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DIGITIZATION OF RELIGIOUS ARTIFACTS WITH A STRUCTURED LIGHT SCANNER

ESCANEADO DE ARTEFACTOS RELIGIOSOS CON UN ESCÁNER DE LUZ ESTRUCTURADA

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Abstract:

The digitization process for religious artifacts is subject to inherent difficulties often ignored in theoretical models or pipelines. In this paper we aim to describe these problems, which are present in practical environments such as temples and churches, using white light scanners instead of other common devices or technologies such as laser scanners and photogrammetry. Our case study is based on the digitization of two religious statues belonging to a Catholic brotherhood located in a village of the Province of Jaén (Spain), one of them presenting especially several limitations. After performing the scanning process with a portable hand-held scanner, the images captured were processed until the final models were acquired. On the basis of the results obtained, we discuss the problems arising after using well-known procedures for the reconstruction of 3D models, their causes and some possible solutions to achieving a correct digitization. It should be noted that it is not the aim of this study to establish procedures for the digitization of religious artifacts, but rather to transmit the inherent constraints of these types of scenes.

Key words: 3D scanning, white light scanner, religious artifacts, cultural heritage, digitization

Resumen:

Los modelos teóricos de digitalización 3D no tienen en cuenta problemas de escenarios específicos como el de la digitalización de objetos religiosos. El objetivo de este artículo es describir estos problemas presentes en entornos prácticos como templos o iglesias usando un escáner de luz blanca en lugar de otros instrumentos o tecnologías comunes como los escáneres láser y la fotogrametría. Nuestro caso de estudio se basa en la digitalización de dos tallas religiosas pertenecientes a una cofradía de una localidad de la provincia de Jaén (España), siendo especialmente restrictiva una de ellas. Tras el procedimiento de escaneado llevado a cabo con un escáner de mano, las capturas se procesaron usando procedimientos clásicos de reconstrucción de modelos 3D hasta obtener los resultados finales. Basándonos en los resultados obtenidos realizamos una discusión de los problemas, causas y posibles soluciones para llevar a cabo una correcta digitalización. Cabe destacar que el objetivo del artículo más que establecer un flujo de trabajo es el de presentar las restricciones que presentan este tipo de entornos.

Palabras clave: escaneado 3D, escáner de luz blanca, artefactos religiosos, patrimonio cultural, digitalización

1. Introduction

The digitization and reconstruction of cultural and religious heritage are providing artists, historians and the general public with a new methodology for learning about and researching these items. These novel technologies allow the dissemination of cultural heritage to the general public through virtual museums and tours (Styliani, Fotis, Kostas, & Petros, 2009; Kiourt et al., 2015); the restoration and conservation of heritage (Lanitis, Stylianou, & Voutounos, 2012) and research into other cultures or eras (Hermon et al. 2013).

There are several types of scanners that can be used to digitize the cultural heritage such as white light scanners, laser scanners and computerized tomographies (CT). Many of these former scanners are portable or hand-held devices, which makes the data acquisition much easier. Photogrammetric methods are also widely used in order to digitize and document temples or artifacts in an accurate way. For instance, there are recent papers focused on this technique such as the one presented by Rodriguez-Gonzálvez, Nocerino, Menna, Minto, & Remondino (2013) and the work of Menna et al. (2016). However, this technique is less suitable for the digitization of small pieces, such as in our case study (Nicolae, Nocerino, Menna, & Remondino, 2014).

In this paper we include the experiences of scanning religious artifacts in a real-world environment and the problems involved. The rest of the article is structured as follows: in Section 2 we present an overview of the state-of-the-art related to structured light scanning religious artifacts. Section 3 depicts the hardware and software used during the scanning process. In Section 4, we detail the process carried out and the problems encountered. Then, we discuss the results obtained in Section 5. Finally, we conclude the paper in Section 6.

