NEW LOW-COST 3D SCANNING TECHNIQUES FOR CULTURAL HERITAGE DOCUMENTATION

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ABSTRACT:

In the last ten years, direct 3D documentation techniques are very popular and in a great advancement. There are two different methods: ranging scanners and triangulation scanners. A very high price and expensive processing software are the disadvantages of both the above-mentioned systems. However, the market demand in historical monuments documentation is to be cheap, easy and fast. This problem is striking by sculptures documentation. A historian or restoration specialist demands documentation of hundreds of sculptures annually. Such amount of work is not possible to be done by today's techniques and mainly prices. Unfortunately, destruction, vandalism, wars, terrorism and environmental status are faster than documentation and restoration process. For sculptures preservation a good documentation is needed. For hundreds or thousands of sculptures the simple and cheap methods are preferred. In many cases, sculptures are situated on hard-accessible places – it is a big problem for precise measurement by 3D scanners. In the Czech Republic, we have done a market research; the results are very interesting: by usual sculptures, a high precision is not demanded. The combination of simple 3D model with good images is sufficient – this information is used for possible sculpture reconstruction and copying. Artists and restoration specialists are not ordinarily the specialists in 3D modelling or animation. They don't use special software for 3D scanning and presentation. The simple 3D model is good for right stone selection and for space conception; the possibility of simple 3D measurement is often demanded – a simple solution in this area provides the Adobe Acrobat with 3D functions. At the Czech Technical University in Prague, we work for a long time on low-cost and simple documentation methods in historical monuments documentation. One of these methods is the image correlation technique for 3D model obtaining. The system uses only a calibrated digital camera and software, or LCD projector and laser markers. Primarily, the scanner is designed to be independent on any additional light (structure light, laser pointers), but in some cases (dark room, very clear surface with no pattern), there is an option (in software settings) to use any kind of light system with or without pattern (structured light). According to this statement, it is necessary to take a sequence of images with a short step and with the same orientation (stereo). The image coordinates of points move by step correlation throughout the sequence of images from the first one, to the last. This is especially effective for the points located on a steep slope surface, undetectable with ordinary two-image correlation. If the base is long enough, it is possible to set one or more key images inside the base and use them to compute the points not visible from one of the edge image. Then, the system becomes multi-centre point base measuring. In comparison to laser scanner, the coverage of measured object is much higher here. Because the surface structure of measured object has almost an ideal pattern, visible even from a long-distance, we decided not to use structure light for lightening the object. The second one is tracking of thin laser line on a measured object by digital cameras. There is a big problem with object illumination – by daylight the laser line is not clearly visible for detection by using image processing. For this reason, the near infrared laser light is used. However, usually digital cameras cannot take images in near infrared range. At the Czech Technical University, we probe adapted digital Canon cameras, converted to near infrared range. In this case, the principle is similar to the first type; in the middle of a known photogrammetric base the line laser slowly turns over by using small stepping motor. On both ends of photogrammetric base two digital cameras take images in the maximum image sequence (10–15 times per second); images are stored in a laptop. Last part is post-processing of images and computing of object point 3D coordinates. The paper refers about latest results in this area.

1. INTRODUCTION

1.1 Motivation

3D scanner is any device that collects 3D coordinates of a given region of an object surface. In this time, it is used a lot of devices on different measuring principles:
a) Laser scanners (technical principle: time of flight of a laser pulse, phase comparison method)
b) Triangulation scanners (technical principle: one camera and laser marker, two camera and structured light and scanned object can be static or on a rotating platform).

Both types use special devices and the results are in many applications too expensive.

In the framework of co-operation between the Laboratory of Photogrammetry of the Department Mapping and Cartography, the Department of Special Geodesy and the Laboratory of Quantitative Methods of Monuments Research (Faculty of Nuclear Physics and Physical Engineering), new methods of 3D objects documentation are tested on school level. The aim of this research is to develop a small inexpensive device for special purposes of 3D documentation. There are two base types of 3D optical scanners under developing: first type uses triangulation method: two infrared sensitive cameras take photos of laser path on object; laser is used only as a point or profile marker. Second type uses image correlation technique on images taken by moving calibrated camera.

