PHOTOGRAMMETRIC APPLICATION OF SPHERICAL IMAGING

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ABSTRACT:

Spherical imaging is a technical approach of collecting scenery by viewing it through a single perspective. A typical realization of spherical imaging is a panoramic mosaic covering a part of the hemisphere. According to a photogrammetric definition, we introduce here, spherical imaging is an exact central projection explicitly determined by its projection center. They are linear images without any geometric distortions within their spherical coverage. Their orientation, or georeferencing, is defined by three coordinates of the projection centre and by two directions of the attitude, namely the horizon and the azimuth, or, the Zenith and North. Spherical images are suitable for photogrammetric applications both in interior and exterior surroundings. The ease of use is a major advantage of spherical imaging. The procedure of utilizing them for surveying and mapping processes will be discussed. This includes methods for generating spherical images with rotating camera, methods for measuring 3-D objects from spherical images, methods for building stereo pairs and visualizing the views, and methods for combining laser measurements with spherical images.

1. INTRODUCTION

Spherical imaging is a technical approach of collecting scenery by viewing it through a single perspective. A typical realization of spherical imaging is a panoramic mosaic covering a part of the hemisphere. According to a photogrammetric definition, we introduce here, spherical imaging is an exact central projection explicitly determined by its projection centre. They are linear images without any geometric distortions within their spherical coverage. Spherical images are usually created by combining a panoramic mosaic of a sequence of digital images (Figure 1).

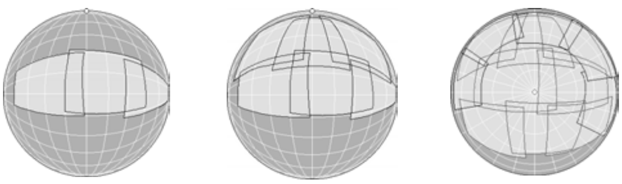

Figure 1. Alternative panoramic mosaics of spherical imaging are horizontal, half hemispheric, and full hemispheric imaging.

Basic solutions of panoramic photography are the use of super wide-angle optics, or a fish-eye lens, a swing lens or a rotating camera. These old and proven mechanisms are still in use but modern technology presents new possibilities in image acquisition. Several digital camera systems are commercially available, e.g. by Panoptic Vision, Inc., to name one only.

In order to facilitate producing of panoramic image sequences for virtual models, DLR has designed a high resolution panoramic camera employing line scan sensors. (Eckardt and Sandau, 2003, Schneider and Maas, 2003).

The application possibilities of the panoramic mosaic vary from art to aerial surveillance. Panoramic imaging has originally been developed to imitate the seeing of human being. Artists and photographers are probably the widest user group of panoramic images. Full spherical view is difficult to perform, but wide-angle or half-hemispheric screens are applied in cinemas, such as in IMAX(r) theatres, or in Verne theatre of the Finnish Science Centre Heureka (Haggrén, 1999, 2001). Corona satellite acquired panoramic photography for providing wide angle stereoscopic scope on Earth from space (Smith, 1997).

Panoramic models visualize three-dimensional space. A recent example of applying panoramic imaging in the virtual environments is their use in caves. Caves, e.g. HUTCAVE (Jalkanen, 2000), are spatially immersive displays and may fully surround the viewer. When panoramic models can provide the observer the possibility to move from one place to another, the power of panoramic images is in its localness. The observer can stop and look at the details by zooming. One can also look at the surroundings by turning the image on the screen. A practical web-based application of displaying panoramic images is the QuicktimeVR.

Early examples of panoramic photography in photogrammetric use are given by J. W. Bagley (Bagley, 1917). The panoramic

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camera was first employed in topographic surveying in Alaska by C. W. Wright in 1904. He designed the camera to use a swinging lens and film on circular slit guides. The frame size was 125 mm x 300 mm, and the camera constant 138 mm. The horizontal scope of view was approximately 126°, including a margin of 6° for overlap and identification of second photograph. The vertical scope was 18° above the horizon and 26° below it. The camera was used for surveys on scales of 1:48000 and 1:180000.