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2. Previous work

Some religious heritage scanning projects have been performed, mainly inside temples or churches. Some examples are those carried out in the Church of San Francisco, the Church of A Coruña (Spain) (Pérez & Robleda, 2015), the Cathedral of Notre-Dame des Amiens (Crombez, Caron, & Mouaddib, 2015) and the Cathedral of Jaén (Soria, Ortega, Feito & Barroso, 2015). Some of these projects related to religious artifacts are performed outside of temples, as in the case of the ancient city of Herculaneum where the amazon woman's head was scanned (Happa et al., 2009). In 2003 some projects were carried out for the digitization and subsequent restoration of several sculptures located in the Cathedral of Santa Mara in Florence and the Basilica of San Pietro in Vincoli, amongst many other Italian temples. For example, in this project they digitized the statue of the Prophet Habakkuk sculpted by Donatello and the sculpture built by Nanni di Banco, The Four Crowned Saints. These statues are located in Orsanmichele (Florence) (Salimbeni, Pini, & Siano, 2003). In (Van Gasteren, 2013) a project is presented for the reproduction of two sculptures, Saint Teresa de Jesús and Christ Tied to the Column, both located in the Convent of Santa Teresa (Ávila, Spain). More recently Díaz-Marín et al. (2015) digitized the fragments of an archaeological Terracotta statue in order to obtain a 3D model of the whole statue.

Other digitization processes of cultural artifacts can be performed by means of techniques such as Structure from Motion (SfM) (Barsanti, Micoli & Guidi, 2013; Nabil & Saleh, 2014) and photogrammetry (Remondino, 2011; Rinaudo, Chiabrando, Lingua & Spanò, 2012; Dall' Asta, Bruno, Bigliardi, Zerbi & Roncella, 2016).

3. Material

Artec (Artec Group, 2016) markets two hand-held scanners. On the one hand the Eva version, that is suitable for medium size models (as in our case study), and on the other hand the Spider version which is more appropriate for working with small models.

The 3D scanner used in this study is the Artec Eva (Fig. 1). This hand-held structured-light scanner captures 3D images with a frequency of 16 frames per second. Artec Eva is not completely appropriate for scanning small figures or details even though the scanner has a huge resolution, 0.5 mm. The minimal distance needed to scan is between 0.4 m and 1 m, subject to the illumination in the particular scene. The capture resolution is 1.3 MP.

Figure 1: Hand-held scanner Artec Eva.

Artec Studio 9 software was utilized for the processing of the scans. The features provided by this software are sufficient for a common scanning process. These features include sharp fusion and mesh simplification, among others (Cignoni, Montani, & Scopigno, 1998). Unfortunately this tool is a commercial software solution, and therefore it is not an easy task to know the concrete algorithms used. Recently Artec Group released a new version of this software, Artec Studio 10. This version contains a faster alignment algorithm and an improvement in the geometry and texture editing process. Figure 2 shows a screenshot of the software package.

In order to test the quality of the scanner we carried out a previous test with two sample figures (a tooth model sculpted in clay and a clown model). As shown in Figures 3 and 4, the perceived visual quality of the results is reasonably accurate. This software was executed in a computer with an Intel Core i7-4600U processor and 16 GB RAM.

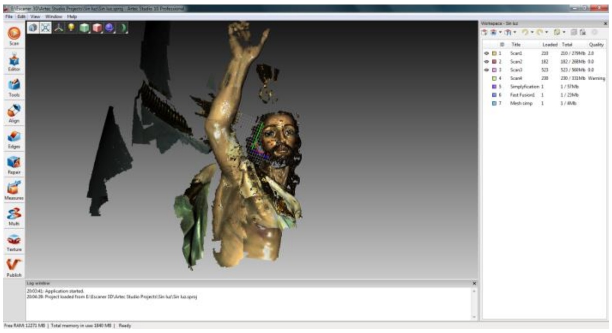
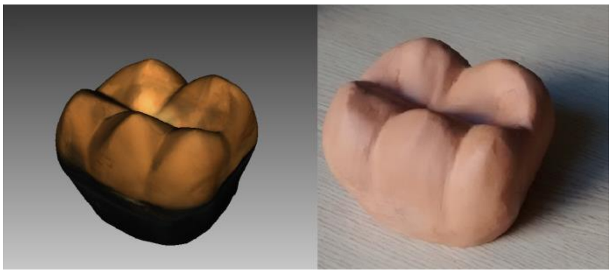


Figure 2: Screenshot of Artec Studio software.

(a) (b)

Figure 3: Clown model: a) 3D scanned model; b) real model.



(a) (b)

Figure 4: Tooth model: a) 3D scanned model; b) figure modeled in clay.

4. Digitization process

The digitization process of 3D models from the scans must follow a succession of steps (pipeline) in order to achieve proper results. The following pipeline was introduced by Bernardini & Rushmeier (2002). This pipeline consists of two process streams; one for the geometry of the model and another for the appearance properties of the model surface (Fig. 5).

