DIGITALLY DEVELOPING WORKS OF ART

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ABSTRACT

During a strong earthquake two years ago, the Byzantine Monastery of Daphni in Athens suffered severe damages. This particular monument is considered one of the most important specimens of Byzantine art and architecture worldwide.
For the purposes of detailed archaeological and artistic research, the recording of the magnificent mosaics of the main church (Katholikon) at a very large scale was considered necessary. The problems of recording such works of art at a scale of 1:5 are numerous. However the requirements included, among others, the raster development of those mosaics which are constructed on developable, i.e. cylindrical or conical, surfaces.
In this paper all considerations for this task are presented and their implementation is described in detail. The issue of the reference systems combination is firstly addressed. Secondly the problem of suitably performing the stereoscopic photography is also considered. Finally the required photogrammetric measurements are performed on a digital photogrammetric workstation.
For this task specialized software has been developed in order to accommodate for the data acquired during the surveying process. Several examples of the resulting digital raster files are also discussed and assessed for their usefulness and accuracy.

1. INTRODUCTION

The Dafni Monastery is one of the two remaining today excellent specimens of the culmination of Byzantine architecture (Figure 1). It was built in the 11th century and is situated in the southeastern part of Attica near Athens. The whole monastery extends on an area of 0.7 hectars and in the centre of that area lies the majestic central church, the Katholikon. In essence it is a cross-domed octagon type of church extending approximately 25x15 m^2 and 20 in height. The Monastery is considered to be the Parthenon of the Byzantine era and is internationally protected by UNESCO.

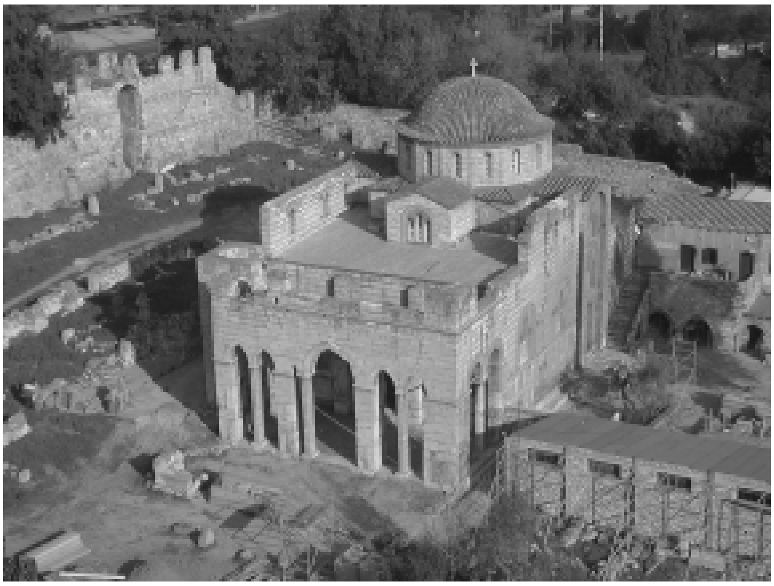

Figure 1: The Dafni Monastery

The strong earthquake of 7th September 1999 caused severe damage to the Katholikon and the rest of the buildings of the monastery. The Ministry of Culture immediately decided to take strong measures in order to protect the monument. Before any static or structural interventions a thorough survey of the monument at a general scale of 1:25 was decided. The Laboratory of Photogrammetry of NTUA undertook this task.

2. RECORDING THE MOSAICS

One of the features, which make this monument unique, is the famous mosaics. They are fine specimens of byzantine art following the well-established iconographic programme of Middle Byzantine churches (Figure 2). The tesserae are unusually small in size (approx. 0.5 cm^2) and they are decorated with a wide variety of colours. The great majority of them are gold plated. The mosaics are situated on the walls of the church in various heights and on any kind of surface. Some of them are on planar surfaces, some on cylindrical, i.e. arches, and others on spherical surfaces, i.e the dome and the pendentives underneath.

Figure 2: A specimen of the fine mosaics

For reasons of documentation, but also in order for the conservationists to be able to work on the mosaics and restore the damages, it was required to produce colour orthophotographs at a scale of 1:5. In the case of mosaics on curved surfaces, it was required, in addition, to produce the development, if possible, of each mosaic at the same large scale.

The above products called for very specialized and careful photography, in order to avoid reflections, to ensure even lighting and realistic colours and, at the same time, guarantee an image quality, which would ensure the high accuracy requirements. The fact that most of the mosaics are situated on difficultly accessible positions and are not easy to photograph, made the job even more difficult. Moreover the lighting conditions in the church are extremely adverse. A series of experimental photography was performed and it was decided to use a system of two large softboxes, in order to ensure even lighting on one hand, to bring out the wonderful colours and keep unwanted reflections to an acceptable minimum, on the other.

