AN ALTERNATIVE METHOD FOR LARGE SCALE ORTHOPHOTO PRODUCTION

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ABSTRACT

In this paper the development of an alternative method of producing orthophotos is presented. The existing methods of orthophoto production present certain inflexibility in the manipulation of the object, mainly due to the way the pictures have to be taken in order to be accepted by the processing software. That is, all axes of the photos should be almost parallel to each other. This fact has serious consequences to the possibility of the selection of the projection level which will be used, while on the other hand it creates serious problems in the quality of the final products. That is why a way to formulate a method which will take account of photographic images freely taken was investigated. At the same time, ways to assure some important presuppositions of the orthophoto were investigated, such as the capability to control the image scale and the rejection of useless information from the final picture.
In order to take advantage of the possibilities offered by the computer technology, as well to automate the procedure, to reduce the cost of equipment, to save time and human labour, it was considered expedient to process the radially taken pictures in a digital environment, through the development of a programming application, which could run on a simple personal computer. So, an algorithm was developed for producing digital orthophotos and orthomosaics in the MATLAB programming environment. To certify the effectiveness of the algorithm, it was necessary to apply it in a suitable object. For this reason an ancient monument was chosen, the Black Tower on the island of Siphnos. Because of its profound roundness and its considerable relief, it was an ideal object for checking the function of the program. After the execution of the necessary field work, the collection of photos and surveying measurements and the processing of the collected material, it was decided to produce an orthophotomosaic, picturing the northwestern face of the tower.
In addition to this orthophotomosaic, orthophotos corresponding to view under extreme rotation were produced. The analysis of both products was the base to reach some very useful conclusions concerning the reliability, the functionality and the possibilities of the proposed method, as well as the accuracy standards that can be supported, the minimization of failures and distortions, the facility in the use of the program, the rejection of useless information, the definition of the image scale and other important parameters of this process.

1. INTRODUCTION

Monuments are undeniable documents of world history. Their thorough study is an obligation of our era to mankind's past and future. Respect towards cultural heritage has its roots already in the era of the Renaissance. During the 19th century archaeological excavations became common practice and they matured during the 20th century. Over the recent decades, international bodies and agencies have passed resolutions concerning the obligation for protection, conservation and restoration of monuments. The Athens Convention (1931), the Hague Agreement (1954), the Chart of Venice (1964) and the Granada Agreement (1985) are only but a few of these resolutions in which the need for geometric documentation of the monuments is also stressed, as part of their protection, study and conservation.
The geometric documentation of a monument may be defined as the action of acquiring, processing, presenting and recording the necessary data for the determination of the position and the actual existing form, shape and size of a monument in the three-dimensional space at a particular given moment in time (UNESCO, 1972). The geometric documentation records the present of the monuments, as this has been shaped in the course of time and is the necessary background for the studies of their past, as well as the plans for their future.
Geometric documentation should be considered as an integral part of a greater action, the General Documentation of the Cultural Heritage. This comprises, among others, the historical documentation, the architectural documentation, the bibliographic documentation etc. The Geometric Recording of a monument involves a series of measurements and -in general- metric data acquisition for the determination of the shape, the size and the position of the object in the three dimensional space. Processing of these data results to a series of documents, i.e. products, at large scales, which fully document the geometric -and other- properties of the monument. Usually such products include two-dimensional projections of parts of the object on horizontal or vertical planes, suitably selected for this purpose.

2. LARGE SCALE ORTHOPHOTOS

2.1. Special problems

The Geometric Recording of Monuments at large scale, i.e. larger than 1:100, presents several difficulties and peculiarities, which call for special attention by the users. The need for large scale images, the presence of extremely large height differences compared to the relatively small taking distances and the multitude of details usually present on the surface of the monuments combined with the high accuracy requirements are the main sources of these difficulties for the production of the conventional line drawings. The production of orthophotographs presents even more special problems, as it usually is a case of a highly demanding true orthophoto. Special techniques have been developed to address these problems in the best possible way (Dequal & Lingua 1999, Mavromati et al. 2002, Wiedemann 2002).
Orthophotos are an essential visualization medium containing both quantitative and qualitative information. Their production has already reached a high level of maturity as far as aerial images are concerned. In the case of monument recording, orthophotos are extremely valuable. Provided suitable raw data

acquisition, orthophotos may well replace traditional line drawings, while at the same time they contain the precious qualitative image information (Fig.1).

Figure 1: A detailed orthoimage at scale of 1:25.

The extensive experience of the Laboratory of Photogrammetry of NTUA has shown that archaeologists and architects, i.e. the end users, tend to appreciate the information content of orthophotographs and accept this product as a serious alternative. Recent typical examples of large-scale orthophoto production include the ones produced for the exterior and interior of the Dafni Monastery (Fig.1), for Hadrian's Gate, for the famous Hermes' statue of Praxitelis and the Samarina Church.