Optical 3D scanner is a precise, non-contact measurement device collecting a huge amount of points in a 3D space. This measurement technique, as well as other 3D scanning technology is used in many areas, such as surveying, civil and mechanical engineering, archaeology, historical artefacts documentation etc. In the Czech Republic, there are a lot of valuable sculptures that are in a very bad condition; expensive scanning with laser is not acceptable. Our primary interest is in the field of non-expensive survey documentation of sculptures and parts of historical monuments or buildings.
The functional principle of an optical scanner, in comparison to a laser scanner, is historically much earlier, known since photography has been invented. A huge improvement comes together with the development of computer technology. Now, it is possible to use the whole potential of all the data stored in image format.

2. SCANNERS

2.1 Limitations of short-distance scanners with structure light and laser scanners

The Laboratory of Photogrammetry of Civil Engineering Faculty at the CTU Prague collaborates in close connection with historians and restoration specialists who need precise documentation. After survey we set the limitations of today's systems and parameters for a new demanded scanner.

Short-distance scanners:

- Only for short distances. The precision of some of these scanners is very impressive (up to 0.01 mm), but in many areas, like documentation of monument buildings is not needed, even for architectural details.
- Often requires structured light. Measuring in a bright sunlight is impossible, in many cases bad transportable.
- The operation is slow, because the measured area is relatively small.
- The operation price is too high.

Laser scanners:

- The shortest usable distance is too big and the precision is usually poor.
- The intensity of the beam depends on the reflectivity of the material. Some kinds of materials cannot be even detected (wet sandstone with bryophyte – typical for sculptures).
- Centre point based measuring.
- The operation price is too high.

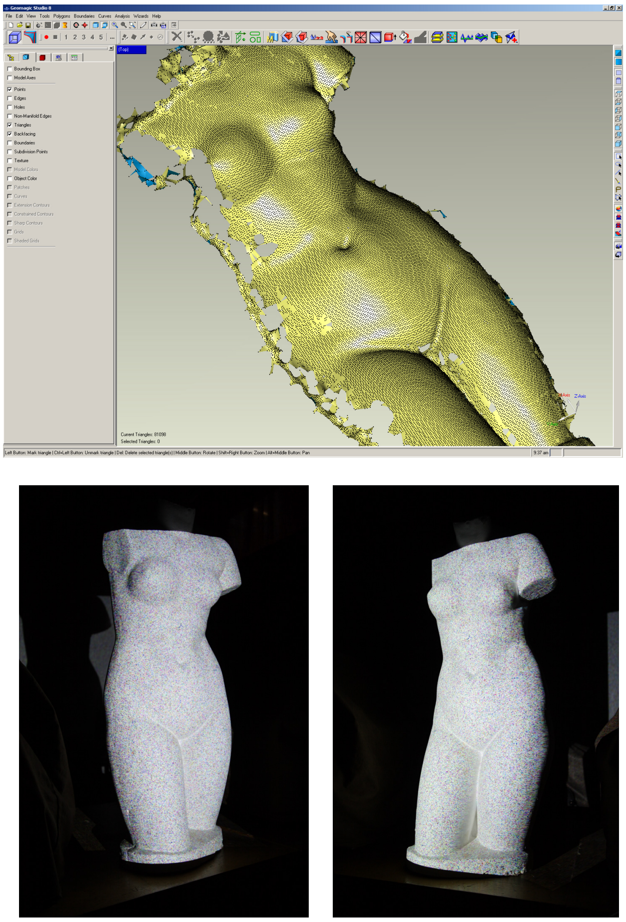

Figure1. Image correlation method for creating 3D model, using projected raster on sculpture

2.2 Demanded scanner parameters

Our optical scanner OKS (Optical correlation scanner) can solve some of the above-mentioned problems. The scanner is universal; by changing the base length, it is possible to measure short-distance objects (architectural detail), as well as long-distance (the base is variable up to 1.5 meters). Primarily, the scanner is designed to be independent on any additional light (structure light, laser pointers), but in some cases (dark room, very clear surface with no pattern), there is an option (in software settings) to use any kind of light system with or without pattern (structured light). The operation is cheap, fast, and precise enough in comparison to laser scanner technique or short-distance triangulation scanners. Most of these advantages come from the basic idea of a scanner that works with a short step (mm, cm) sequence of images in the same orientation – it is the best for the correlation. The scanner consists of a digital camera (Canon 20D, 8Mpix), a photogrammetric base (10–150 cm), tripod and the most important part – the software. The final 3D triangulated data are stored in pdf format. In the new Adobe Acrobat 3D product, many kinds of measurements can be made, especially section profiles. This software is very easy to use and satisfies most of the needs of historians and restoration specialists. This solves a very frequent question of non-specialist on laser scanning: on which non-expensive and easy software we can utilize the measured and processed 3D data.