The process is totally sequential, as indicated by the dotted line. It is very usual to obtain a feedback between both streams in order to improve the quality and efficiency of the processing of each type of data. This model assumes perfect conditions for data acquisition but, in fact, it may often be deficient. These difficulties may be due to the device used (e.g. scanner accuracy), the model to be digitized (shining/reflective material) and the environmental conditions (e.g. adequate illumination or freedom of movement).

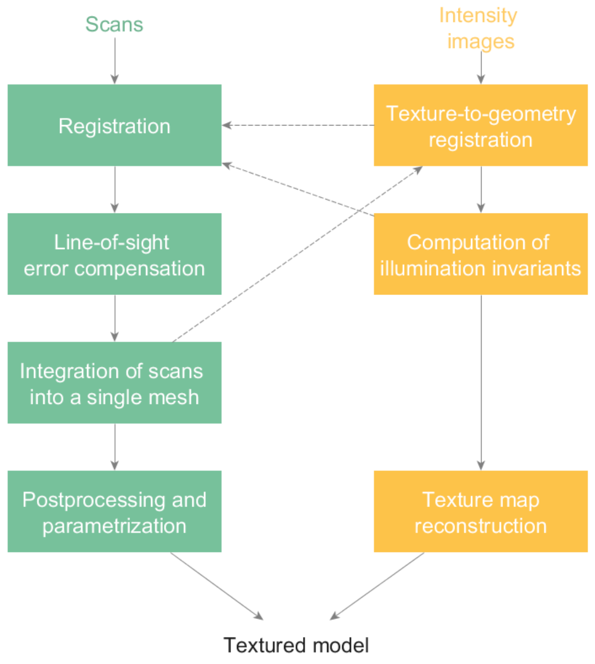


Figure 5: Pipeline for the digitization of an object in order to achieve a 3D model.

4.1. Problems involved in scanning religious artifacts

In practice we may find ourselves with some problems when scanning religious artifacts. Many of these problems, such as poor illumination or elements with little geometry (for instance, thin or small objects), can be found in many other scenarios, but the constraints that this specific scene provides can increase the difficulty in achieving proper scans. For instance, small features can be removed from the statue and scanned separately; but this often cannot be allowed due to religious reasons, as explained below. Although some of the problems can be solved by means of data postprocessing tasks, poor data capture conditions can require the repetition of the data acquisition procedure. In our case, in a first test run, we noted the following difficulties during the capture process with a structured light 3D scanner.

- **Poor illumination**. Generally, these sculptures are located either in churches or in cathedrals, places where the illumination of the ambient is usually insufficient. The inclusion of any other type of illumination such as focal point lights or directional lights is not suitable due to the generation of shadows in the model. Shadows can be a problem because of two reasons: on the one hand, the geometry of the model may not be captured completely since many white laser scanners do not recognize parts of the model that are overly dark. On the other hand, the output textures can contain different shades depending on these shadows. The final result can be improved to a certain extent by performing a 3D reconstruction of the illumination in order to edit the light sources (López-Moreno, Hadap, Reinhard, & Gutierrez, 2010).
- **Shiny ornaments**. Some vestments and crowns, or sceptres, usually contain metallic or golden details. Scanning these kinds of materials can often leave gaps in the model, mainly because of the reflections produced by these kinds of objects. As stated earlier, also relevant are the cases in which the addition of some types of scanners, such as laser scanners, may not recognize dark or black parts of the model. This problem can be partially solved by adjusting the light sensitivity for capturing highly illuminated parts; however, some darker parts may not finally be scanned.

(a) (b) (c) (d) (e)

Figure 6: Example in digitization pipeline: a) raw scans; b) scans registration; c) mesh fusion; d) mesh simplification; e) textured model.

- **Difficult access**. The movement of these statues outside the church or cathedral is often complicated because of administrative or religious issues. Furthermore, not everybody can manipulate this kind of artwork; it needs specialized personnel in order to prevent its damage. In addition to the inability to move the statue to a room suitable for the scanning process, it is even possible that these sculptures cannot be removed from their altar. These specific situations can make the access to several parts of the statue difficult or even impossible.
- **Elements with little geometry**. Thin parts of the sculpture with little geometry may not be captured, such as banner poles and fringes. This factor mainly depends on the minimal resolution of the device. Commonly, these elements are scanned separately in order to be added to the final model later.
- **Direct manipulation of the sculpture**. Due to the delicateness and the religious meaning of this sort of figure, it is necessary that the handling be undertaken by specialized staff, not only with regard to its movement but also to any kind of manipulation, like undressing it or removing any element such as crowns and banners.

