Methods for 3D digitization of Cultural Heritage

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Abstract

Complete digital recording of Cultural Heritage is a multi-dimensional process. It depends highly on the nature of the subject of recording as well as the purpose of its recording. The whole process involves the three-dimensional digitization, digital data processing and storage, archival and management, representation and reproduction. In this paper we briefly review methods for three-dimensional digitization that are applicable to cultural heritage recording.

Keywords: 3D digitization, cultural heritage recording

1. Introduction

Complete recording of Cultural Heritage is a multidimensional process. It does not only address the problem of three-dimensional (3D) digitization of objects and monuments but involves all the aspects of this new digital content management, representation and reproduction. It addresses issues affecting the whole life cycle of the digital cultural content. Five main processes can be identified in digital recording. These processes are shown graphically in Fig. 1. All there processes have their own demands for advanced algorithms, new hardware and more sophisticated software implementations.

3D digitization of cultural heritage is the first step of the overall process of the complete recording of objects and monuments.

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It consists of multiple processes and exhibits variations in accordance with specific application requirements. Due to the complexity of the digitization needs that emerge from the objects themselves, there is a plethora of methods and technologies. The target of every such technique is to address successfully a particular type of objects or class of objects or monuments, or to fulfill particular demands and needs of a specific digital recording project (i.e. complete recording for archiving, digitization for presentation, digitization for commercial exploitation).

The plethora of available 3D digitization systems is the result of three main factors that influence the suitability and the applicability of a method:

1. Complexity in size and shape
2. Morphological complexity (level of detail)
3. Diversity of raw materials

There are techniques with satisfying results for microscopic objects, others for small, medium and large objects and others for monuments. There are different techniques for ceramic or metallic or glass objects. It should also be noted that techniques with satisfying results for one kind of objects. An extensive study on the available methods for 3D digitization of the cultural heritage has been done in our Institute. One of the important outcomes of this study is the construction of the Nine-Criteria-Table (Table I), which summarizes the possible parameters for choosing a 3D digitization system for cultural heritage applications.

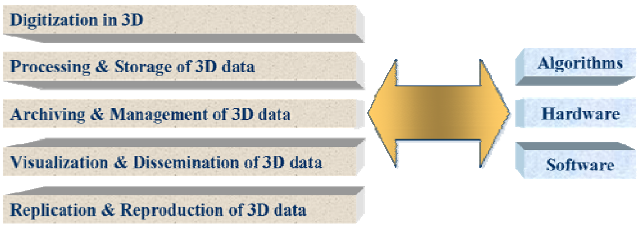

FIG. 1. Complete recording of cultural heritage

TABLE I.
The Nine-Criteria-Table for choosing an appropriate digitization system

No	Criterion
1.	Cost
2.	Material of digitization subject
3.	Size of digitization subject
4.	Portability of equipment
5.	Accuracy of the system
6.	Texture acquisition
7.	Productivity of the technique
8.	Skill requirements
9.	Compliance of produced data with standards

3D digitization is a complex process that consists mainly of three phases:

1. Preparation, during which certain preliminary activities take place that involve the decision about the technique and methodology to be adopted as well as the place of digitization, security planning issues, etc

2. Digital recording, which is the main digitization process according to the plan from phase 1

3. Data processing, which involves the modeling of the digitized object through the unification of partial scans, geometric data processing, texture data processing, texture mapping, etc.

2. Three dimensional (3D) digitization

3D digitization of cultural content can be mainly categorized by the size of objects it is applied to. Due to technical limitations and application requirements, there must be a distinction between the digitization of objects and the digitization of monuments. Digitization of monuments is, is many cases, based on methods that involve traditional topographic techniques (due to the scale in this problem). On the other hand digitization of objects is a field of continuous research and development that can offer with many possibilities, again under the scope of a specific digitization plan. In the following paragraphs we briefly review some of these methods.

2.1. Digitization of objects

2.1.1. Laser scanning techniques

Laser scanning techniques are based on a system with a laser source and an optical detector. The laser source emits light in the form of a line or a pattern on the surface of the objects and the optical detector (usually a digital camera) detects this line or pattern on the objects (Fig.2). By applying the well known triangulation principle the system is able to extract the geometry of the objects. The advantage of using laser sources is that laser light is very bright and highly focused for long distances. As a result the emitted pattern can be always focused on the surface of the objects.

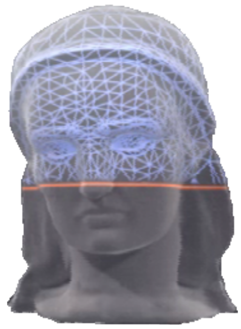

FIG. 2. Laser scanning of objects

One of the most significant advantages of laser scanners is their high accuracy in geometry measurements. On the other hand, it should be noted that in many such systems, geometry can be extracted without any texture information. Additionally, special attention should be paid for surfaces with specific properties, such as reflectance and transparency. One other important aspect is the high cost of such devices, which renders this method useful to specific applications. Finally, the productivity of the method, as well as the portability, depends upon the used system and can vary significantly [1-3].

