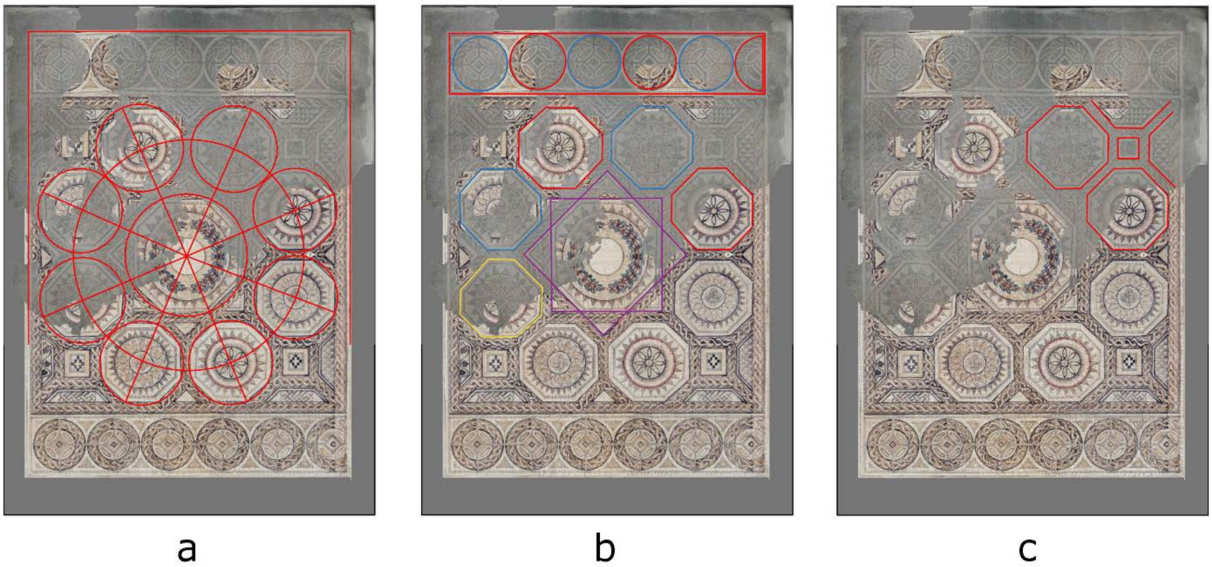

Figure 4. Auxiliary geometric elements built on the "reconstructed" Roman mosaic, in order to highlight and analyse its ornaments and their arrangement within the mosaic.

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The division between the motifs is given by intertwined elements with shaded colours, one from white to black and the other from white to red, so that the diversity of tones makes the weave stand out better. The central octagon (in purple, in Fig. 4b) has a circular pattern with a white background containing a laurel wreath and, presumably, a figured centre; the line forming the outer edge is equipped with a series of triangular points of black colour and with different height so as to adapt to the available space. The inner, circular wreath seems to be made up of laurel leaves, mainly dark green, partially overlapping alternating bands of light and dark leaves. The importance of decoration is also confirmed by the presence of red and green glass tesserae, arranged randomly, but clearly visible to the light. The external octagons are only partially preserved, so that it is not possible to say whether they symmetrically repeated; all of them include internal circular motifs, with pointed triangles border in black on white.

3.3. Augmented Reality implementation

The AR application is implemented within the Unity engine platform (Unity Technologies) by means of EasyAR tracking technology library. The implementation follows the listed steps:

Step 1. Import the EasyAR plugin package into the Unity platform.

Step 2. Setup of the scene: The essential components for the scene setup are already available (as prefab) in the plugin package. In EasyAR, we can find the following tools: CameraDevice Behaviour, logical abstraction that allows interfacing with the hardware device camera; ARCamera Behavior, virtual camera of the scene that allows the overlap between video flow and realtime 3D rendering; Tracking ImageTracker, for target tracking; ImageTracker, component that detects and traces ImageTarget; ImageTarget, flat image that can be traced by an ImageTracker.

Step 3. Insert an image to be traced: Once a new ImageTarget is inserted in the scene, the image to be traced is set as follows: copy the image (in .jpg or .png format) in the subfolder of the "StreamingAsset" project, then set the X and Y proportions in the size of the ImageTarget in a manner consistent with those of the reference image; assign an ImageTracker present in the scene in the Loader field; then, the application may recognize and trace the image (Fig. 5 Left).

Step 4. Assign an object to render to the tracker of images: the object to visualize is set as a "child" of the ImageTracker. Specifically to the mosaic, the orthophoto of the mosaic is set as a tracking image which appears in the background and then a polygon with the texture of the mosaic painting is superimposed as a child. In this way, when the camera will frame the real mosaic, the mosaic painting will be rendered on the video stream (Fig. 5 Right) as well as the geometric patterns (Fig. 6). The possibility of having a preview of the tracking image allowed to place the child plan on the mosaic in order to obtain a perfect match with the missing parts of the real mosaic.