4.2. Digitization process of religious artifacts

In our practical case we digitized a wooden statue of Risen Christ placed in the Church of St. Mary in Torredonjimeno (Jaén, Spain). These digitization services were requested by the Catholic brotherhood in order to disseminate their religious heritage. Due to the difficulty of the manipulation and the inability to scan the whole statue, a replica of a statue of Holy Week was also digitized in order to offer a full preview of the scanning process. The replica was also provided by the Catholic brotherhood. The statue of Risen Christ is approximately 1.60 m tall, whereas the replica is approximately 0.5 m tall. While the statue of Risen Christ could not be moved from its altar, the replica could be located freely. In Figure 7 can be seen a moment during the scanning process.

The digitization process for both statues was carried out following the pipeline described in Section 4. It is remarkable that the alignment step (included as a first step in the registration one) has been alleviated by the scanner used. The steps carried out are listed below:

1. **Scanning.** One of the golden rules of the scanning steps is to take the minimum number of scans that cover the whole target. In the case of the Risen Christ four scans were needed whilst only three scans were required for the replica. To ensure a good quality of the results, this step must be carried out carefully. Scanning the Risen Christ model took around one hour whilst the replica took only 30 minutes.
2. **Registration of the scans**. In this process all the overlapping captured scans must be fully referenced under the same common coordinate system in order to obtain a single scan (Besl & McKay, 1992; Digne, Morel, Audfray, & Lartigue, 2010). This process is the most expensive in terms of computational time of the overall pipeline, taking 4 h for the Risen Christ and 6 h for the replica. A previous alignment process of the scans captured with a different orientation might be necessary (e.g. if the model is rotated on an arbitrary axis). The Align step (so called in the Artec Studio) serves as a hint for the registration. Pairs of conjugate points have to be selected manually in order to rotate and translate the scan toward a reference scan. This step is optional and, in our case, was not required, as we stated above, because we did not move the statue.
3. **Removing unnecessary parts**. It is necessary to remove superfluous information from the scans such as backgrounds or holders. This process is mainly manual since the use of automatic algorithms may not be accurate and may remove valid parts of the model. Neglecting unnecessary geometry can provide less accumulated error in the following steps since there is less geometry to be processed.
4. **Removing outliers**. Commonly, we may obtain noise provided by glitters, an improper illumination or accumulated errors of previous steps. In particular, a bad alignment which can produce overlapping areas between distinct scans. This process is performed again manually or semiautomatically, since it needs the supervision of an expert in order to prevent deletion of valid parts of the model.
5. **Definition of the shape**. Once the scans have been processed, it is necessary to create a single triangle mesh from the point cloud provided by the scans. After this step it needs to be determinated that the mesh is completely watertight.
6. **Small object filtering**. After these steps, it is very usual that the model has generated new large noise. Classical algorithms for the detection of outliers may not work properly in this case. Isolated elements whose size does not exceed a certain threshold have been removed. Once again, it is necessary to ensure that necessary parts have not been removed.

Figure 7: A photograph taken during the scanning process.

7. **Postprocessing**. Once we have a single model, there are additional tasks which need to be performed. For example, it is important to carry out a smoothing process to edges and corners, to remove flaws in the mesh such as small holes, and to simplify the number of triangles. The reason why we scanned at high resolution and then performed a decimation of triangles was because the triangle mesh decimation algorithms only simplify zones with small geometric changes, keeping the model's fidelity. This ensures that zones with many details will be simplified little or not at all. In Table 1 we can see the number of initial and final triangles, as well as the file size for both models.
8. **Texture mapping**. It is necessary to perform a mapping between the image pixels (called texels) and the mesh triangles in order to provide the model with texture (Sander, Snyder, Gortler, & Hoppe, 2001). Finally, an adjustment of parameters such as shining, contrast or saturation of the final texture is carried out.

An overview of the pipeline process can be seen in Figure 6.