For the photography the combination of a Hasselblad non-metric camera with colour slide film of 100 ASA was used. A wideangle lens of 50mm focal length allowed for larger portions of the mosaics to be recorded stereoscopically. Metric cameras, although available, were practically useless, either because of their size, bulkiness and the relative unavailability of colour film plates (e.g. Zeiss UMK), or because of the presence of a reseau (e.g. Rollei Metric 6006). The taking distance, considering the required large scale of the final image product, was kept around 1.0 to 1.2 m thus producing image scales around 1:20, adequate for the 1:5 final scale.

3. DEVELOPING THE MOSAICS

As already mentioned those mosaics, which were not on plane surfaces, lied on developable, i.e. cylindrical or conical, surfaces and on non-developable surfaces, i.e. spherical, or general second order surfaces. The development or, rather, the suitable cartographic projection for the "development" of the latter will be reported elsewhere. For the rest of the curved mosaics it was reasonably presumed that most of the surfaces were cylindrical. It was established that the eventual deviations from the perfect cylinder would not have a significant effect on the accuracy of the final product, even at such a large scale. Previous similar researches (Rapsomaniki et al. 1995, Theodoropoulou 1996) had proven the above fact.

3.1 Special Problems

Most of the cylindrical mosaics were a combination of a part on a plane surface (e.g. on the pillar) and a part on the arch (Figure 3). The planar part was treated normally using digital photogrammetric rectification of single images. The cylindrical part was photographed stereoscopically in order to produce the required digital surface model. The latter was used to produce the colour orthophotography and, of course, in order to determine the cylindrical surface and the raster development.

Figure 3: Typical mosaic with a cylindrical surface

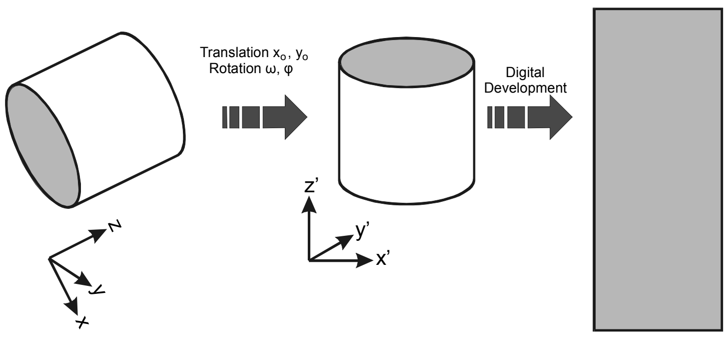

Figure 4: The development algorithm

The cylindrical surfaces in the monument are, mainly, in the form of arches and niches. Their orientation and position, however, in space differs and presents a severe difficulty as far as the suitable reference system is concerned. Considering the desired reference system of the final product, one should carefully determine the initial reference system. Moreover the points which are used to determine the surface are being measured geodetically in a general and common for the whole monument refernce system. In general it was found out that the best course of action would be to determine the surface in the geodetic system, then rotate and translate it to a suitable and independent and arbitrary system in order to produce the development (Figure 4).

3.2 Determination of the Geometry of the Cylinder

In common usage, the term “cylinder” refers to a solid of circular cross section in which the centers of the circles all lie on a single line. A cylinder is a right cylinder if it is “straight” in the sense that its cross sections lie directly on top of each other; otherwise the cylinder is oblique. In a more sophisticated approach, a cylinder may be a second-order algebraic surface with elliptical, hyperbolical or parabolic cross sections. In this work, an oblique circular cylinder is considered as a sub case of an elliptical cylinder in space.

A second-order algebraic (or quadratic) surface is defined as a set of points, which satisfy the following equation:

$$ax^2 + by^2 + cz^2 + 2fyz + 2gzx + 2hxy + 2px + 2qy + 2rz + d = 0 \tag{1}$$

This quadratic equation can be classified in 17 different surface types, including the elliptical cylinder. The equation contains 10 coefficients of which only 9 are effective; surface type and size (3 parameters) and surface position and orientation (6 parameters). The unknown parameters can be approximated using Least Squares Adjustment, if the three-dimensional coordinates of a sufficient number of surface points are available. The parameters of the quadratic equation cannot be used “as is”, since they do not have any physical significance. However, the parameters of the normal form of the above equation can be derived from the parameters of the quadratic equation by performing the appropriate 3D transformation.

The normal equation of an elliptical cylinder has the following form:

$$\frac{x^2}{a_c^2} + \frac{y^2}{b_c^2} = 1 \tag{2}$$

In the case of the circular cylinder, the semi axes a, b are equal and the surface of the cylinder is expressed by the form:

$$x^2 + y^2 = R^2 \tag{3}$$

Equation (3) actually is the equation of a circle with radius R. Unfortunately, this is not the common case in architectural applications where geodetic measurements are usually referenced to arbitrary coordinate systems. Therefore, additional orientation parameters should be introduced into equation (3):

$$\begin{aligned} x'^2 + y'^2 &= R^2 \\ x' &= r_{11}(x - x_0) + r_{21}(y - y_0) + r_{31}z \\ y' &= r_{12}(x - x_0) + r_{22}(y - y_0) + r_{32}z \end{aligned} \tag{4}$$

In the above equations x', y' are the coordinates of a point on the right cylinder coordinate system, x, y, z are the corresponding coordinates in the arbitrary system, x_o, y_o are the translation parameters and $r_{11}, r_{21}, r_{31}, r_{12}, r_{22}, r_{32}$ the rotation parameters (elements of a rotation matrix). According to the equations (4), five unknown parameters have to be determined:

- the orientation of the cylinder (i.e. two translations x_o, y_o, two rotation angles about X and Y axes) and
- the radius R.