O. Gruber employed panoramic image acquisition using a photo theodolite in topographic survey of the glacier of Hochjochferner on scale of 1:10000 in Austria in 1907. The size of the photographic plate was 120 mm x 160 mm, and the camera constant 150 mm. Thus, the horizontal scope of each image was approximately 55° x 45°. At each station point Gruber widened this by taking two to six pictures facing side-to-side. In case of six pictures this resulted in 330°. (Gruber, 1911)

More recent studies are on the use of panoramic images in close range photogrammetry (Antipov and Kivaev, 1984). Shum et al. (1998) presented a system for constructing indoor scene 3D models from one or more panoramas. Apollo 17 mission provided high-resolution panoramic camera photographs of the lunar surface to support scientific and operational experiments, and to document operational tasks on the lunar surface and in flight. In Mars Pathfinder 1997 and Mars Spirit 2004, stereo camera was used for the creation of the panoramic mosaic to reveal the terrain and to study promising rock and soil targets for more intensive study, and to pick new regions for the rover to explore.

According to our photogrammetric definition of spherical imaging the image sequence should be explicitly determined by its projection center. Then they can be applied in a photogrammetric way for 3-D measurement and modelling. The concentricity can be fulfilled by attaching camera e.g. to a motorized theodolite (Chapman and Deacon, 1997) or to a robotic arm (Findlater et al., 2003). The mosaics are then produced based on the directions recorded by controlling support.

At Helsinki University of Technology (HUT), Institute of Photogrammetry and Remote Sensing, we have applied spherical imaging for recording of both interior and exterior surroundings. Instead of video theodolites, we have used digital cameras for image acquisition. We utilize the internal geometry of the imager chips to create a common spherical reference frame and have developed a method based on projective transformations in order to re-project images to this frame. In-house built mechanical platforms for spherical photography are employed for control of concentricity during image acquisition. Panoramic images have been studied in the Institute of Photogrammetry and Remote Sensing since 1997 (Haggrén, 1999). Petteri Pöntinen (2000, 2001, 2002) has developed algorithms for creating and combining both planar and spherical panoramic images from concentric image sequences. Rotation platforms needed for panoramic images have been developed by Pöntinen and Kukko (2001). Pöntinen together with Jyrki Mononen (1999) developed an algorithm for relative orientation of concentric image sequences. Ilkka Niini (2000) has developed block adjustment and camera calibration methods based on projective transformations with singular correlation in his dissertation thesis. Since 1999, Petri Rönnholm (2003) and Olli Jokinen (2002) have developed methods to combine laser scanner data and digital images. Milka Nuikka (2002) has oriented and measured panoramic images in a digital stereo workstation. Tuija Pitkänen (2002) has recorded stereoscopic panoramic close range image sequences in order to visualize and verify airborne laser scanner data. Henrik Haggrén (1999, 2003) has used panoramic image sequences to develop archaeological documentation methods.

This paper summarizes the work done in creation of spherical images, algorithm development to measure 3-D objects from spherical images and the use of spherical images for various applications. This paper includes the acquisition of spherical images, mechanical platform and camera mount, projective transformations, creation of image mosaic, validation and applications of spherical imaging.

2. METHODS

2.1 Spherical image acquisition

The production of spherical mosaics deals with combining two or more images taken from same place into one wide-angle image (Figure 2). The adjacent images should have an overlap of at least 20-30 %. The projection centre should not move during photo acquisition. The quality of the final images is related to the stability of the projection centre from image to image (Haggrén, 1999). Once the concentricity is achieved, the images can be re-projected and combined to one spherical mosaic. The obtained mosaic is consistent with an image taken with ultra-wide-angle objective.

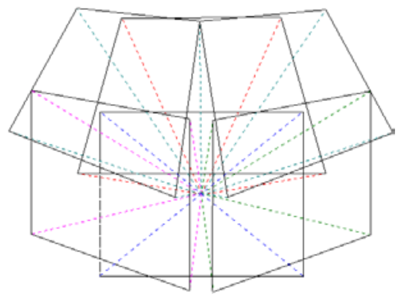

Figure 2. A block of concentric images.

2.2 Mechanical platform and camera mount

The concentric image capturing is essential for consistent image mosaics except in the case of planar objects. Thus there must be a mechanical platform and camera mount attached to the tripod, which allows the camera to be rotated around its projection centre. A cross-slide is used for turning the camera for horizontal image acquisition. For hemispherical image acquisition we use a platform that allows full rotation in both horizontal and vertical directions (Figure 3). The two rotation axes are perpendicular and intersect each other.

