GENERATION OF A PANORAMA MOSAIC FOR THE DOME OF A PLANETARIUM

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ABSTRACT:
This paper describes the generation of a panorama mosaic to be projected onto the hemispherical dome of a planetarium, in particular the Planetarium of the City of Vienna. Digitized amateur photographs serve as input. For the projection of the pictures eight pairs of off-the-shelf slide projectors of the planetarium (positioned approximately along the equator) must be used. The main objective of this work is the creation of a homogeneous and continuous panorama projection (as far as both geometric and radiometric properties are concerned) by means of digital image processing. We assume that perspective distortions match those of a fictitious observer sitting in the centre of the planetarium's audience hall.

KURZFASSUNG:
Dieser Beitrag beschreibt die Herstellung eines Panoramamosaiks, das auf die halbkugelförmige Kuppel eines Planetariums (im kontreten Fall auf die des Planetariums der Stadt Wien) projiziert wird. Als Bilder dienen digitalisierte Amateuraufnahmen. Für die Projektion der Bilder werden acht Paare von Standard-Diaprojektoren verwendet, die etwa im Kuppeläquator angeordnet sind. Der Hauptzweck dieser Arbeit liegt in der Herstellung eines homogenen und kontinuierlichen Panoramas (was sowohl die geometrischen als auch die radiometrischen Eigenschaften betrifft) mit Hilfe der Möglichkeiten der digitalen Bildverarbeitung. Angenommen wird, daß sich die perspektiven Verzerrungen für einen fiktiver Beobachter, der sich in der Mitte des Zuschauerraums des Planetariums befindet, richtig darstellen.

1. INTRODUCTION

The planetarium of the City of Vienna is equipped with a ZEISS star projector for the projection of star constellations and with a double ring of eight pairs of standard slide projectors for accompanying demonstrations. Besides lectures in astronomic topics the projection hall of the planetarium is utilized for various presentations in earth and planetary sciences. In the latter case the standard slide projectors are also used for projections of circular panoramas. As the projectors are neither fixed on their positions nor calibrated, until now the panorama mosaics were rather approximate with overlaps, gaps, scale and brightness differences. The geometric distortions were even quite obvious and annoying due to the eccentric locations of the projectors and the oblique projection directions.

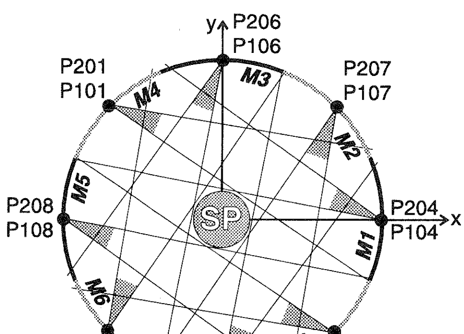

Figure 1: Star projector (SP), slide projectors (P#), and projector's coverage (M#)

The given (and in general unchangeable) arrangement of the projectors is able to cover a 360° zone of the dome between the equator and the 40° parallel. The remaining zone from some 40° to the pole is currently not covered but could be included in the mosaic by employing at least two further (wide-angle) projectors situated near the centre of the planetarium and pointing approximately towards the pole of the dome. Figure 1 and 2 show the current situation in an XY-section and a cross section of the planetarium with the equatorial slide projectors and their coverage.

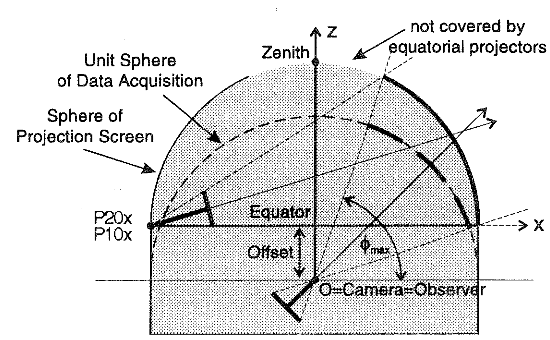

Figure 2: Cross-section of the audience hall, position of fictitious observer and slide projectors