2.1.2. Shape from structured light

This method is based on projecting a specific pattern on the surface of the objects and trying to extract geometry information from the deformations of this pattern (Fig. 3). This method is also based on triangulation but does not need to use specific laser sources. In many cases this method is confused with the laser scanning methods and there are commercial systems that can not be absolutely categorized to the one or the other method.

FIG. 3. Shape from structured light

The method works by projecting a specific predefined light pattern that covers the whole (or part of the) surface of the objects. This scene is then captured by a typical digital image detector and processed in order to deduce the geometry from the deformations of the pattern in the digital image. These patterns can be simple multiple fringes of different colors or complex patterns with curves, either time or space coded. This method is accompanied by texture acquisition and can lead to very impressive results in terms of accuracy and productivity. The systems are usually portable and easy to use. A lot of work is still being done to develop even more the resolution of the method, which is one of the main fields of research in 3D scanning today [4-16].

2.1.3. Shape from silhouette

This technique is based on multiple photographic capturing of the object from different viewing angles, and deducing the geometry from the object's silhouettes (Fig. 4). This is, actually, an old idea originating back to 1960 when Francois Villeme discovered a method called photo-sculpturing: 24 photographs covering the surface of the object are taken and are projected onto clay. This method regained interest about 100 years later with the advent of computers. Recent improvements of this method use texture information to correct or enhance geometry with very interesting results in terms of the final recorded geometry.Shape from silhouette is an automated process with high productivity and relatively low cost. As of this it is very popular. It can capture both geometry and texture. It is portable and easy to use. The main disadvantage is the medium-to-low resolution in geometry measurements [17-23].

FIG. 4. Shape from silhouette

2.1.4. Shape from stereo

Main goal of this method is the extrapolation of as much geometry information as possible from only a pair of photographs taken from known angles and relative positions, simulating the human visual system. Stereo-photography has a significant application in robotic and computer vision. It is based on taking pairs of photographs from slightly different angles. When certain parts of the object in the scene are visible to both photographs, specific algorithms from vision can be applied to extract the geometry of the object. The external as well as the internal parameters of the optical system are used for calibration. Calibration is critical in terms of achieving accurate measurements. The method can either be fully automated or man-operated. The final result is a depth map of the object in the scene, reflecting the distance of each recognized point on the surface of the object from the photographic sensor. Advantages of this method are the ability to capture both geometry and texture, the low cost and the portability. Disadvantage of the method is its low resolution [24-25].

2.1.5. Shape from video

Shape from video is a variant of shape from stereo. Here the two photo cameras are replaced by a video camera that captures the object in a sequence of images from different views. A basic requirement for the application of this method is that the object is at complete rest and with no movable parts. The algorithms that are being used are similar to the ones in shape from stereo and are sensitive to noise in the video sequence. A key point in the process is the identification of common points between different images and the registration of these points onto a virtual 3D scene. The results are, sometimes, ambiguous due to the fact that there is no prior knowledge about the position of the camera or the objects. Advantages of this method can be considered the low cost, the portability and the ability to capture both texture and geometry. Significant disadvantage is the low resolution in capturing the geometry [26, 27].

2.1.6. Shape from shading

Shading plays an important role in depth perception. Many researches have already tried to simulate the way the human visual system uses shading information to perceive the depth. This method requires the capturing of the object from one viewing angle. What should vary is the position of the light source, which would cause the shading to vary on the surface of the object. This way, special algorithms could deduce the geometry of the surface of the object by using multiple photos of different shading conditions. The method is simple and has low cost. It captures both geometry and texture, with a minor disadvantage in capturing texture in shaded areas. It is portable but has the disadvantage of low accuracy. There are thoughts of using this method combined with other methods (such as shape from stereo) in order to enhance its accuracy [28].

2.1.7. Shape from texture

Texture can be a very significant source of information for the surface geometry. The calculation of 3D primitive shapes on a surface can be done if there exists some prior knowledge about the surface texture. It is well known that the human visual system can easily identify surface geometry when the surface texture is homogeneous. Researchers tried to exploit this observation in order to simulate the process. So, the idea is to identify small structuring texture elements (texels) and to find their possible transformations in order to reproduce the whole surface of an object. These identified transformations are then used to extract the actual 3D surface geometry. The method is, again photographic, simple and of low cost, but has limited applications (like capturing of fabric or human skin). It is portable and easy to use. On the other hand it has low accuracy [29].

2.1.8. Shape from photometry

Shape from photometry is a variant of shape from shading. Here the photos show the object from one viewing angle but varying lighting conditions. Additionally, the usage of reference objects (or, in some cases, reference lighting sources) in the scene is critical, since they are used as calibration objects. Calibrated lights can improve significantly the result of the method but can only be found in special laboratories, so in this case the method is not portable. In studies against laser techniques there have been reports that favor this method in terms of the produced data volume and the immunity to laser limitations. Generally it can be regarded as portable, and it is easy to use and of low cost. Main disadvantage is its current need for laboratory environment [30-32].