Each camera is mounted on the platform with the help of an adapter. The mount is adjusted along all three dimensions horizontally and vertically. The task is to move the camera mount on the platform until the projection centre will join the intersection point of the horizontal and vertical rotation axes. This will be controlled by parallaxes on the images. As soon as the projection centre of the camera and the intersection point of the rotation axes coincide, there will we no parallaxes when rotating the camera.

The mount can be performed with the help of a theodolite, a levelling instrument, and four specially designed targets in order to facilitate two lines in space (Figure 4). The platform will be centred to the intersection point of the lines. For practical reasons, all targets and the rotation centre of the platform are arranged in a horizontal plane and controlled by levelling. The camera will be moved on the platform, so that the targets appear in line. The correct position for the camera is found when these lines remain free of parallaxes in spite of the rotation of the camera.

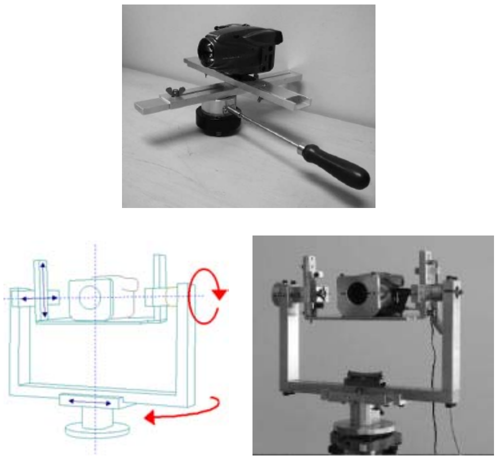

Figure 3. The spherical panoramic camera platforms are used for concentric mounting of the camera. For horizontal centring a cross-slide is used (above). The two-dimensional rotation mechanism contains a cardanic joint of both horizontal and vertical rotations, and three linear shifts (below).

Figure 4. The practical arrangement for mounting the camera consists of vertical and horizontal targets (left). When joint in line, the targets appear as symmetric cross and free from parallaxes as seen from the camera (middle). The set up for camera mounting is arranged in one horizontal plane (right).

2.3 Projective transformations

A picture taken by an ordinary camera is a central projection of the view in scene. In the case of the concentric image acquisition, any two adjacent and overlapping images can be further projected to a common plane by projective transformations without distorting the original common perspective (Figure 5). The mosaic image will fulfil the requirement set for spherical imaging but projected on plane.

It is noteworthy that the camera constant and the principal point do not have any effect on the transformation itself. However, the central projection assumes collinearity, which does not hold in ordinary camera lenses. Therefore, in photogrammetric applications cameras are calibrated in advance and the effects of e.g. optical distortions will be removed accordingly.

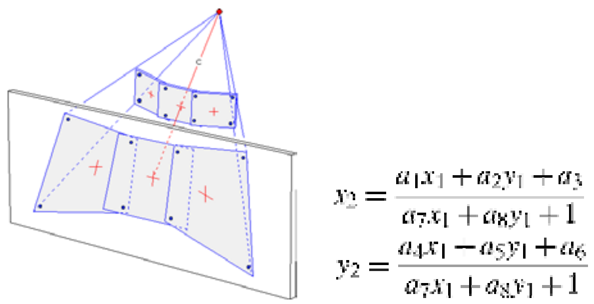

Figure 5. Concentric images are projected to a common plane by 2-D projective transformations.

Within the two-dimensional projective transformation the image coordinates $(x_1, y_{2,})_i$ are the ones on the original image planes i, and the parameters $(a_1, a_2, ..., a_8)_i$ are the ones of respective projective transformations. The image coordinates (x_2, y_2) are the new transformed ones. The transformation parameters can be solved if the image coordinates of at least four corresponding points are known on both planes and expecting that any three of them are not lying on same line. After the parameters have been solved the entire image can be transformed to the new plane.

The direct way to solve the transformation parameters between two concentric images is to measure the image coordinates of four corresponding points between to overlapping images and then solve the parameters $(a_1, a_2, ..., a_8)_i$. The most used approach is to use the whole image content of the overlapping area and to determine the transformation parameters. Therefore we set two conditions.