The main objective of this work is the generation of a uniform and homogeneous 360° panorama mosaic from a set of eight photographs (in a panorama arrangement) or from one single super wide angle or fish-eye zenith photograph. As mentioned above the current work deals with the zonal panorama only, without taking into consideration the coverage of the pole. The double ring of eight projectors (i.e. 16 projectors all together, numbered as 101 to 108 and 201 to 208 in fiugre 1) is intended to allow fading and blending. Therefore, the second set of eight projectors (numbers 201 to 208) covers exactly the same area on the sperical projection screen, namely the 45° wide mosaic portions *M1* to *M8* (see figure 1). The projection centres of the P20x projectors are some 20 cm above those of the respective P10x projectors.

2. THE PLANETARIUM AND THE EQUIPMENT

The main audience hall of the planetarium has been constructed as a cylindrical room with a wall height of some 2.5 m. On the top of the wall lies the hemispherical projection dome. The diameter is 20 m with an accuracy of approximaty ±2 cm (according to the specifications of the building constructor). In the centre of the hall is the dumb-bell-shaped star projector, which will not be used in our project at all. In contrary, the rather big projector turned out to be an obstacle as it cannot be moved arbitrarily and occludes the rays of the slide projectors if not set to a certain position. The star projector causes the projection direction of the slide projectors to be laid outside the diameter of the dome (see figure 1). This assymmetric projection leads to assymmetric distortions of the slide pictures with a small image scale on one side of the projected image and a rather large scale on the opposite side. The arrangement of the projection directions has been chosen in a way so that adjacent projections always overlap either along the small scale area or along the large scale area in order to minimize distortions of unrectified pseudo-mosaics. The slide projectors (besides other equipment) are located behind a blind (with openings for the lenses) on a hidden shelf running rim-like around the hall slightly below the equator.

The projectors are off-the-shelf Kodak Carousel with a 50-100 mm zoom lens, approximately set to 80 mm due to the planetarium's requirements. Though usually the focus setting will not be changed, the lens body has no possibilities for fixing neither the focus nor the zoom and unexpected changes in settings may occur. In a similar way the projectors themselves are not unmoveably mounted on their positions near the equator. One must even expect minor changes of projection directions after replacing the slide magazines. The positions of the projection centres may vary within ±5 cm at most. In order to restore the original positions after manipulations at the projectors by the panetarium's personell very simple possibilities for adjustment had to be worked out and are explained in section 5.

3. DATA ACQUISITION

The photographs for the panorama should be taken by conventional, non-metric amateur cameras (image format 24 mm x 36 mm). In order to avoid mosaicking of the projected slides we try to assign one original photograph to one slide projector. The joints of the panorama mosaic, therefore, will be located along the overlap area of the projectors. As we use eight individual projectors we must be able to cover the original panorama by eight photographs. In our case we employed a Nikon camera with a standard 28 mm lens, that is sufficient to cover a 360° ring with eight slightly overlapping pictures assuming that we do not change the positions of the camera's projection centre while we change the camera direction. The diagram of coverage can be seen in figure 3, represented as a equidistant projection of the unit sphere around the camera position (equator of acquisition system = horizon = dashed line). In order to achieve this ideal configuration in reality one needs to fix the camera on a mount that allows exact setting of azimuth and zenith angles rather than to take hand shots. While the zenith angle remains constant (as long as we concentrate on a zonal panorama only), azimuth is incremented by 45°. Assuming an accuracy of ±2 cm on the projection surface the azimuth angle must be set to approximately ±0.1°. (Note, figures 3 and 4 include two almost vertical photographs that would be needed for the coverage of the polar area of the dome, but are not used in this project due to the lack of appropriate slide projectors)

