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Case study

Virtual reconstruction of paintings as a tool for research and learning

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ABSTRACT

This paper presents the work related to the 3D reconstruction of the scene depicted in the famous Piero della Francesca's fresco "The Resurrection". The work has presented many challenges due to the fact that deliberate alterations to a mathematically correct perspective were introduced by the artist in order to visibly underline the contrast between the divine plane (Christ resurrected) and the human plane (a group of soldiers witnessing the scene). The reconstructed 3D model has been used in an interactive application enabling the virtual visit of the scene as seen from relevant viewpoints corresponding to the different perspectives and to details of the depicted figures. The application also allows to change in real-time the lighting conditions of the scene in order to compare the virtual illumination with the one present in the fresco so as to illustrate possible alternatives about the debated original collocation of the artwork.

1. Research aims

The aim of this research is to provide an interactive tool to be used for educational purposes, in order to explain the use of perspective in the painting and the alterations introduced by the artist to achieve the desired effect. A secondary aim is to investigate the lighting of the depicted scenery in order to give arguments in favour of one of the existing theories about the original collocation of the artwork as, in order to enhance the immersion of spectators, these artworks were often realized to present an illumination compatible with the one of the real hosting place.

2. Introduction and related work

Virtual reconstructions of historical elements have always aroused a great interest, not only for the undoubted appeal exerted by the feeling of being transported to the past, but also for the rich opportunities offered by such tools for study and research. Existing literature offers countless examples of such 3D reconstructions based on documents of several types, such as text descriptions, drawings and pictures, or on tangible facts like finds and ruins (among the others: [1,2]). Commonly, most of them share the need of balancing the attractiveness towards the general public and the scientific validity of the presented hypotheses.

A peculiar case is that of virtual reconstructions of paintings. In this case, three-dimensional adaptations of an inherently bi-dimensional content offer a way to explore environments, objects and characters as conceived by artists and to observe them from points of view different from the only one originally foreseen [3].

Although every virtual reconstruction presents the risk of introducing biased filters, due to the subjective interpretation of the sources, 3D transpositions of paintings are more prone to these risks. In order to offer a wider freedom of exploration, it is required in such cases to insert elements not present in the original image because they are hidden or outside the frame of the picture. This often leads beyond the concept of interpretation, embracing the hazardous concept of "imagination". While this kind of stretching, if aimed to a better involvement of the public, can be tolerated for recreational or popularization purposes, it is obviously not acceptable from a rigorous scientific perspective. The main purpose of such transpositions is commonly to enrich the user experience, exploiting the immersion and the interaction capabilities of virtual environments [4] in order to improve the emotional exchange and achieve a more active participation to the communication process.

Two general approaches to 3D reconstructions of 2D pictorial elements exist: automatic procedures, attempting to algorithmically reconstruct relevant 3D shapes referenced in the picture, and manual procedures, building on 3D modelling skills of experienced professionals. Ideally automatic techniques should be preferred because they result in cheaper and quicker processes, potentially allowing large-scale transpositions of pictures, and also because they minimize the impact of the reinterpretation introduced by the human factor. On the other side the passage from 2D to 3D

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commonly implies adding non-previously existing information, which can hardly be produced by algorithms, unless they are related to entities with recognizable structures - for instance architectural components [5]. The contribution of human operators, namely 3D modellers and art experts, is therefore usually needed in order to formulate plausible hypotheses to reconstruct the missing context and to accordingly provide a 3D translation of such assumptions. This is particularly true for scenes involving living subjects such as vegetation, animals or humans. Interesting attempts exist [6] to exploit this strategy not only for the 3D reconstruction but also to actually breathe life into characters through animation, although such experiments further transcend the aim of a simple 3D transposition of the author's original artwork.

3. Materials and methods

In the framework of the St@rt research project our group realized the 3D transposition of the "Resurrection", a renowned fresco by Piero della Francesca currently hosted in San Sepolcro, Tuscany. Different aims justify this difficult transposition. The first is to attempt to provide a coherent spatial structure to a scene that contains, as well known, deliberate alterations of the perspective. As the name suggests, the artwork portrays the resurrection of Christ, placed in the centre of the composition and rising from his tomb over four sleeping soldiers. The difference of the two levels, the divine (Christ) and the human (soldiers), is emphasized not only by the different heights, but also by two different perspectives, as the soldiers are portrayed from below whilst Jesus appears portrayed from a more central viewpoint. Other minor inconsistencies appear in the shapes and in the positions of two soldiers, and in the somehow "squashed" perspective (for instance, although belonging to different depth planes, the soldiers' heads have roughly the same size).