The first condition will require that for each corresponding point pair $(x_1, y_{1,})$ and (x_2, y_2) the grey values (or colours) become equal

$$g_1(x_1, y_1) = g_2(x_2, y_2) \quad (1)$$

The second condition will require that the two-dimensional projective equations between the pair $(x_1, y_{1,})$ and (x_2, y_2) will hold. If we consider the first solved parameter values $(a_1^0, a_2^0, ..., a_8^0)_i$ as approximations, we may solve the exact values by minimizing the residuals of grey values. If there are n point pairs, a linear equation set can be formed for de residuals v (size $nx1$)

$$v = A\Delta a - l \quad (2)$$

where matrix $\boldsymbol{A}$ includes the partial derivatives, vector $\boldsymbol{l}$ the grey value differences $g_1(x_{1i}, y_{1i}) - g_2(x_{2i}^0, y_{2i}^0)$, vector Δ_a the corrections to the approximations of transformation parameters. The residual vector is $\boldsymbol{v}$.

The elements of the matrix $\boldsymbol{A}$ (size nx8) are

$$\alpha_{ij} = \frac{\partial g_2(x_{2i}^0, y_{2i}^0)}{\partial x_2}\frac{\partial x_2}{\partial a_j} + \frac{\partial g_2(x_{2i}^0, y_{2i}^0)}{\partial y_2}\frac{\partial y_2}{\partial a_j} \quad (3)$$

The elements of the vector l (size $nx1$) are

$$l_i = g_1(x_{1i}, y_{1i}) - g_2(x_{2i}^0, y_{2i}^0) \quad (5)$$

The vector $\boldsymbol{a}$ (size $8x1$) includes the corrections of the unknowns $(a_1, a_2, ..., a_8)_i$. The least squares minimization leads to

$$\Delta a = (A^T A)^{-1} A^T l$$

(6)

The steps for solving the transformation parameters are:

1. Solve the approximated values $(a_1^0, a_2^0, \ldots, a_8^0)_i$ for the parameters of projective transformation.
2. Select a pixel $(x_1, y_1)_i$ inside the overlapping area and calculate its transformed coordinates (x_2^0, y_2^0).
3. Interpolate transformed grey value $g_2(x_{2i}^0, y_{2i}^0)$, and calculate the observation $g_1(x_1,y_1)-g_2(x_2^0,y_2^0)$.
4. Calculate α_{ij}:s.
5. Update A^TA and A^Tl.
6. Return to step 2 until all pixels of the overlapping area are handled.
7. Calculate corrections a and update the $(a_1^0, a_2^0, \ldots, a_8^0)_I$ for the parameters.
8. Return to step 2 until the corrections are negligible or the maximum amount of iteration steps are reached.

2.4 Creation of image mosaic

A central image in the block is chosen as a base onto which others will be transformed. The images adjacent to it are transformed sequentially. The radiometric differences are not compensated.

The original images in our examples are 1280 x 1024 pixels in size (Figure 6). When transforming a block of 3 x 3 adjacent images with an overlap of 30-50 %, the resulting panoramic scope will cover an angle of view of approximately 110° x 100° (Figures 7 and 8). The wider the overlap is, the stronger the joint geometry of the composite. If the composite is projected to a plane, a wide panoramic angle will result in reduced image resolution on the ends of the view. This is due to the re-sampling of the pixels during the two-dimensional projective transformation. This effect is avoided, if the images are re-projected to a cylinder (Figure 9) or a sphere.

Figure 6. Single images (1280 x 1024 pixels) of the Tapiola Culture Centre in Espoo. The scene of each image corresponds approximately to an angle of view of 50° x 40°.

Figure 7. The panoramic image mosaic composed of nine images and projected to plane. The image size is 4084 x 3347 pixels (110° x 100°).

Figure 8. Details of the joints between transformed images. The radiometric differences allow a gross visual check of the transformation. All linear edges crossing the joints should appear as linear in the composition.

Figure 9. A hemispheric image projected to cylinder. The composition is made from a video sequence and covers the full scope of view of 360°.

3. RESULTS AND DISCUSSION

3.1 Camera calibration

According to the photogrammetric definition, the projection centre explicitly determines spherical imaging and the image is linear. The images are free from any geometric distortions. On the other hand, the images are free from parallaxes. This leads us to camera calibration by rotation, which is a procedure that does not require any three-dimensional control data. The principal idea is to collect a block of concentric images and solve the rotations directly from image observations (Figure 10). The calibration parameters, i.e. the camera constant, the principal point, the scale difference and the angle between coordinate axes, and optical distortions, are modelled and solved as additional ones.