Initial approximate values are necessary in order to solve for the 5 unknown parameters with Least Squares Adjustment.

Because equations (1) and (4) are equivalent, either of them may be used in order to describe a tilted circular cylinder. By combining the two equations, initial values for the translation parameters x_o, y_o can be found by solving the following equation system:

$$\begin{aligned} p &= -ax_0 - hy_0 \\ q &= -hx_0 - by_0 \\ r &= -gx_0 - fy_0 \end{aligned} \tag{5}$$

The initial values for the semi axes of the elliptical cylinder are calculated from the eigenvalues of equation (1). In the case of a circular cylinder, the semi axes should be equal to the radius R. The rotation angles ω, φ about X and Y axes respectively are initially set to zero.

3.3 Image Development

In order to develop an image of a cylindrical surface the physical parameters and the orientation of the surface in space must be known. The parameters of the exterior orientation of the image must be also available. In a first step, the area of the image to be developed as well as the pixel size of the rectified image should be defined. For each pixel with developed coordinates x_d, y_d, the corresponding cylindrical coordinates x_c, y_c, z_c are calculated by using the following equations:

$$\begin{aligned} \theta &= \frac{x_d}{R} \pm \frac{\pi}{2} \\ x_c &= R\cos(\theta) \\ y_c &= R\sin(\theta) \\ z_c &= y_d \end{aligned} \tag{6}$$

The coordinates x_c, y_c, z_c are referenced to the normal cylinder coordinate system, whitch is different from the geodetic coordinate system used in the exterior orientation of the image. The normal cylinder coordinates must be transferred to the geodetic system, in order to be used in the collinearity equations. Since the transformation parameters from the geodetic system to the normal cylinder are known from equations (4), an inverse transformation is actually applied.

By applying the above transformations, the 3D coordinates of the centre of each developed pixel are determined in the geodetic coordinate system. The corresponding image coordinates are then calculated by using the well-known photogrammetric collinearity equations. The color value whitch is assigned to the each pixel is calculated using bilinear interpolation.

4. APPLICATIONS

The development procedure for cylindrical mosaics that has been described above, was applied with great success in various parts of the church. In all cases the main problems that have been presented were firstly the requirement for high quality initial colour photography and secondly the correct determination of the suitable reference system. Two typical examples of the application of the development procedure with a comparative presentation of its results in relation with the results from the orthophoto production are presented:

(a) The first application refers to the drum under the main dome, where there are 16 mosaics (figures of profits) at the walls between the windows. The whole surface consists a cylinder with a vertical axis. In Figure 5. the orthophoto (at the top) and the corresponding development (at the bottom) of a part of the cylinder which includes three of the 16 figures, is presented. The differences between the two representations and the successful result of the development procedure are clearly visible.

Figure 5: The orthophotograph and the corresponding development of a vertical cylinder

(b) The second application refers to a mosaic on an arch above a pillar. The mosaic consists of a flat part (at the bottom) and of a part of a cylindrical surface with horizontal axis (at the top). The final product is a combination of a single image digital rectification and of a development as described above. In Figure 6. this product is shown (on the right) together with the orthophoto of the mosaic (on the left). Tests done by measurement the distances between characteristic check points of the mosaic, proved that the accuracy of the development is better than 1cm.

Figure 6: The orthophotograph and the corresponding development of a horizontal cylinder

5. CONCLUSIONS

The possibility of using photogrammetric methods for the production of pictorial presentations in the fields of architectural visualisation or monument preservation has been specially emphasized recently (Hemmleb et al 1997). The procedure which is described above for the production of reliable digital image developments of cylindrical surfaces, proves the existing capabilities of specialized approaches when the classic procedures of the single image or differential rectification are not sufficient enough to cover the user demands. The combination of a carefully taken photography, with the use of an appropriate camera and special lightning, and the right selection of the reference system for each surface development, give results of fully acceptable quality and accuracy for restitutions of even very large scales (1:5).

REFERENCES

Hemmleb, M., Wiedemann A., 1997. Digital rectification and generation of orthoimages in architectural photogrammetry. Proceedings of CIPA International Symposium ‘Photogrammetry in Architecture, Archaeology and Urban Conservation’, IAPRS, vol. XXXI, part 5C1B, Goeteborg, Sweden, pp. 261-267.

Rapsomaniki, A., Santrivanopoulos, S., 1995. Determination and development of cylindrical and conical surfaces. Diploma Thesis, Dept. of Rural & Surv. Eng., NTUA, (in Greek).

Theodoropoulou, I., 1996. Single image digital survey of cylindrical surfaces. Algorithm, determination and survey of a water tower. Diploma Thesis, Dept. of Rural & Surv. Eng., NTUA, (in Greek).