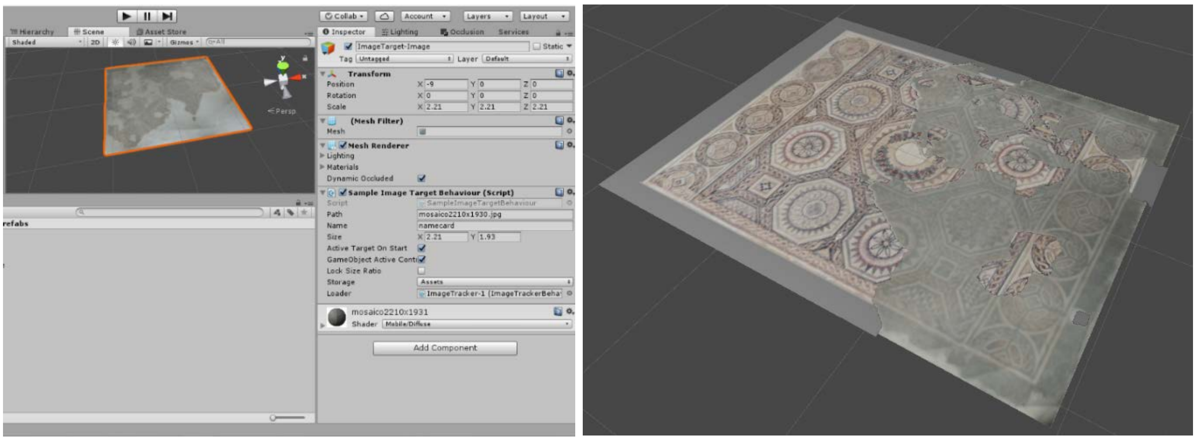

Figure 5. Left: Inserting an image to be traced. Right: The mosaic painting rendered on the video stream.

Step 5. Adaptation for stereographic rendering: In order to use the AR application with the VR viewer, we are required to generate a stereographic rendering, so that the display will be split in two parts: one will render for the left eye (left camera), the other one for right the eye (right camera). This is achieved by inserting in the scene two virtual cameras spaced apart by 0.6 on the horizontal axis and assigning to each a specific area on which to render in the viewport respectively x = 0, y = 0, w = 0.5, h = 1 for the right camera and x = 0.5, y = 0, w = 0.5, h = 1 for the left camera. This requires a double rendering pipeline, so the scene is rendered twice.

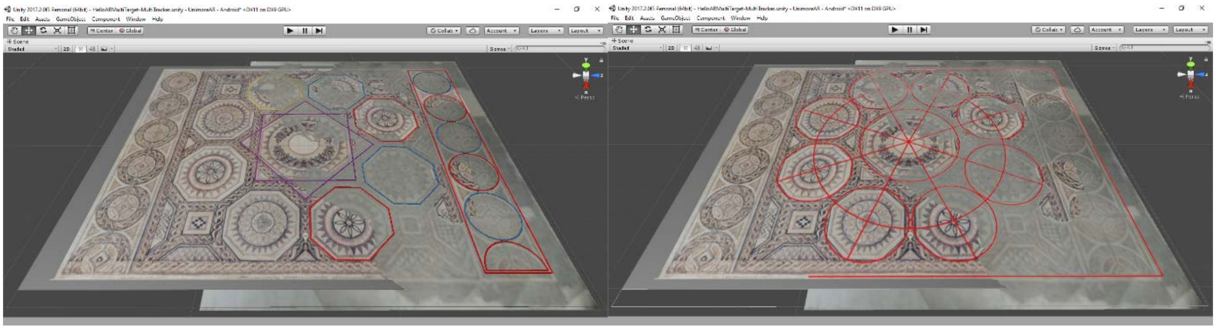

Figure 6. The painting and the geometric pattern rendered on the real mosaic.

4. Discussion and conclusion

This paper proposed a method aimed at reconstructing and integrating the missing areas of mosaics and similar artefacts by means of AR techniques. The real mosaic is “augmented” by means of images of the missing areas, and so virtually reconstructed, with the final aim of supporting the analysis of the mosaic pattern. The final result is a custom Android application able to recognize and track the mosaic figures, used to obtain a coordinate system for the real-time rendering of the mosaic reconstruction.

Some drawbacks of the method consist of: 1) The proposed integration of the areas of the damaged artefact with an image is limited to those cases in which an image is available, as in the case of recent damages or natural disasters or, as in the case of the Roman mosaic there is an original image (drawing, painting, old photo, etc.). 2) The image may differ from the real artefact due to colours (as in the case of the Roman mosaic, due to dust deposition or to lighting conditions), so to require to digitally modify the image. Moreover, the image may present differences in geometry, as shown in the comparison between the orthophoto and the painting, where the octagons are irregular (real) or regular (painted). Moreover, in the Roman mosaic, some elements are warped, probably due to damaging, therefore the watercolour image has required to be deformed and adapted to the real geometry. 3) In the specific case of the Roman mosaic, the small room in which it is installed causes great distortions in taking photos of the details and the overall geometry, so to require the use of photogrammetry for developing an orthophoto. 4) The use of a VR viewer requires a double rendering pipeline, so that the scene needs to be rendered twice: this could be a critical factor in the case of highly complex scenes, but negligible in the present case study.

On the other hand, the method is able to reconstruct damaged artefacts and their geometric patterns, supporting the visualization and analysis during their observation. The missing elements may be achieved from the existent ones (e.g. thanks to symmetry) or, in other cases, from different sources (e.g. images or photos) or be directly remodelled based on studies or hypothesis of scholars. Moreover, the use of AR supports the analysis of the artefact by means of interactions with observers, scholars or tourists, as an educational tool able to guide the understanding of what they observe. Finally, the method can be extended from floor mosaics and pavements to other similar artefacts, as wall mosaics and frescos, even if not planar: as further developments, we will investigate the application of the method in this last case.

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Photo credits

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