Third Turkish-German Joint Geodetic Days, Istanbul, June 1-4, 1999, Conf. Proceedings, Vol.1, pp. 387-394

DIGITAL MAPPING OF SPHERICAL SURFACES FOR THE INVESTIGATION OF HISTORICAL GLOBES

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For different applications in the area of cartography as well as the restoration and publication of cartographic representations the mapping of globe surfaces in a plane is desirable. For this purpose a method has been developed, which allows, with the help of digital photogrammetric methods, the transformation of photographs of globes into cartographic mappings. Only the knowledge of the globe's radius is needed. The approach that has been applied assumes an exact projective mapping of a sphere in the photograph. With the help of a cartographic mapping law an exact map of the globe can be produced. The results allow beside a direct scaled comparison of single regions a close mapping of the whole globe. Moreover, single globe segments can be produced for instance for restorational purposes.

1. INTRODUCTION

The mapping of globe surfaces into a plane has significant meaning for many scientific problems as well as for practical work for the restoration of globes. This includes the examination and comparison of cartographic depictions on globes and also the production of duplicates. Since, for this purpose, a complete pictorial coverage is exactly as important as an exact geometric reconstruction, it is obvious to solve such problems by approaches of photogrammetry and image processing. In cooperation with the Technical University of Berlin, Department of Photogrammetry and Cartography, the current developments of Fokus GmbH concerning rectification and unwrapping of digital image data were extended in order to be able to use the presented methods for the mapping of spherical surfaces, which also include globes.

In order to examine the efficiency of the newly developed software, in cooperation with the Mathematisch-Physikalischer Salon Dresden two historical globes were chosen from the stock of the collection of the Dresdner Zwinger. They were photogrammetrically surveyed and exemplarily evaluated by Fokus GmbH. The results presented here shall document the new possibilities which are offered by the employment of modern image processing technologies and can be applied with a suitable material and financial effort.

2. APPROACH AND APPLIED MAP PROJECTIONS

In the photogrammetric practice methods of digital image rectification on the base of projective transformation relations are often used. Still these methods are limited to the rectification of plain faces. In contrast, a parametric approach offers the possibility to rectify and unwrap cylindrical and conical surfaces [*Hemmleb, Wiedemann,* 1997]. First of all the parameters of the surface have to be determined by geodetical surveying. These are, for instance for a cylindrical surface, the position parameters and the radius of the cylinder. Independently, several pictures of the surface to be unwrapped are taken. For this purpose, metric cameras or at least large format cameras with a static focal length are used in order to achieve a reproducable accurate geometric mapping into the image plane. By using reference points the single camera positions can be calculated and the geometric situation during the photography can be reconstructed (spatial resection). So all pre-conditions are fulfilled to rectify in true scale a surface which is represented on several photographs.

In general these connections are based on the mapping law of the central projection, which is the basis for a parametric rectification. This approach can be applied to the mapping of globe surfaces into the plane. Admittedly, several particularities have to be considered. First of all the question of the geometric description of the form of the globe has to be answered. In order to design the developed method as applicable as possible, the geometric description of the globes dealt with was considered to be a sphere. With this pre-condition the existing net of latitudes and longitudes can be used as reference information. In this case the geographic coordinates of the globe have to be transformed into orthogonal cartesian coordinates.

Consequently, for an evaluation merely the radius has to be known or determined. Beside the photography no local work is to be done. In order to test the quality of the results, additionally a geodetical survey was carried out with one of the globes. At the moment, the form of the globe is analysed precisely with the existing data. In case of the globe surface differing far from an ideal sphere, this circumstance has to be taken into account by choosing an adequate configuration concerning the photograph. Moreover, it has to be considered during the calculation by the use of a digital surface model.

An additional particularity is the fact that spherical surfaces, which include globes as well, can not be mapped into a plane directly. So a mapping law has to be chosen, which allows the calculation of a consistent mapping of the spherical surface into a plane. For the plain representation of globe surfaces a whole lot of cartographic map projections are suitable. Temporarily those, which are absolutely necessary for the tasks mentioned in the introduction shall be sufficient. Thus, three cartographic map projections have been chosen.

For a consistent mapping of the whole globe, which also serves, beside an attractive visualisation, the comparison of the cartographic representations, the true distance cylindrical map projection (square flat map) has been chosen. Since this projection fails concerning the polar areas, in order to map these a different map projection has been applied. The true distance azimuth map projection has been used, in order to allow metric comparisons in these areas, too. Beside a consistent visualisation and a true scale comparison of the globe

surfaces the software was meant to serve a reproduction of globes as well. Therefore the calculation of globe segments from the photographs is necessary. For this purpose the true distance cylindrical map projection with true longitude equator in transversal position seemed to fit best.