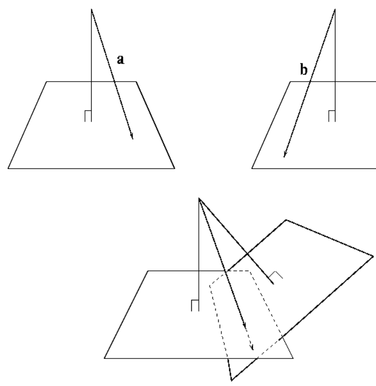

Figure 10. In camera calibration concentric images are registered by rotation.

According to (Pöntinen, 2002) the linear correspondence of two concentric images can be formulated as

(7)

in which ***a*** and ***b*** are the corresponding image vectors and ***R*** is the unknown rotation matrix. It is obvious that only two corresponding image vectors are needed to fix the three rotations. By defining normalized image vectors

$$= \frac{}{|\,|} \quad \text{and} \quad = \frac{}{|\,|} \qquad (8)$$

the two vector pairs give

$$= \begin{bmatrix} \\ \\ \end{bmatrix} = \quad = \begin{bmatrix} \\ \\ \end{bmatrix} \qquad (9)$$

and

$$= \begin{bmatrix} \\ \\ \end{bmatrix} = \quad = \begin{bmatrix} \\ \\ \end{bmatrix}. \qquad (10)$$

These relations give six equations and if there are more corresponding vector pairs, each of them gives three more equations. The orthogonality conditions of the rotation matrix also give six equations. If there are approximated values for the rotation matrix elements (or for the rotations angles), the final rotation matrix elements (or the rotation angles) can be obtained by iteration based on least squares estimation.

In an example given in (Pöntinen, 2002), a set of three concentric images was captured for calibration. The view was natural scenery. The camera was rotated horizontally in order to have an overlap of 50 % between adjacent images (Figure 11). Totally 102 corresponding image points were measured manually. The iteration converged well, the RMS value of image residuals being δ = 0.20 pixels. As can be seen in Table 1, the estimated values of some of the parameters (β, k_2, k_3, p_1 and p_2) have large standard errors compared to their actual values. In a second example of his paper, Pöntinen avoided this problem partly by adding a second row of images to the block. Obviously this could be partly avoided also by turning and tilting the camera for a second set of images to an upside-down position. The rest of the calibrated parameter values were very close to those obtained by a test field calibration.

Figure 11. A block of three concentric images used for the camera calibration. The horizontal overlap between these images is 50%.

parameter	estimate	std. error
px	6.184062e+02	1.125537e+00
py	4.775455e+02	2.995073e+00
c	1.402611e+03	5.532361e+00
α	9.830809e-01	9.389204e-03
β	-3.767164e-04	1.795160e-03
k_1	1.226342e-07	5.110449e-09
k_2	2.153417e-14	1.478256e-14
k_3	-8.917501e-20	1.436700e-20
p_1	-1.115324e-06	3.976178e-07
p_2	-2.567598e-07	1.327604e-07

Table 1. The results of the camera calibration by rotation from Pöntinen (2002).

3.2 Exterior orientation

In order to validate the usability of the panoramic photography for stereoscopic measurement, a test on exterior orientation was carried out in controlled environment (Nuikka, 2002). The target was the amphi theatre outside HUT main building in Espoo (Figure 12). The images were recorded with Olympus Camedia C-1400L. The image size of the camera was 1280 x 1024 pixels and we used primarily the wide end of the zoom optics, which corresponds to a focal length of 1400 pixels.

The images had an overlap of 30 %. The composed stereo pair consisted of panoramic images of 3346x1398 pixels and 3131x1382 pixels in size. This corresponds to viewing angles of 100° x 55°. The distance to the object was about 5 m and the base was 0.5 m. The control points and the location of the projection centre of the camera were measured with a tacheometer.

The procedure of orientation of a stereo pair carried out in a stereo photogrammetric workstation consisted either a) of both relative and absolute orientations of the model, or b) of direct exterior orientation of both images. According to this experiment, the direct exterior orientations proved to be the preferred alternative in orientation of panoramic stereo pairs. The RMS-values of the object coordinates after exterior orientations vary from 1 to 2 cm (Table 2). In relative orientation the RMS-value for the residual vertical parallaxes was 0.72 pixels, which is high compared to the previous value of 0.20 pixels obtained in the camera calibration. The fact, that a poor relative orientation will deform the stereo model, becomes evident in large residuals of absolute orientation (6 to 14 cm).