For the production of these -and numerous other- examples several technical problems had to be solved. As there is no specialized software to confront the adverse geometric conditions of the large scale terrestrial stereophotography, own solutions have been developed for this purpose, the main problem being how to best describe the object's surface and assign the right colour value to the pixels of the orthophotography.

These problems have their roots in various causes. Firstly the compulsory large scale of the original images dramatically increases their number and hence the necessary calculations. At the same time more control points are necessary, resulting in inevitable uncertainties of the calculations, as accuracy requirements are high. Secondly the task of describing the object's surface itself, having to cope with the very frequent case of two Z values assigned to the same planimetric position, requires very careful point and breakline collection, a task which cannot be carried out automatically.

Combination of laser scanning point clouds (as DSM) and photogrammetric images for the production of orthophotos could prove ideal for orthoimage production. Problems, however, may arise with compatibility of data from the two sources, as very often there are parts of the object which are not imaged on one or the other set of data. Careful planning of image and point cloud acquisition stations is required or multiple coverage of the object from both data sources. This does not add to cost or time, as no additional geodetic measurements are needed and the processes are automated anyway.

2.2. Conventional Method

The conventional digital orthophoto production software, assumes that straightforward continuous imagery is present, with orderly forward and -perhaps- side overlap, as exactly in the case of aerial photography. Moreover this software assumes that the height variations within the object are minimal, i.e. around 10-15% of the flying height, or taking distance. Hence when confronted with the adverse conditions of large scale photography for monument recording, they are unable to cope and serious problems arise.

3. PROPOSED METHOD

3.1. Concept

In order to overcome these shortcomings of commercially available software for the production of orthophotos, an alternative method has been developed and put to test. The concept of this alternative method is based on actually planning the fieldwork in a way to produce an extended DSM of the object. The extended DSM includes the colour information for each point conventionally determined. In order to achieve that, an algorithm was developed, which may reliably assign to each point of the DSM the most suitable colour value. For this to be realized the planning of photographing the object should be altered.

Conventionally for producing orthophotos of an object, parallel stereopairs ought to be taken. This would ensure common reference plane for all orthophotos forming the final mosaic. However in case of complex objects, especially cylindrical, or conical ones, this would result in either loss of information, or extreme distortions during the imaging phase. In these cases, which are quite often in practice, non parallel photography would be more suitable.

In order to exploit such planning of photography the extended DTM concept was developed and realized.

3.2. The extended DSM

It is assumed that usually the necessary anaglyph information of the object's surface will be determined by photogrammetric methods, i.e. from the stereopairs, which will later be used for the orthophoto production. In case this information is obtained by other means, e.g. a laser scanner, the method may still be applied with minor sdjustements.

The main idea is to assign to the DSM points the right colour value. For this purpose it is necessary to take care for referring the stereopairs and the DSM points to the appropriate reference system or systems.

It is common practice in terrestrial stereopairs to rotate the reference system in order to simulate the one common in the case of aerial photogrammetry. This is necessary for two reasons: Firstly because later, while pointing streoscopically in order to digitize information, the user is used to observe the floating mark moving along a z axis pointing towards the observer. Secondly, in most cases of digital workstations, the software, which expects to solve for an aerial case, and not for an unconventional terrestrial stereopair with strong inclination angles and large height differences in the object, is unable to converge to a solution for the orientations. There are, of course, exceptions to this, but the large majority of algorithms is unable to cope with terrestrial cases.

The extended DSM is formed piecewise from the colour value assignment to the normal DSM points. Assuming that a DSM has been conventionally produced, i.e. either automatically or

manually, the developed algorithm refers the XYZ points back to the image in order to interpolate the R, G and B values. The DSM file is augmented by four columns. The first one is the point code, calculated by the sample and line value of the point in the DSM grid. the three other columns contain the values for the red (R), green (G) and blue (B) channels, in case of a coloured image. This DSM initially refers to the local co-ordinate system of the stereopair. The algorithm converts this back to a common reference system for all stereopairs involved.
The procedure continues with the next DSM from the same or usually another stereopair. Again the final extended DSM, when referred to the common system, is added to the initial one. In this way the algorithm implemented forms a common extended DSM file containing all determined points with their correct colour value assigned.

3.3. Orthophoto projection

The next - and final - step is the actual orthophoto production. For this the projection of the extended DSM on a desired projection plane is required. For this purpose the user is asked to specify the azimuth of the projection plane in the common reference system. Moreover the user specifies the value of the pixel size on the object. The projection of the extended DSM to the specified plane requires the interpolation of the colour value for each pixel of the resulting orthophoto. This is carried out using the bicubic convolution algorithm. Needless to say that in this way the orthophoto on any specified plane may be produced.

3.4. Information filtering

In addition the developed algorithm takes care of the fact that for any given projection plane there may be two or more colour values. Using a simple discrimination routine the software picks the colour value with the maximum z value for the specified plane (Fig. 2).
In this way only those points -and colour values- not obstructed by other objects are allowed to appear on the final orthophoto. In Fig. 2 points A, B, Γ and Δ should all appear if projected on plane ε, but only points A and Γ should appear if the projection plane were in position ζ. The algorithm takes care of all such cases.