The single steps, which are necessary to transpose a spherical surface from photographs exactly into a plain map, are summarised again below. It has to be taken into consideration that, for calculatory reasons, an indirect procedure is applied:

- pre-calculation of the orthogonal coordinates of the existing net in knowledge of the globe radius as basic reference,
- determination of the image orientation of each image with the known reference points (spatial resection),
- transformation of the map coordinates (x'', y'') into geographic coordinates (B, L) according to the chosen map projection,
- transformation of the geographic coordinates (B, L) into orthogonal coordinates (X, Y, Z) knowing the globe radius,
- central projective mapping of the orthogonal coordinates (X, Y, Z) into image coordinates (x', y') in knowledge of the image orientation.

Thus, each image element (pixel) of the scanned original image is placed correctly in the desired cartographic representation. It has to be taken into account that, for a photographic reproduction of the results, high resolutions have to be used, which lead to a high amount of data.

3. EXAMINED GLOBES

For the development of the method and a first exemplary comparison of the representation of the course of coast lines on different globes, two exponates of the collection of the Staatlicher Mathematisch-Physikalischer Salon in the Dresdner Zwinger were chosen. The first of the two earth globes from the year 1792 was made by Johann Georg Klinger, Nuremberg (Fig.1), the second by Johann Gabriel Doppelmayr, Nuremberg as well (Fig.2). Both of the globes have an approximate scale of 1:40.000.000 a diameter of 32cm. The coincidence of having two globes with identical diameters has no effect on the work, since globes with different diameters can be treated in exactly the same way.

4. IMAGE ACQUISITION

The photography of the globe of Klinger, which served as reference, was taken with a large format camera on optical bench. A 120mm APO-optic was applied as objective. The planning resulted in 24 photographs for a complete registration of the globe surface with an appropriate covering of the single images.

Six of these 24 photographs were taken at a time in 60°- distance equatorial and of the Northern and the Southern hemisphere. Additionally, three photographs of each of the polar regions were taken.

As film material served the Fuji Reala 100 ASA in a rollfilm cassette 6cm x 7cm. Because of its very high detail resolution this film guarantees sufficient reserves for the digital processing of the negatives and also for a possible photographic enlargement of the original patterns. According to its special layer structure this film material shows extremely robust reactions to the different circumstances concerning the illumination in rooms, which was very important during the photography, since it had to take place directly in the exposition rooms. Moreover, the rollfilm material is clearly less expensive compared to plain film in larger formats (such as 4' x 5').

The photographs of the globe of Doppelmayr, which served the comparison of the representation of the course of coast lines, were taken by hand by a small size camera in day light, since, originally, the images were merely to be used for method development purposes. For these photographs a Nikon reflex camera with a 1,8/80mm-objective and a 200 ASA small size film was used.

It is recommendable to take the globes out of their holdering and to put them into a stable position in order to turn them, segment by segment, for the photographs along the equator. It is important to use an aperture as powerful as possible (aperture 16 and smaller) to obtain as much depth of focus as possible with the macro or large format objectives with long focal length. With low depth of focus the usable covering of the single images diminishes because of the indistinction of the photograph caused by the curving.

Figure 1: Klinger globe

Figure 2: Doppelmayr globe

5. EVALUATION AND RESULTS

In principle the evaluation is carried out digitally. Thus at first all photographs have to be scanned. For this purpose the Kodak PhotoCD-method has been chosen, since it delivers outraging scan quality at adequate cost for small size photographs as well as for large format patterns (Kodak PhotoCD Professional). Because of its high geometric stability this method is especially suitable for photogrammetric applications [*Hanke*, 1994].

For the further processing the newly developed software and commercial image processing programs were used on a standard personal computer. Because of the high image resolutions (up to 6144 x 4096 pixels per image) and the connected amount of data it had to be ensured to have sufficient memory at disposition. As with many photogrammetric applications the interactive work includes the measuring of reference points at the monitor, the orientation of the images and the choice of the correct calculating parameters. Each single image was prepared this way. After the calculation of the resulting images, which are in a uniform coordinate system, the images are put together to one image map. Finally, because of the differing illumination during the photography, a radiometric adaptation was necessary. Beside the adjustment of brightness and contrast, the main difficulty is to correct the colours, in order to reconcile the illumination differences and to compensate changes of colours caused by scanning and printing.