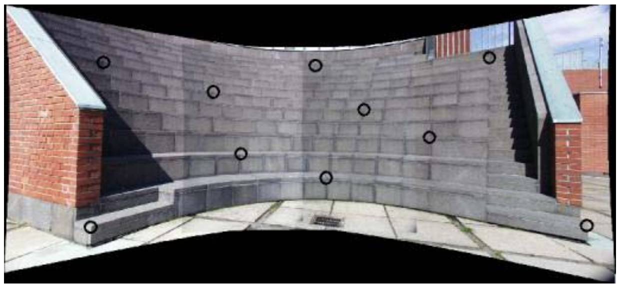

Figure 12. The control points of the experiment at the amphitheatre HUT main building were located evenly on the object area and measured with the tacheometer.

Orientations		x	y	X	Y	Z
relative	[pixels]	0,04	0,72			
absolute	[m]			0,14	0,09	0,06
exterior, left image	[m]			0,02	0,02	0,02
exterior, right image	[m]			0,01	0,01	0,02

Table 2. The RMS-values of the observations after alternative orientations.

3.3 Digital Terrain Modeling

Terrestrial horizontal panoramic photography has been applied for densification of DTM, originally produced from aerial photography. The example is from the Finnish Jabal Haroun Project, FJHP (Haggrén et al., 2001).

In order to be used for data acquisition of DTM, a stereoscopic pair of panoramic image sequences was recorded from the area

(Figure 13). This was typically taken at a longer distance, i.e. 100-200 m, as the landscape was open and free of vegetation. The base-to-distance ratio varied between 1:5 to 1:20.

We have used a digital photogrammetric stereo workstation for analysing the images. Due to the lack of control points we applied an orientation procedure, which was merely based on control features. These features were measured by tacheometer and consisted of terrace walls and barrages. We also had to limit us on applying those orientation modules, which were available at the workstation.

The practical orientation procedure, which we applied for processing of terrestrial stereo pairs, consisted of following steps: interior orientation, relative orientation, absolute orientation, feature extraction, and exterior orientation. The relative and absolute orientations were performed to identify the control features. The individual points of these polygons were then identified in stereo view and their image coordinates were measured as control points. The exterior orientation was shown to be necessary as far as it regards exact matching between the images and control features (Figure 14).

The DTM, which was based on aerial photography, was interpreted and processed as triangular network. The distance between two adjacent points on the road area varied between 20 to 50 meters. The terrestrial stereo models were used for densification of this aerial DTM. We characterized the terrain surface both as a regular grid with a grid size of 4 meters and with the help of additional break lines. Occluded areas were interpreted and outlined from the DTM. Thereafter a new triangular network was been processed.

Figure 13. A panoramic stereo view (4707 x 1000 pixels, 120º x 40º) built from the three images in the second row. The images in the third row belong to the left image of the stereo pair. The base of this stereo photography is 13 meters and the distance to the road on the opposite slope about 120 meters. The size of a single frame is 1280 x 1024 pixels (50º x 40º).

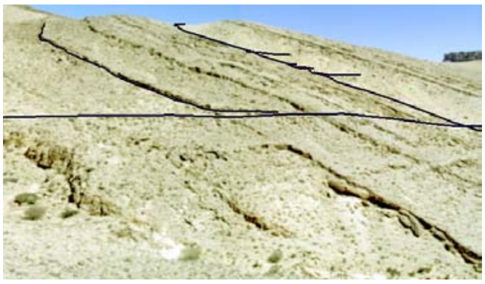

Figure 14. The orientations were visually controlled by features measured with tacheometer and projected on the panoramic images after exterior orientation. The features as polygons present two geomorphologic break lines, road and terraces.

A second example of terrain modelling deals with producing a high density DEM to validate and visualize the topographic data measured with an aerial laser scanner, an example from the EC-funded OMEGA project (Development of Operational Monitoring System for European Glacial Areas).

In case of the test model (Figure 15), the camera constant was 1410.8 pixels and the panoramic image consisted of four images. The size of the composite was 4624 x 1052 pixels (120° x 40°). For the purpose of exterior orientation, the model consisted of five control points. They were measured with a tacheometer and marked on site by painting. The RMS-value for the residual image coordinates after the relative orientation was 0.54 pixels. The RMS-values for the control points in X-, Y-, and Z-coordinates varied within 2 – 7 cm.