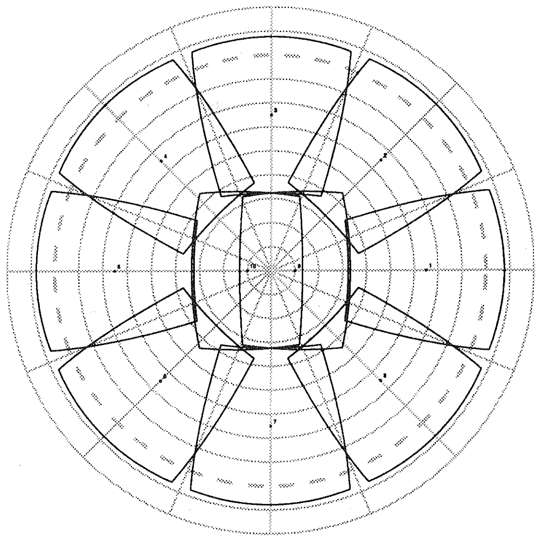

Figure 3: Coverage of photographs taken by a 28 mm lens plotted as equidistant projection of the unit hemisphere around the camera position

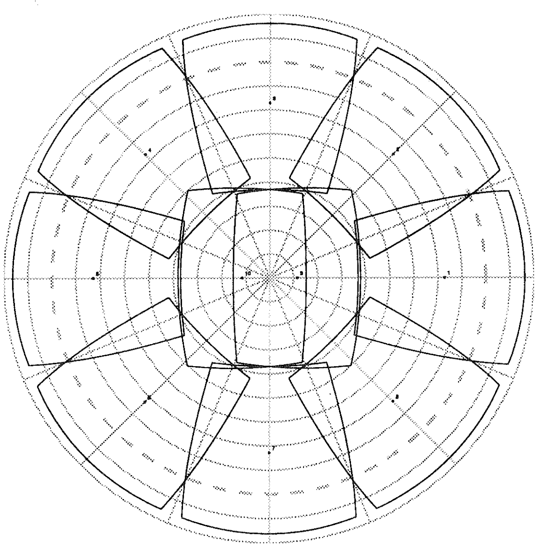

Figure 4: Coverage of photographs taken by a 28 mm lens plotted as equidistant projection of the projection system of the planetarium

As the eyes of the observer in the planetarium are about 1.5 m below the equator of the dome, the hemisphere of the acquisition system (and therefore that of the observing system) is not identical to the hemisphere of the projection system (i.e. the planetarium). With respect to the planetarium system the acquisition hemisphere lies 1.5 m below the projection hemisphere (see figure 2). In other words the observer of a panorama will never be able to see the real horizon (i.e. 0° latitude of the acquisition system). The lowest latitude with respect to the acquisition system is, therefore, atan(1.5 m/10 m)≈10°, what corresponds to the equator of the projection system. Figure 4 shows the coverage of the same photographs on the hemisphere of the projection system (planetarium's equator = dashed line).

We would like to mention here, that any arrangements of photographs could be projected as a panorama mosaic as far as the acquisition covers 360°. The real perspective impression with all the original perspective distortions and occlusions can be restituted only if the observing directions are approximately that of the original camera directions. Still, even this ideal condition can be fulfilled for only one position in the audience hall. In our case we assume a fictitious observer in the centre of the hall exactly beneath the pole of the dome and 1.5 m below the level of the equator. Since the star projector is mounted in that area the actual observer will always sit somewhere around the centre and for that reason will never be able to see the correct perspective impression.

4. PRINCIPLE OF GEOMETRIC RECTIFICATON

The rectification procedure applied to the original photographs is related to the process applied for conventional orthophotos [Kraus 1993]. In the plane of the rectified slide (i.e. the slide to be projected) we virtually define a regular square grid. This grid is mathematically projected through the optical system of the projector onto the spherical screen of the planetarium's dome, from where it is virtually photographed by the camera positioned in the centre of the audience hall 1.5 m below the equator. In this way we obtain a distorted grid in the film plane. This grid bears the entire geometric information we need for resampling the original picture. The grid points may serve as a mesh of anchor points. The image contents (i.e. the pixels of the photo) within a patch defined by four neighbouring anchor points is bilinearly transformed to a square, thus yielding one tile of the slide to be projected. By transforming all mesh patches we obtain the entire rectified slide (see figure 5).