The result, a digital image map in the chosen map projection or even derived represen tations or overlayings, can be exposed on paper or film or be printed on qualitatively high-class colour printers. In the following the evaluations, carried out at Fokus GmbH within the bounds of this project, and their results are presented and explained.

5.1 Consistent Cartographic Mapping of the Globe Surface

For the complete representation of a part as large as possible of the globe surface the true distance cylindrical mapping, also called square flat map, has been chosen. For this purpose at first 18 single images had to be rectified in such a way, that the globe is completely registered over 360° longitude. Since this method fails in the polar areas, an evaluation area from 70° Northern latitude to 70° Southern latitude was determined. The montage of the single images into one image map could be carried out afterwards in the reference system of the map. For the post-processing, especially the adjustment of colour and brightness of the single images, the image processing program Adobe Photoshop was applied. The result, a true scale image map of the globe, can be seen in Figure 3.

For the polar areas, which could not be represented in the square flat map, the true distance azimuth projection has been chosen. Because of the hindering knob several single images had to be rectified first, which were then put one upon the other. This procedure was tested at first on the Doppelmayr globe (Fig.4).

Figure 3: Klinger globe, Square flat map

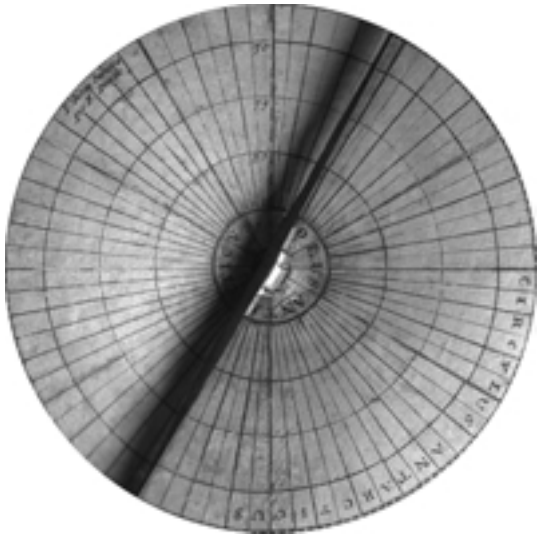

Figure 4: Azimuth projection of south pole (Doppelmayr globe)

Figure 5: Globe Segment (Klinger globe)

5.2 Mapping of Globe Segments for the Production of Duplicates

In some cases it is necessary to complete damaged globes with the help of segments of a different globe of the same edition. The reconstruction of such segments is carried out best with a true distance cylindrical mapping with true longitude equator in transversal position. The segments can be adjusted on the damaged globe then. In order to do so a segment of the Klinger globe was calculated exemplarily (Fig.5). Thus with a complete registration by globe segments and both of the polar regions (as explained above) a duplicate of the globe can be produced.

5.3 Comparison of Cartographic Representations

For the comparison of the course of coast lines a uniform map coordinate system is needed, in order to put the interesting areas one upon the other. Because of its high illustrational quality the choice fell on the square flat map again. The Indochinese coast was picked out as a test area on both of the globes. The pictures were rectified individually. In order to allow a comparison the digitised coast lines of the Doppelmayr globe were laid over the appropriate image section of the Klinger globe (Fig.6). The longitudes and latitudes of both of the globes served as a reference system.

Figure 6: Comparison of the coast lines (left: part of Doppelmayr globe with digitised coast lines, right: same part of Klinger globe with overlayed coast lines from Doppelmayr globe)

6. CONCLUSIONS AND FURTHER WORK

The method presented here offers the possibility to transpose cartographic representations on globes into plain mappings in a rather uncomplicated way. In consideration of earlier projects [*Kager*, 1992] special attention has been paid in order to allow evaluations on standard PCs without additional technical effort. This approach became possible by a consequent application of methods of digital photogrammetry in connection with image processing techniques. A small size camera is sufficient for the photography in the simplest case. The method allows an exact true scale survey and the comparison of cartographic representations. In addition the method offers the possibility to reproduce globe segments and, this way, to copy the original. If desired, beside the already existing, other mapping plans can be implemented.

At the moment the effect of uneven areas of the globe surface on the accuracy of the evaluation is examined. One emphasis of the future work lies on the correct reproduction of the true colours of the original, which is a special challenge for restorational applications.

Acknowledgements: The authors like to thank the Staatlicher Mathematisch-Physikalischer Salon at the Zwinger in Dresden for the choice and the disposal of the globes. Special thanks due to Dipl.-Ing. Wolfram Dolz for his stimulation and the support of the project.

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