Table 1: Triangle mesh simplification

Model	*Initial triangles*	*Final triangles*	*Initial size (MB)*	*Final size (MB)*
Risen Christ	1002289	204928	23	5
Replica	803521	148497	18	4

5. Discussion

The final models of this process can be seen in Figure 8. Figures 8a and 8b show the resulting digitization of the Risen Christ and the replica respectively. These results are obtained from a first contact with the sculptures and the indoor scene. The impossibility of removing one of the statues from its altar increases the difficulty of scanning the complete statue, for example, the back of the statue. Neither could lateral parts be scanned since it is required to keep a minimum distance between the model and the scanner. Furthermore, the spot and point lights located in the church did not help in capturing the scans. Additionally, the final textures showed small glares, as can be seen at the bottom part of the Risen Christ model (Fig. 8a). Finally, we decided to take scans only from the statue's bust in order to test the process and show the results to the Catholic brotherhood. In addition, a complete process for the improvement of the replica captures was performed.

Scanning with a structured (white) light scanner instead of with a laser scanner presents some advantages based on previous experiences scanning artifacts. In prior work we used a Polhemus FastSCAN I (Polhemus, 2016). This laser scanner uses an electromagnetic tracking technology to reference each scan into the same coordinate system. One of the main conclusions reached in that study was that this type of technology is not suitable for scanning sculptures of large size. This is due to the fact that the receptor can miss the signal from the electromagnetic transmitter if they are distant, which is not the case using a white light scanner.

Moreover, the benefits of scanning with this technique versus photogrammetry are clear in this scenario. A hand-held scanner is more appropriate to scanning parts with difficult access due to the freedom of movement that it offers in comparison with a static setup. For instance, the digitization of parts close to a wall might be more complicated since the camera setup might not fit sufficiently between the statue and the wall. Likewise, the inherent problem derived by a poor illumination also affects the digitization performed by means of photogrammetric techniques. Also, the time required for taking the photographs can be significantly higher than the time for taking all the scans if a resolution of the 3D model is required comparable to that offered by a 3D scanner. However, the hardware for a photogrammetry study is much cheaper than for a hand-held scanner device.

(a) (b)

Figure 8: Final 3D models: a) Risen Christ; b) replica.

The scanning of inaccessible parts could be achieved using mirrors. This solution imposes a couple of restrictions: (1) the use of a laser scanner since white light scanners do not work properly with mirrors, and (2) the need to place the scanner in a fixed position in order to reference the reflected scans with the other scans. Due to the material used (a hand-held white light scanner); this method could not be employed.

Figure 9: 3D printed model of the replica. A few elements, such as the banner or parts of the crown, were neglected during the scanning process because of the printer resolution. The figure has a height of 70 mm.

Regarding texture correction, there are several techniques, like "inpainting" (Criminisi, Pérez, & Toyama, 2004), which may repair the glares caused in textures by external light sources. These kinds of techniques are very interesting in order to manage the model in a 3D modeling tool and to be able to calculate the correct shadows properly.

Finally, one of the next logical steps after the digitization of the religious heritage is its impression in a 3D printer and its commercialization (Fig. 9). It could be interesting to introduce some watermarks to these figures in order to avoid their illicit exploitation. Some of these techniques are invasive and the figures reproduced could be partially deformed, which would not be accepted by the devoted community. For this reason, non-visible or local watermarking techniques could be applied (Wang, Lavoué, Denis, & Baskurt, 2011; Luo & Bors, 2011).

6. Conclusions and future work

In this paper, we describe the practical process of scanning religious artifacts. This study does not intend to create a workflow, but rather transmit the main problems encountered in possible working environments, as well as some possible solutions.

This study has served as a first contact with scenes existing in either temples or churches. Some of the problems presented during the scanning process were partially solved. The software package used fixed some issues such as the removal of outliers, the removal of unnecessary parts, the creation of a closed polygonal mesh, including its smoothing and simplification or texture correction. However, some problems regarding the physical location could not be solved. Therefore certain parts of one of the sculptures could not be scanned. In addition, several illumination issues dealing with glares and shadows remain still unsolved.

In the near future, we expect to digitize the whole artifact in order to provide the Catholic brotherhood with a faithful representation of their sculptures and thus deal with the unsolved issues. In this new digitization procedure we hope to be able to: (1) change the location of the sculpture; and (2) scan it in a controlled environment, with proper illumination and without space constraints.

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