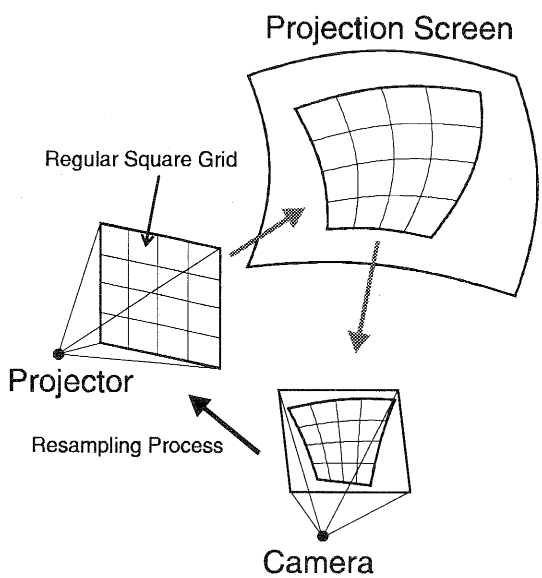

Figure 5: Principle of rectification process

From the generation procedure explained just before we see that the following parameters must be determined:

- the interior and exterior orientation of the projectors
- the shape and position of the projection screen
- the interior and exterior orientation of the camera positions

As reference system we define a planetarium coordinate system with its XY-plane being identical to the equatorial plane and the Z-axis running through the pole. The X-axis may be chosen arbitrarily but it seemed to be advantagous to select one specific meridian of the dome that can be easliy restituted in case of a (hopefully not) necessary remeasurement in future. We further select this reference meridian somewhere close to the centre of a mosaic patch. Subsequently, we assign the number *M1* to that very patch and number the remaining patches counter-clockwise in ascending order *M2* to *M8*. The respective projectors are given the numbers P101 to P108 (of the lower ring) and P201 to P208 (of the upper ring), respectively (see figure 1).

Besides this purely geometric process we need to take into consideration some radiometric properties too. Firstly, we have to define the boundaries of the mosaic patches. Due to our regular arrangement of 8 patches we prefer to define the boundaries in terms of longitude and latitude of the dome, in particular simply as meridians and parallels. The mask boundaries in the slides are found by projecting the dome coordinates back into the slide plane. In order to avoid visible artifacts along the mosaic boundaries (for instance a black stripe in case of a gap or a bright stripe in case of an overlap due to minor inaccuracies of camera or projector orientation) we define two boundary lines between adjacent mosaic patches (thus causing a slight overlap) rather than one unique (ideal) boundary line. The user defined overlap region serves as transition zone where the intensity values are weighted with respect to their distance to the two boundaries. Weight 0 is assigned to the outer boundary and 1 to the inner boundary, the weights of the transition area are somewhere in between (see figure 6).

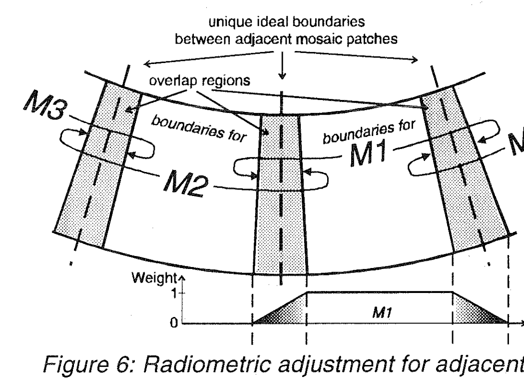

Figure 6: Radiometric adjustment for adjacent mosaic patches

Another radiometric adjustment could be applied within the mosaic patches in order to adjust the different projection distances. A rough estimation of the minimum and maximum distance yields a ratio of 17.5 m/20 m = 0.87. According to the photometric laws the ratio of illuminance (as a measure of recognized brightness) should obey the 2nd power of the ratio of the distance, thus yielding 0.75 [Kraus, Schneider 1988]. Experiments showed that the brightness differences are not that significant, mainly because of the chosen arrangements of the projectors with neighbouring image areas being equally distant to their respective projector. Therefore, this type of radiometric adjustment has not been applied during the initial prototype stage of panorama generation.