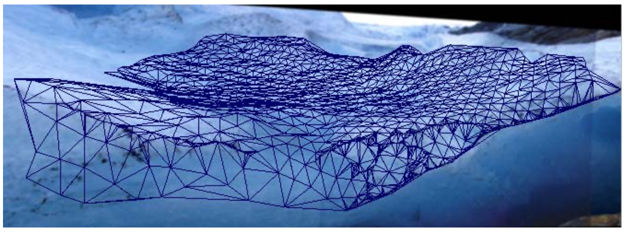

Figure 15. A DEM projected on the image of the stereo pair. The DEM was measured using a regular 20 cm grid of 800 points. The size of the modelled area is about 5 m x 5 m.

3.4 Relative orientation of laser scanner point cloud and spherical images

A fusion of close range panoramic images and laser scanning data has great potential to reveal how the laser beam actually behaves on targets. The fusion enables investigation of the laser scanner data quality and calibration of the algorithms of laser scanning. Visual examination is useful to change detection and to understand better the effect of internal errors, incident angle, pulse density and coverage of laser pulses.

When considering data fusion, both image sets have to be transformed in one and same coordinate system. This might be the WGS84, in which e.g. the raw laser data is acquired, or a local one, which most end user would prefer. Usually the transformations are performed separately, e.g. by exterior orientation, which in fact will result in unsatisfactory relative orientation. This is due to the fact that both exterior orientation include uncertainties, which accumulate and cause unsatisfactory relative orientation. Therefore, we prefer direct relative orientation in case scanner point clouds are investigated on spherical images.

Rönnholm has developed an interactive procedure for direct relative orientation of digital images and laser point clouds. (Rönnholm, 2003) The core idea is based on superimposing existing 3D data on the image by back-projection. By changing the orientation parameters interactively, an operator is able to fit the superimposed 3D data and visually verify the orientation. The orientation parameters have six degree of freedom, three independent camera rotations and three shifts of the projection centre (dX, dY, dZ). The process is iterative, in which shifts, rotations and back-projections follow each other until the 3D reference data will fit with the image.

The interactive orientation is significantly easier if images are panoramic, since many distinguishable targets should locate within the image to gain reliable orientation. With close-range images it is usually essential to expand the viewing angle of the camera form normal to ultra-wide.

If airborne laser scanner data is back projected on terrestrial wide-angle images, the verification of laser data is effective, since horizontal viewing is favourable for validating vertical range measurements and on extremely close viewing distances the image scale becomes large.

Interactive relative orientation of laser scanner data and a wide-angle image will succeed even without control points, control features, or digital terrain model (Figures 16 and 17). This feature is especially advantageous in areas where reference measurements become difficult or even impossible to perform.

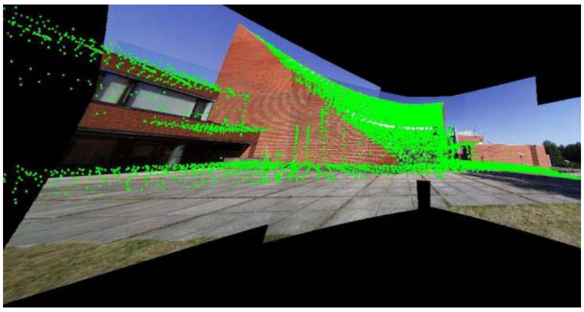

Figure 16. Overview of back-projected laser scanning data on interactively oriented panoramic image. In case of built structures the orientation is visually controlled mainly through edges. The image size is 10729 x 5558 pixels which corresponds to a horizontal viewing angle of 150º x 125º.

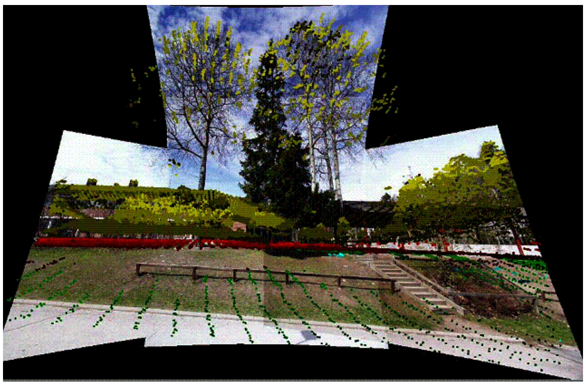

Figure 17. In case of natural features the orientation is visually supported by the very intensive structural appearance of the dense point cloud. Close to the camera even small topographic features become useful, like the edge of the pavement. The image ~~is~~ size is 3245 x 2902 pixels (110º x 85º).