The second aim is to investigate the illumination of the depicted scenery. There is currently a strong debate on the actual original collocation of the fresco; some historical sources, in fact, assert that the fresco was moved, but it is not clear if this relates only to a variation of the height or to a completely different location [7]. Some historians speculate that the painting was on the other side of the same wall, whilst other assert that it was originally placed at the end of the room behind the one currently hosting the artwork. This last hypothesis has some strengths, however it could not be confirmed by objective investigations made impossible by the current conditions of the place. In this respect, the analysis of the scenery lighting could represent a cost-effective solution to give arguments in favour of one of the theories, as many similar artworks, in order to enhance the immersion of spectators, would often present an illumination compatible with the one of the real hosting place.

Due to the characteristics of the painting, mainly focusing on human figures and presenting a few architectural elements, we did not opt to use automatic techniques that, in spite of being time-effective and more precise (to some extent), offer less flexibility for non-visible portions of the scene which in this case, being the reconstruction aimed at a real-time interactive walkthrough, must be modelled and shown as well. Moreover, automatic procedures would hardly comply with the requirement of coping with perspective inconsistencies and with different alternatives in the characters' postures.

Fig. 1. Different views of the 3D reconstruction of The Resurrection.

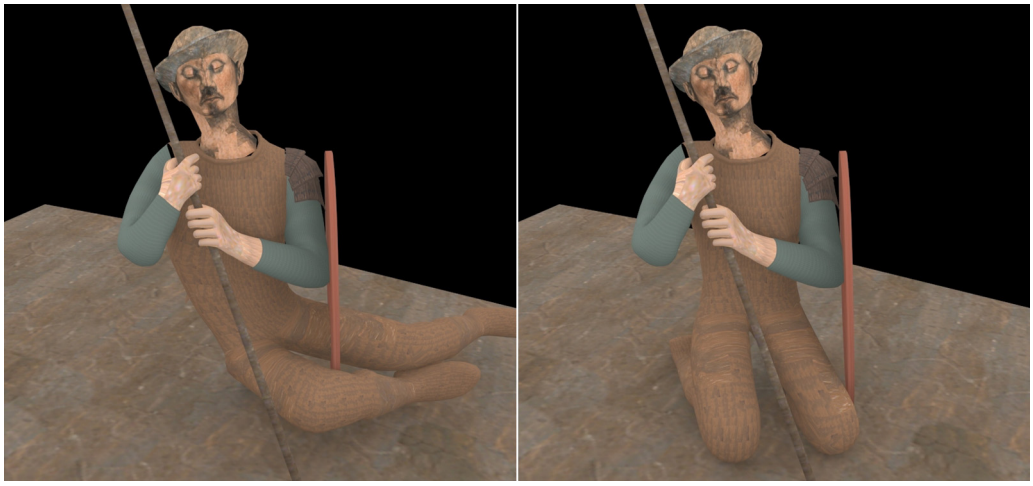

Fig. 2. Two possible alternatives for the position of the third soldier.

The 3D reconstruction (Fig. 1) has therefore been carried out manually using 3D modelling tools such as Autodesk Maya and 3ds Max, which have been used to model the static scene, and Smith-Micro Poser, a tool specialized for modelling human figures with correct anthropometric proportions.

In spite of the fact that Piero completely mastered the use of perspective, in this case its deliberate alteration due to the presence of at least two different viewpoints constitutes a practical issue to produce a 3D version of the scene, as this mixes up geometrical hints. An additional issue is the poor presence of rectilinear elements: "the three-dimensional structure of the Resurrection has been established by means that, while they may have been mathematical, do not provide the viewer with substantial clues for a precise mathematical reconstruction" [8]. Moreover, the wish to emphasize the figure of Christ leads to the presence of few chromatic contrasts, hiding additional shading clues commonly helping in identifying 3D features. The analysis of the few elements present was anyway sufficient to sketch a possible reconstruction where the following assumptions have been formulated:

- the squashed perspective is simulated by using a small aperture of the field of view (20 degrees);
- the tomb and the columns perspective is mathematically correct, therefore these elements were easily reconstructed;
- we suppose that the leftmost soldier covers his face with both hands, although only the right one is visible in the painting;
- the second soldier (reportedly a self-portrait of Piero) is resting against his shield; the right arm, hanging from the shield, is almost not visible, but we can assume, given the proportions of the body, that his right hand does not touch the ground;
- the lower half of the third soldier is not visible; only a few positions are physically compatible with the visible part, i.e. the soldier may be knelt, crouched or lying. However, the most plausible position is the first, as the soldier's helm seems to almost touch Christ's tunic, and therefore he should be very close to the sarcophagus, making very difficult for the figure to assume the other positions (Fig. 2);
- the rightmost soldier has his right arm (only partly visible) seemingly resting against a rock; this position, although physically plausible, would hardly allow natural equilibrium conditions;
- there is no perspectively correct solution for the terrain on which the tomb is placed, unless it is assumed that it is moderately sloping (about 5%). This would agree with the general vision of the painting where "the effect is simply that we are looking uphill" [8].

The reconstruction has been completed by texturing the models using pictorial elements manually extracted by the painting itself, processed using Adobe Photoshop, and mapped onto the 3D model as plain diffuse textures.

In order for this reconstruction to be used as an educational instrument, a real-time interactive tool has been developed using the XVR technology [9]. The tool, available both as a web3D (Fig. 3) and as an immersive application, allows to experience a "guided" tour around the 3D reconstruction, moving across a set of predefined relevant viewpoints, or to freely move inside the virtual environment. The predefined viewpoints correspond to the two main vanishing points identified, one in agreement with the Christ figure and one with the remaining environment, and to figures close-ups.

The discrepancies between the two perspectives have been highlighted by using a picture-in-picture solution showing, for instance, that when the viewpoint gives a representation correctly corresponding to Christ, as seen in the picture, the lines of the columns' capitals do not match the painting ones (Fig. 4). The evaluation of these evidences is eased by the possibility of adding a semi-transparent layer, containing the painting superimposed on the 3D model, which can be moved on the orthogonal axis to show

Fig. 3. The web-based interactive application.

Fig. 4. The use of picture-in-picture to show the alterations of perspective.

Fig. 5. Two different lighting conditions for the environment: light coming from up right (left pic) and from up left (right pic).

how the perspective "wrongly" matches with the figures at different heights and at different depth levels. A GUI enables the interactive selection of these viewpoints triggering also an accompanying narrative describing the painting, the use of perspective, and the hypotheses made in order to perform a complete and plausible three-dimensional reconstruction.

Exponential Variance Shadow Mapping [10], an algorithm allowing to produce real-time soft shadows giving good control on filtering and intensity, was implemented through a GLSL shader in order to enable lighting investigations. As the illumination is supposed to be produced by sunlight, only one directional light source has been used to simulate this condition. It is therefore possible to interactively change the direction of the light showing in real-time how the surfaces shading and the casted shadows change (Fig. 5). This feature confirms that the environment light of the painting seemingly comes from a source roughly corresponding to the windows of the real hosting environment, although minor inconsistencies still subsist. However, this could be partly justified by the different relevance of the scene elements, which might be reflected also by the amount of the received light.

4. Conclusions

The presented work highlights the potential of virtual environments not only to provide a captivating experience, as in this case to feel immerse in a renowned artwork commonly viewed only in two dimensions, but also as an interesting tool for learning and research. In this case the possibility of interactively control the viewpoint allows to effectively illustrate the concepts of perspective and to demonstrate how this can be manipulated and "tricked" in order to achieve artistic effects; moreover, the real-time control of lighting conditions enables to immediately verify how the changes of these conditions are reflected in the 3D scene and to appropriately illustrate the different hypotheses related to the interaction between the real lighting of the hosting place and the lighting of the painting. Finally, the option of experiencing the educational

tool through the web makes it possible to considerably enlarge the base of users, enabling either a self-learning approach or a more classical approach mediated by a teacher.

Possible extensions of the work involve the possibility of referencing additional layers of information on the elements of the 3D scene (as, for instance, in cited [1,2]) and the creation of specific interaction features to be used in immersive installations such as CAVE-like systems.

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