5. CALIBRATION OF CAMERA AND PROJECTORS

The calibration of the camera (Nikon with 28 mm lens) has been performed with the help of a special test field and the versatile bundle adjustment programme ORIENT [Kager 1989]. As the focus was set to infinite no problem is to be expected when the camera must be reset to the calibrated settings. The accurary of the interior orientation may be described by the residuals in the image plane of the control points. After modeling principal distance, location of principal point and lens distortion the residuals were within ±5 µm (i.e. about 2 mm on the projection surface).

The outer orientation of the camera is well-known because of the exact pointing direction during image capture. The local coordinate system is that of the planetarium (see section 4). The projection centre is assumed to be the same for all pictures, although minor displacements are likely. The projection centre will probably vary within a few cm that does not cause any troubles.

For the calibration of the slide projectors a different approach has been chosen though the projector could have been assumed as inverse camera and ORIENT might have been employed in a slightly modified way. It turned out that it is not necessary and even not feasible to perform a complicated calibration procedure either on-site or under laboratory conditions. The projector calibration should be kept as simple as possible, firstly because of the limited possibilities in the planetarium, and secondly for reasons of an uncomplicated and easy maintenance by the planetarium's staff. Practice showed that the very projectors are used for different types of slide projection and are subject to adjustments according to the requirements now and then.

The standard test slides provided for the projector adjustment for utilization of blending and fading proved to be very accurate and offered proper means for restoring the initial positions and settings of projectors within the required accuracy. Visual differences by replacing one test slide by another one are not detectable. Fortunately, the slide holders of the projectors behave in the same accurate way. Hence, no additional developments were necessary for a simple and easily performable restoration process. Firstly, test slides were inserted in each projector. Thereafter, the lens settings and the positions of the projectors were manually adjusted in order to cover the entire panorama area, with small overlaps (some 20 cm) of adjacent slides and without occlusion by the star projector. Then small, nearly invisible reference targets were glued permantently onto the dome surface at the projections of selected check points of the test slide (figure 7). In case of later changes the operator just needs to match the target positions by inserting the test slides again and by moving the projectors and/or by varying the focus or zoom settings without taking care of any (obscure) calibration data and without support by a photogrammetric expert.

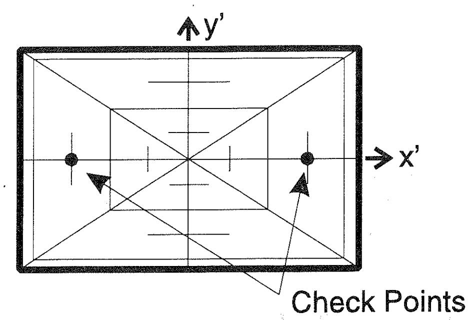

Figure 7: Test slide and check points

The next step deals with the determination of the interior and exterior orientation of the slide projector. Again the reference system for exterior orientation is the planetarium system as defined earlier. Therefore, with the help of theodolites the front lenses of the projectors (as approximations of the projection centres), the reference targets, other points of the dome (in particular the pole), and selected points of the audience hall were measured. The observations were adjusted as a network in a local system with an accuracy of ±2 cm. Although a photogrammetric bundle arrangement would have been a certainly faster and more convenient way for the determination of the required point coordinates, the poor lighting conditions in the audience hall made it impossible to take pictures of suitable quality.

The shape and size of the dome have been assumed to be the ideal hemisphere as originally defined by the specifications of the building company and were not remeasured in the course of this project. For the definition of the reference coordinate system (i.e. the projection system) a sphere was adjusted by least squares to the measured dome points. The residuals were again in the order of ±2 cm, thus indirectly proving the correctness of the preassumptions. By laying the Z-axis through the pole we find the equatorial plane which will serve as XY-coordinate plane. For the definition of the X-direction we select a reference meridian. All geodetically determined points can now be transformed to this new reference system (the so-called projection system or planetarium system).