3. BASIC PRINCIPLES

Optical scanner OKS is based on image correlation. It consists of one calibrated camera, photo-base with moving camera-holder, tripod and software only. However, the software is the most important part of this system. It is possible to take the images manually (hand-held), but in this case it is necessary to know outer orientation of all the camera stations (it can be computed with other software, e.g. Photomodeler). Only two identical images can give the best possible correlation (= 1). This idea is irrational, but it is a good baseline for developing the following strategy. With the increase of the distance between images, the correlation coefficient decreases. According to this statement, it is necessary to take a sequence of images with a short step and with the same orientation (stereo). The image coordinates of points move by step correlation throughout the sequence of images from the first one, to the last. This is especially effective for the points located on a steep slope surface, undetectable with ordinary two-image correlation. If the base is long enough, it is possible to set one or more key images inside the base and use them to compute the points not visible from one of the edge image. Then, the system becomes multi-centre-point base measuring. In comparison to laser scanner, the coverage of measured object is much higher here. Because the surface structure of measured object has almost an ideal pattern, visible even from a long-distance, we decided not to use structure light. It was assumed that 16bit images would work the best for correlation. Dynamic range of halftones is incomparable (65.536 × 256) to 8bit image and correlation coefficient is higher.

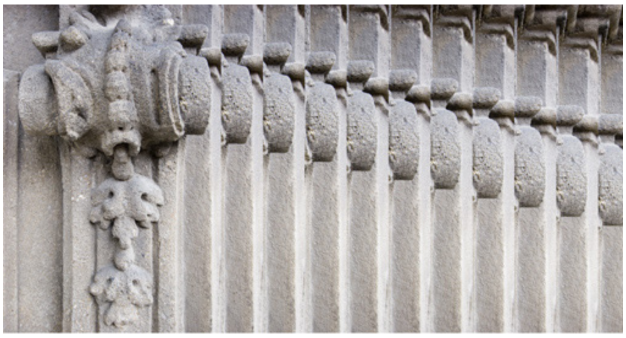

Figure 2. Images taken by moving camera

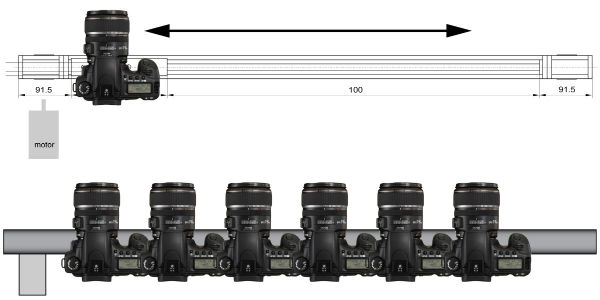

Figure 3. Scheme of camera motion

3.1 Correlation matrix

The correlation matrix has usually the shape of a square. It was assumed, that the rectangle (ratio is about 1:6) with longer edge perpendicular to the direction of camera movement is more suitable. In this direction, the perspective deformation of image is bigger and therefore it is better to enlarge the matrix in a cross direction. Sometimes the corner of correlation matrix hits the jut of an object in a different horizontal level and the correlation is poor. If this happens, a transverse matrix is used.

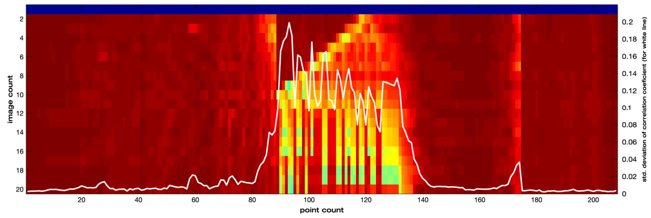

Figure 4. Graphical visualisation of the correlation process along the line in the image below

Figure 5. The first and the last image (crop) in sequence

3.2 Software modules and principle

All software modules are written in Matlab2007 and use pre-defined functions including correlation coefficient (corr2).

The OKS computing system consists of the following modules:

- Tie points
- Bundle adjustment
- Rectification
- LUT computation
- Correlation

3.3 Tie Points

This module is performed for semi-automatic tie point's identification, which is necessary for computing of outer camera orientation. Six tie points are the minimum for computing; usually about 30–100 tie points are measured. Tie points are identified manually only on the first image; on other images they are located automatically by using image correlation and LUT_0 table (look up table, searching of homological points is restricted only to a small part of the next image), which helps to identify the tie points on other images. This process takes usually about 15 minutes. Fully automatical searching for tie-points by feature extraction methods gives worse results; of course it depends on object and its structure.

