Technology of Three-Dimensional Scanning "Structured Light"

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Abstract. Protection and preservation of cultural and historical heritage are particularly relevant today. The paper presents essence and challenges in the process of three-dimensional scanning of objects. Special attention is paid to the methodology of 3D scanning of cultural artifacts.

Keywords: digitizing, 3D scanning, historical artifacts.

1 Introduction

Structured light is the process of projecting a known pattern of pixels on to a scene. The way that these patterns deform when reflect by surfaces allows vision systems to calculate the depth of surface of the objects in the scene, as used in structured light 3D scanners.

This technology has many applications in practice. In this paper we present it from the point-of-view of digitization of cultural heritage artifacts. 3D scanning is a new way for protection and promotion of cultural heritage material. 3D digital recordings have more information about the volume, shape and structure of the surface of the object from the classic photo shooting.

In section 2 we describe the essence of the "structured light" and 3D scanning process. In Section 3 are presented some challenges and solutions during the 3D digitization process.

2 Three-Dimensional Scanning. Structured Light Technology

3D scanning is the process whereby capture, measurement or touch creates a 3-dimensional digital image, a copy of a thing, object or surface.

2.1 Digital Three-Dimensional Object

Digital 3D object is a digital representation of an object or surface in 3-dimensional space, where besides the height and width of each point of item carries information about depth. Essential for 3-dimensional image is the location of the individual points,

objects and surfaces in space. In modern digital technologies can add additional data of color, texture, material and in 3D animation can be added a movement in space.

There are several principal methods of building a 3D image:

- 3-dimensional computer modeling - it is a process where a specialist-operator by using specialized computer application, point by point, surface after surface builds three-dimensional object. This method is primarily used in architecture, geodesy, computer animation, computer restoration, etc. In this method, critical to the quality of the 3D image is the skills of the operator (3D designer) and it is possible to obtain a digital objects in a small volume;
- 3-dimensional computer generation - a process where a computer application generate 3-dimensional image from a set of images or other information. The quality of the generated 3-dimensional images is dependent on some subjective factors: the quality of the input images; enough images from different angles to cover the volume of the entire object; enough contrasting elements of the side to allow the software to assemble the individual images and etc.;
- 3-dimensional scan - it's a process that creates a 3D digital model of an existing object or surface by measurement.

Elements of digital three-dimensional model.

Digital 3D model contains digital information about the surface of the volume object or scene in 3-dimensional virtual space by building a mesh of points and surfaces.

Elements of mesh of 3D model are:

- Vertex or points containing details about position in space and may contain some other information about color, texture, etc.;
- Edges or lines - connecting two positional points (vertex);
- Face (surface) - closes edges in a geometric figure, usually triangles, squares or polygons;
- Polygon - not always used because it is built from several triangles;
- United surfaces - complex geometric figures combined into one face surface.

Example of 3D mesh of triangles that modeling a dolphin is show next (This picture is taken from Wikipedia: http://en.wikipedia.org/wiki/Polygon_mesh).

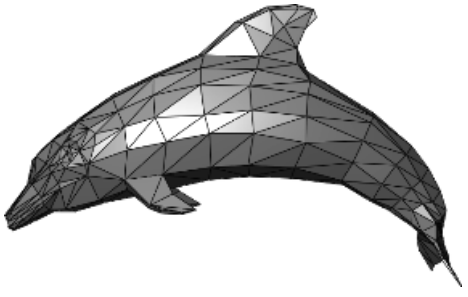

Fig. 1. Example of triangular mesh on dolphin

2.2 3-Dimensional Scanning

There are a variety of technologies to digitally recreate the shape of the object. Classification of 3D scanners starts with a division into two types - contact and non-contact. Contact 3D scanners use probe to touch the surface of the object to determine the position of each point and hence the shape of the object. Non-contact scanners are divided into two main types: active and passive. Passive scanners are capturing multiple images of an object and according to them, determine spatial location of individual points on the surface of the object. One of the passive methods is stereo recording, which is shooting simultaneously with two or more cameras of the object from different angles, and according to the differences in the images is determined position of individual items (recreates human vision). Active 3D scanners use radiation of some kind of light, sound, ultrasound or other and capture the reflection of this radiation. Usually active 3D scanners use several types of measurements:

- Time-of-flight - This is a type of measurement, where 3D scanner emits a laser beam, and by measure a time of that beam reaches the surface of the object and reflected beam to return to the sensor, calculate the distance to the point of reflection. This type of scanner is crawling with beam entire visible surface to determine its form and shape. The technology allows to scan large areas at long distance;
- Triangulation - This method determine the distance to a point of surface of object by trigonometric functions. The mode of action of this method is as follows: 3D laser scanner emits in a line laser beam. Sensor or camera at a certain distance from the line of the laser, detects the point of reflection. These formed three lines: line of emitted laser beam, line of reflected beam and line between laser and sensor, form a triangle. Triangulation is shown below on figure 2 and explain at next section;
- 3D imaging modeling - Method in which, a set of two-dimensional images (sections or slices) on a short distance between then, computer builds three-dimensional image through a special algorithms (called: isosurface extraction algorithms). This method is very well developed in the medical field, using the superimposition of X-ray, ultrasound images of CT or MRI slices at a small distance to build 3D full image.