2.1.9. Shape from focus

Lately, a new possibility has attracted the interest of researchers: the possibility of exploiting the depth of field in a photo in order to deduce the 3D geometry of the scene. The method is recursive and is based on taking photos of an object while adjusting continuously the focus plane. By knowing the position of this focus plane (from the whole setup and the positioning of the system) we are able to map the focused pixels in an image on the correct position in the 3D depth map. The system, recursively, rebuilds the whole object geometry photo by photo. Resolution, as well as accuracy is limited, but the results are, in general, “reliable”. One limitation comes from the fact that in order to take photos with so limited depth of field one might need very special lens and a major application is in the usage of microscopes. The cost is relatively high, but the method is simple and easy to apply [33, 34].

2.1.10. Shape from shadow

Shape from shadow rebuilds the 3D model of an object by exploiting the deformation of the shadow of a known object which is projected onto the surface of the subject of digitization, when the light is moving. As obvious, this is a simple variant of the shape from structured light technique. Main advantage of this method is the low cost and the limited demand for computing power. It can reconstruct geometry even in non visible parts on the object, under certain assumptions about the object (or any prior knowledge). For this method, one might even find open source code on the Internet. The method has low accuracy [35].

2.1.11. Contact systems

Very often we might find digitization systems that use lasers mounted on some sort of arm with high degree of freedom. This arm can either be operated manually or automatically, and through its internal positioning system carries geometry information to the controlling software. These systems are generally called Coordinate Measuring Machines (CMMs). Apart from their combined usage with laser devices, they can be operated autonomously. A spike can be mounted on them and by maintaining continuous contact with the object to be measured, very accurate geometry information can be recorded. The method is of high accuracy but very show. There is also the disadvantage of having to be in contact with the objects, which is sometimes inadmissible [36].

2.2. Digitization of monuments

2.2.1. Empirical techniques

During an empirical recording of monuments, measurements are taken (by hand) of distances between characteristic points on the surface of the monument. The definition of the coordinates is being done on an arbitrary coordinate system on a plane surface of the monument. The method is simple and productive, portable and of low cost. On the other hand it is of low accuracy and demanding in terms of time of physical presence near the monument. It can be successfully applied when a monument has simple shape, or there is a need for recording a sectional plan or sections of interiors [37].

2.2.2. Topographic techniques

The topographic method implements a 3D orthogonal coordinate system by using complicated and high accuracy measuring devices. Mainly, this method using a Geodesic Station, a system for measuring angles and distances of characteristic points on the surface of the monument, which are further transformed to coordinates in reference to the initial orthogonal coordinate system. Main advantage of the method is its high accuracy and objectivity of the measurements. It is reliable and it is easy to process its results. A disadvantage is the need of long physical presence near the monument, but it is one of the only methods to be used under difficult conditions, such as complex shape and difficult access. It is referred as ideal for producing high accuracy models of scale 1:50 or smaller [37].

2.2.3. Laser scanning techniques

Laser scanners can actually be considered as advanced geodesic stations and can be used to measure topographic quantities. They can measure the direction of a fictional optical line joining the characteristic points on the surface of the monument to a reference point on the measuring device (Fig. 5). Additionally these scanners can estimate their distance from these points. By applying the known triangulation principle they produce Cartesian coordinates automatically.

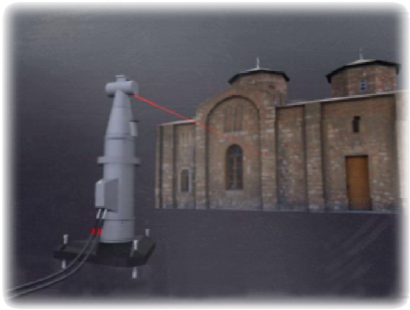

FIG. 5. Laser (range) scanning of monuments

Main advantage is the high accuracy and productivity, as well as the large volume of produced measurement data. It is reliable and objective. On the other hand it is a method of high cost and difficulties in portability and autonomy. It can be applied on almost every monument digitization, but can experience interference from very bright light [38].

2.2.4. Photogrammetry

Common digital photos can be used, under suitable conditions, for measurements that can be of the accuracy obtained by the topographic methods. By applying orientation processes and transformations of digital photogrammetry it is possible to deduce 2D or 3D coordinates from one or two photos. The method is objective and reliable and can be aided by CAD software. It is relatively simple and has low cost. On the other hand it has to be combined with topographical or empirical measurements and the final outcome is a function of the time spent. It can be used for complex objects with high surface detail, but since it is based on photos, there is a need for adequate space. It is also useful when direct access or contact to the monument is prohibited. It can be used to record stages of the monument in time. When combined with accurate measurements it can produce models of high accuracy for scales of 1:100 and even higher [37, 39, 40].

3. Conclusions

Complete digital recording of Cultural Heritage is a multi-dimensional process. It depends highly on the nature of the subject of recording as well as the purpose of its recording. In this work we made an attempt to summarize most of the methods available today for three-dimensional digitization that can be applied to digital cultural heritage recording.

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