Finally the exterior orientations and interior orientations of the projectors were computed in a simplified way. The coordinates of the projectors' front lenses are treated as projection centres. We further assume that the principal point is identical to the centre of the slide. As we know for certain points (for instance the targeted check points) the coordinates in the reference system and in the slide (image) coordinate system, we are able to compute the principal distance and the rotation angles. Since the projection of a upper and its respective lower projector are visually identical, we do not distinguish between upper and lower projector any more.

6. RECTIFICATION OF PICTURES

We now know all parameters necessary for rectification that is to be performed in the way explained in section 4. Firstly, a regular square grid need to be defined in the slide plane only once. For each individual projector this grid is mathematically projected to the dome surface and then further to the respective camera position. The result is a set of eight distorted grids. In a similar way we obtain eight masks (one for each projector) by projecting the mosaic boundaries from the dome surface to the slide. A mask image is black in areas outside the respective region of interest, it is white within the area of interest and it shows a transition zone (from white to black towards the region of no interest) in the predefined overlapping area. The grey shades may be interpreted as weights for the image contents with white being 1.0 and black 0.0. Note that the mask image is not a binary image as it may currently contain any decimal value between 1 and 0 (the term "gain mask" might be a more appropriate name). Additionally the mask image should also contain tiny marks in the corners intended to facilitate exact positioning of the films in the slide frames (see figure 8). The full set of grids and masks remains the same for any panorama rectification as long as the camera for and the way of data acquisition or the projectors have not been changed.

The software for resampling can easily be installed through IDL® The operator, who needs not be an expert neither in computer science nor in photogrammetry, just has to measure the "fiducial marks" (usually the border lines) of the original images for the restitution of the interior orientation of

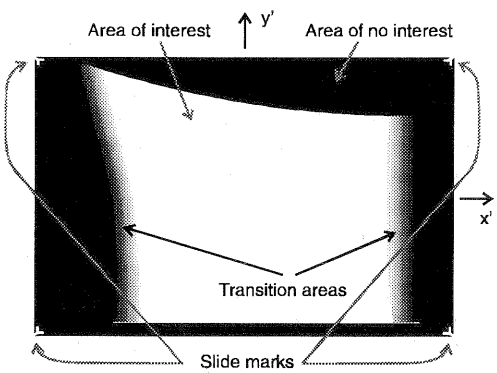

Figure 8: Example of a mask image

the cameras. After defining the order of the images the rectification process commences to run automatically. The resampled images are merged with the mask images by a simple pixel-by-pixel multiplication thus yielding the final slide images. These digital images need to be plotted to film via a slide writer. The final crucial step is the mounting of the films in the frames. Special register frames together with the previously mentioned slide marks facilitate the accurate mounting of the slide films.

The generation of a test panorama that contains a dense "geographical" line grid of the dome is highly recommended as it seems to be very helpful for checking the actually achievable accuracy. The linear features are quite sensitive to small geometric irregularities and allow a rough estimation of the overall precision.

7. CONCLUDING REMARKS

The panorama generation as described in this paper is a prototype and might be adjusted and augmented in one or the other way. Particularly the radiometric adjustment as mentioned in section 4 might be useful when dealing with rather dark pictures and could be easily implemented through the mask image. On the other hand and more importantly there is a need for automatizing the process of generation from data acquisition to film writing. The acquisistion of digital images is one limiting factor that could be overcome by employing digital cameras (such as for instance the Kodak DCS 460) or by recording the pictures on photo CD after development (currently by far the cheapest choice). In the latter case one must be sure that the interior orientation can be restituted. Usually the standard process of generating the photo CD does not digitize the image borders and, therefore, cannot successfully be used with non-reseau cameras. Fortunately non-standard professional digitization delivers appropriate images. The process of resampling can be performed at any state-of-the-art PC and does not cause problems at all. For the time being a more severe limitation is the writing process of digital slides. Though some copy shops offer this service there is still no guarantee that the pictures are written geometrically identically at any time. Experience showed that, after servicing the slide writer, the geometric properties are likely to have changed slightly as far as shifts of the origin and affine distortion are concerned.

8. REFERENCES

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