2.3 Triangulation

Triangulation in 3D area is a method of determining the position of a point by measure orientation of line of reflection beam by trigonometric functions. More precisely, scheme of triangulation is shown on figure 2, where 3D scanner “knows”: position of laser device (point A), orientation of laser beam (line AB), position of camera or sensor (point C), orientation of reflected beam (line BC), distance and orientation of line between laser and camera (line AC). And position of point of reflection at surface of object (point B) can be found by applying a trigonometric functions at formed triangle ABC. On figure 2 is shown also second position of object and different formed triangle AB1C.

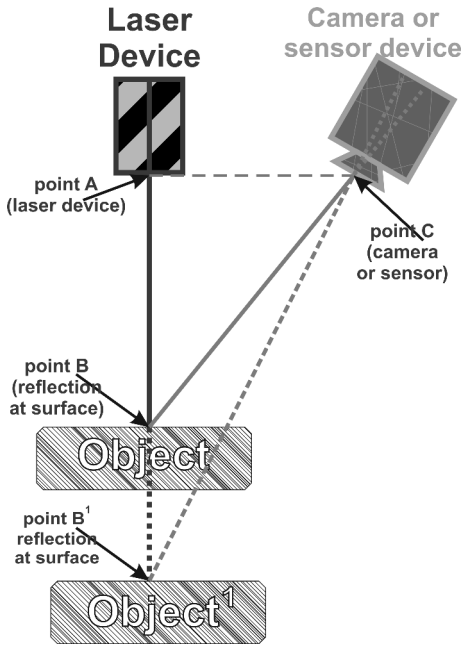

Fig. 2. Scheme of laser triangulation system

2.4 Structured Light Technology

Structured light technology for three-dimensional scanning use method of triangulation to determine the position of the points at the surface of the scanned object, with the difference that do not use a laser beam but use projection of light patterns. On a figure 3 is shown an example of projection of light pattern on spherical object (round vase) and its reflection.

Fig. 3. Staging of projection of light on a round vase

Pattern schemes that use scanner device is usually monochrome (black and white) squares (like chessboard), horizontal or vertical strips, like shown on figure 3. Usually scanner device use a number of that patterns with different size of strips. Smaller size of bands means more scanned points of surface, because 3D scanner catch the edge line of black and white. More precisely, scanner device project black and white patterns and scanner "knows" lines of projection of these schemas. Camera on a distance form projector captures reflections of these patterns at surface of an object. 3D device calculate position in space relative to scanner, of captured points of edge lines (between black and white) [6] using triangulation method.

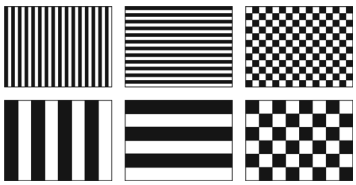

Fig. 4. Example of projection schemes

As many patterns projected as many edge lines captured as many points of surface of object are located in space. For an example using 3D scanning system DAVID SLS-1 [4] to scan a object with size approximately 20 cm by 20 cm, at one scan on one side of that object there is usually three hundred thousand vertexes and half an million triangles captured in digital 3D image. We use this 3D system to scan historical artifacts at project "Digital archive of documentary heritage of the Balkan Wars"[1] [2, 5].

3 Advantages and Challenges of Three-Dimensional Scanning

Digitization by three-dimensional scanning comes more and more in science and in the field of protection of tangible cultural heritage. At [1, 2] we show some three-dimensional digitalization of historical artifacts. Considered technologies and methods have their advantages and disadvantages in the 3D scanning field.

Next is shown brief methodology of 3D structured light scanning of cultural artifacts using system DAVID SLS-1, more detailed in [2], where is presented scanning of machine-gun "Schwarz-loze" (figure 5).

Fig. 5. Views from different perspectives of 3D model of machine-gun "Schwarz-loze"

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Methodology for 3D structured light scanning.