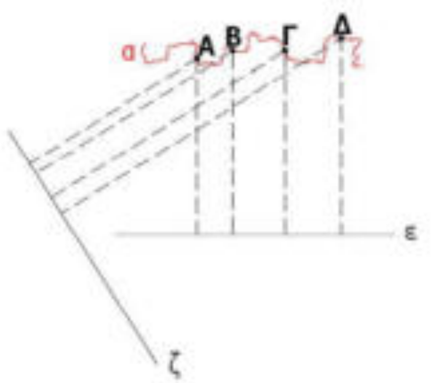

Figure 2: Filtering out unwanted colour information

4. PRACTICAL EXAMPLE

In order to implement and test the developed method a practical example was carried out and is briefly presented here.

4.1. Black Tower of Siphnos

The object of this work is a cylindrical ancient observation tower dating from the 5th century BC. A large number of such observation towers may be found on the islands of Cyclades in the Agean sea. This particular one is one of the approximately 70 towers on the island of Siphnos. The tower has an external diameter of 11.5m and the ruins reach a height of maximum 5m (Fig.3) and has obtained its name from the colour of the stonework.

Figure 3: The Black tower of Siphnos

4.2. Field Work

The fieldwork was carried out in the framework of a set of Diploma theses concerning the towers of Siphnos. The object was photographed with a number of radial stereopairs using a Hasselblad camera and colour slide film. Special targets were used as control points on the tower's surface in order to enable the orientations of the stereopairs. The co-ordinates of these control points were determined geodetically in a common reference system, which was later used as the common reference system of the proposed method.

4.3. Implementation of method

The stereopairs were subsequently oriented on a digital photgrammetric workstation, the SoftPlotter v. 4.0 of Autometric. Digital surface models were then produced initially using automatic matching and later with manual intervantion for their correction and completion. The produced DSM's were extracted from the DPW and fed into the developed algorithm, within the MATLAB environment.
The extended DSM's were then produced with the help of the algorithm and several experimental orthophotographs projected on various planes.

4.4. Products

The implementation of the developed algorithm produced impressive results. A sample orthophoto of the northwestern façade of the tower is shown in Figure 4.

Figure 4: Mosaic of several orthoimages produced from coloured DSM points of a cylindrical tower.

In addition the production of high resolution orthophotos was also attempted, in order to fully exploit the original spatial resolution of the scanned analogue image. A sample of this effort is shown in Figure 5.

Figure 5: High resolution orthophoto at a scale of 1:10

The method developed may also allow for projections under highly oblique angles, since the algorithm permits it. In Figure 6 two such highly oblique projections are presented.

Figure 6: High oblique projections (left 80^g, right 90^g)

5. EVALUATION & OUTLOOK

5.1. Conclusions

The research presented has proven suitable for confronting the production of orthophotos of cylindrical or conical objects. These objects, such as towers, require special arrangement for the image acquisition in the field. Special software has been developed in order to attach colour to manually collected points of a DSM from the most suitable image and then to project this dense mesh of points on a desired vertical plane.
The method developed has proven adequate for producing large scale orthophotos on any projection plane. This fact enables the user to perform the fieldwork independently from the final projection plane, i.e. take the photography in any desired direction. Moreover the metric evaluation of the produced orthophotos has shown that they absolutely comply with the expected accuracy specifications. At the same time the user is not obliged to use commercial software anymore.

5.2. Current Research

Future efforts are directed to contribute to several issues currently under research. Firstly the connection of a camera to a terrestrial laser scanner will be further investigated. Issues such as determining the transformation from the camera system to the laser scanner one and vice versa have already been tackled with. Having established this connection, the attachment of colour information to the points of the laser scanner point cloud is a rather easy task. Nowadays few terrestrial laser scanners provide this feature, however the incorporated digital cameras have very low resolution and the final result does not meet the specifications of large scale geometric recording.
Finally we are currently working on developing in-house software for the automatic production of orthoimages within a CAD environment relying only on the laser scanner data, without the use of any geodetic measurements. As soon as the point cloud and the corresponding digital images are within the environment, the system will automatically measure the targets, both in the point cloud, as well as on the images. These points may act as ground control points. A manual identification stage has to be carried out at this point. Determination of the exterior orientation parameters of the images is initiated by the user. Rectification and orthoimage production are fairly straightforward tasks, which may easily be realized automatically. The results of this proposed process will be assessed for their accuracy and efficiency.
Geometric recording of monuments is a highly demanding task in many ways. All techniques of field data acquisition, however sophisticated, have proven unable to meet the demands of such a task single handed. Experience has shown that only by integration of multisource data is it possible to provide the necessary information with the required accuracy and completeness. Especially in the case of large and complicated monuments parallel use of geodetic measurements, photogrammetric data acquisition and terrestrial laser scans has proven the ideal combination for the desired result.

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