3.4 Bundle Adjustment

The computing of outer orientation is made by bundle adjustment method. The camera parameters (inner orientation), tie points coordinates and approximated parameters of outer orientation are needed. The camera takes images from base by using controlled motion and so the camera positions are known.

3.5 Rectification

To speed up the process of correlation, the function that combines the methods of correlation and epipolar geometry is used. On epipolar images the homological points are located on same image line; it means the searching of homological point is restricted only to one line. Epipolar geometry works only for two images. In this case, a special method has been developed based on epipolar geometry for more images. Homological points are not on common line, but on other lines that can be find by using LUT (look up table). Along with rectification (creation of epipolar images), the correction of lens distortion is also applied. Using reverse process with bicubic interpolation of RGB values on original image makes the rectification.

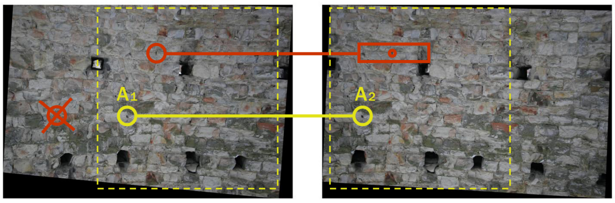

Figure 6. Rectified images

3.6 LUTu, LUTv

The process of correlation can be sped up using the LUT (look up table). There are two types of LUT distinguished by two names: LUTu, LUTv. In homological point searching, it is not necessary to analyse the whole next image. The relations between minimum and maximum object distance and minimum and maximum image columns are used. In this case several transformations between epipolar, general and minimal (maximal) planes are used. The computed relations are stored in a special table LUTu (look up tables), which is further used in computation. LUTv is used for finding corresponding lines to first image.

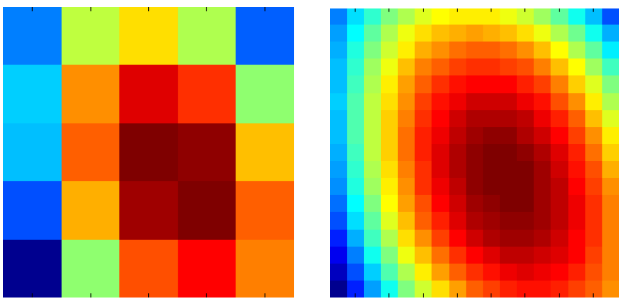

Figure 7. Example of sub-pixel interpolation

3.7 Correlation

By using this module, the coordinates of homological points in whole image sequence are identified. The located point has an extreme value of correlation coefficient.

It is necessary to use a sub pixel method in correlation in order to increase the accuracy of coordination. This is achieved by bicubic interpolation in a matrix that contains the correlation coefficients of relevant pixel-point and its nearest neighbours. 3D coordinates are computed by using bundle adjustment method from all images. For outliers points or errors detection the reverse correlation from the last computed point to original point on the first image is used. If the reversal computed coordinates for the last point are different from the first point, this point is suspended. This method needs laborious calculations, but it is reliable. Computed 3D points are coloured by using RGB values from original image.

3.8 Creation of TIN structure

An important part of the processing is to triangulate all points. For this, 2D Delaunay triangulation is used. Initially, the point cloud is projected (central projection) onto a plane, triangulated in 2D with Delaunay and then reprojected back to 3D. It is also possible to use a smooth filter that averages the neighbourhood points. The advantage of this processing technique is a clean, continuous mesh without any disturbances.

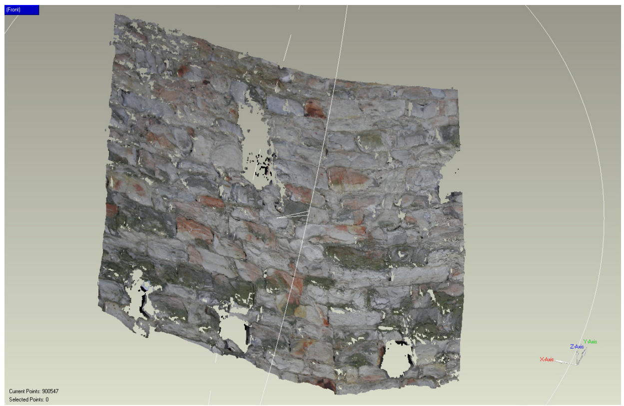

Figure 8. Final 3D model

4. REFERENCE

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