1. Positioning System – it is spatial arrangement of stage of object and position of system: projector, camera and other equipment;
2. Calibration system – it is importance for determining the scanning area and distances between projector, camera and object. It is important for accurate calculations of triangulation method;
3. 3-dimensional scanning of side / part of the object - scan the visible part of the object. To obtain a complete 3D digital model of the object is need to scan all the visi-ble parts separately;
4. Processing all the individual 3D images and combining them into a comprehensive spatial model.

3.1 Characteristics of The Different Technologies for 3d Scanning

The main objective in three-dimensional scanning is getting the digital spatial model of the scanned object, which means that not all scanners measure color, texture, material, hardness, etc. of the surface of the scanned object. For an example: Contact scanning devices can determine the relative hardness of the surface. Devices that use cameras to capture the object can determine the color and texture of it. But those devices that use laser technology can determine only the location of the points of the surface in space, and you should further capture the texture of the object.

Size and distance to the object can range from centimeters to kilometers, depending on the technology used for 3D scanning. Technology "Time-of-flight" is measure time that laser beam travel to surface of object and back through air, which can give a tolerance of precision, but allows scanning of large objects such as buildings, terrestrial elevation at kilometers away. Contact scanning technology by the method of touch of object is much more accurate in capturing spatial surface (measured position of each point with an accuracy of fractions of a millimeter), but the objects must be of such size and location that the scanning device can reach it. Scanning devices using structured light capture portion size which projected schemes of the focal length of the camera, but allow mounting of separate surveys in an image, which means that the size of the object can exceed the size of the staging scan.

Accuracy when scanning bulky objects is measured in deviation from the actual location in space of a point on the surface of the scanned object to the other points. In technology for contact scanning and technology used method of triangulation accuracy is very high (fractions of a millimeter). While technology Time-of-flight has less accuracy because there is deviation due to the measurement of the time for which the beam is go to the surface of the scanned object and go back, with the influence of light speed through air.

Due to the high accuracy of the contact scanners and systems using triangulation reflection density scanning the surface of the object is very large. For example, scanned image of one side of the object, approximately 10 cm by 10 cm using system DAVID SLS-1 [2] with structure light scanning of the surface are of the order of 50

000 to 150 000. For contact scanners density scanning depends on the sensitivity crawl shoulder.

Shortcomings and challenges facing different types of technology are:

- Upon contact scanners drawback is the contact of the device with the scanned object, may lead to deformation of the object;
- At technology Time-of-flight inaccuracy due time measure of beam relative to the light speed in air;
- At 3D scanner devices using technology of reflection of light should also consider the influence of ambient light to the object, which is neutralized when working in a light controlled environment. It should also be borne in mind and the reflective properties of the surface of the scanned object. Scanning of reflective surfaces such as metal, glass and other have difficulties in capturing the reflection of projected schemes. This challenge can be avoided with the use of anti-glare spray or powder-coated pigment on the scanned object. An example of 3D image of reflective surface is shown figure 6 bellow, where there is holes of non-scanned parts of surface of metal historical artifact.

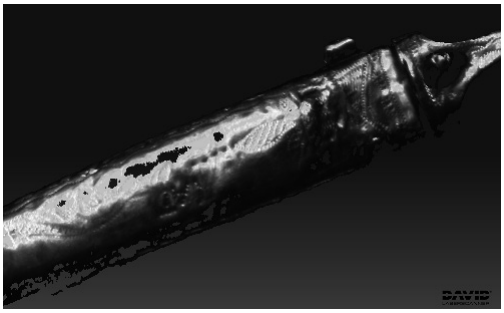

Fig. 6. Part of 3D scanned image of a historical artifact (metal dagger), with non-scanned parts of surface caused by blinks of light reflection

3.2 Instrumentation of Scanning Systems

Systems using three-dimensional modeling of two-dimensional images are mostly used in the medical field, building three-dimensional model of ultrasound, X-ray or MRI images are costly specialized systems with special purpose.

Contact scanning devices are actually robots with loose-round elements, which is specialized expensive equipment.

Devices that use the technology Time-of-flight laser beam are primarily designed for "advanced distance measuring" and are mainly used in construction and surveying and they are specialized expensive equipment.

Scanning system using structured light technology consists a projector, camera, computer, appropriate connectors, racks and background plays. Basic, equipment is not expensive, but the software applications necessary for the process of scanning and processing are costly.

4 Conclusion

Digitization of paper and museum collections as a means of protection is one of the priorities in the development of libraries and museums.

We present a brief but important survey on one of the most widely used digitization technology – non-contact 3D scanning. We paid special attention on one of 3D scanning technologies – structured light. Some of our experience at work with digital 3-dimentional technologies are shown at [1, 2, 3].

Finally we demonstrate how all these approaches could be applied to digitize cultural artifacts.

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