3.5 Stereoscopic visualization

In developing spherical imaging, stereoscopic visualization plays an important role. We have already applied panoramic images for stereoscopic acquisition of DTM data. However, the primary advantage of spherical imaging – as far as it regards visualization – will be on the stereoscopy. The examples shown in previous chapters, where laser data is projected on spherical images, do reveal the registration only across the viewing direction. This becomes evident if we consider the trees in the.

We define the full-scale stereoscopy being a projection of images in a viewing scale of 1:1, and combined with a stereoscopic plasticity of value 1. This would require spherical imaging with a base equal to the one of human eyes, i.e. approximately 65 mm. We motivate us by the fact that we do not have any reasonable means available so far to investigate the behaviour of laser scanner in its details. This becomes evident in considering e.g. the earth surface in Figure 18, or considering, how much the grass affects on the level of laser reflection.

The visual presenting of spherical image mosaics may follow any mathematically defined map projection, e.g. plane, cylindrical, conical, or spherical projection. The approach of using Stereodrome for display of natural 3-D sceneries obtained with spherical images has been introduced for the first time.

Stereodrome consists of a photogrammetric workstation, a high-resolution stereo projector, necessary stereo eye-ware, and a back projection screen (Figure 19). The use of a Stereodrome type of installation for 3-D visualization of geoinformation has already risen up new research issues. How does natural stereoscopic plasticity preserve in full-scale displaying? How laser scanner data should be fused in order to facilitate the change of the original perspective of spherical image while viewing? In which way the full-scale stereo display can be used for validating the quality of existing 3-D geoinformation, such as laser scanner data or geographical feature?

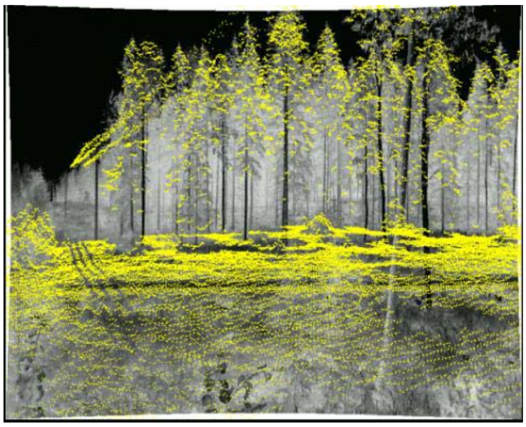

Figure 18. The high topographic intensity of dense airborne laser data becomes visible in horizontal viewing. However, without stereo viewing, the exact registration of the point cloud and the terrain remains uncertain.

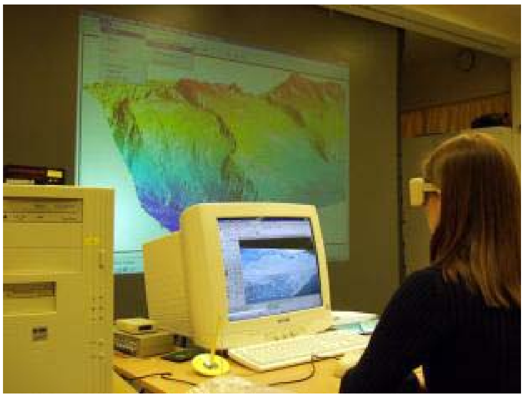

Figure 19. The Stereodrome at HUT is an approach aiming at displaying full-scale stereo models. The size of the screen is 2,7 m high and 3,6 m wide.

3.6 Documentation based on spherical imaging

One of the advantages of spherical images is the obvious ease of the orientation. E.g. the determination of the attitude, i.e. levelling and control of azimuth, requires two horizontal references. A second advantage is that the ultra-wide view angle facilitates documenting in nearly any circumstance. This becomes extremely useful in close-range documentation.

Within the Finnish Jabal Haroun Project, FJHP, we have used spherical images for documentation purposes since 1997. The first prototype of the cross-slide, which was mentioned earlier in Chapter 2.2, was especially developed for this project. It facilitates the turning of the camera for horizontal image acquisition. We currently use panoramic image sequences in documenting of both archaeological excavations as well as in archaeological invention, i.e. in field surveying. In field surveying we record for each image sequence the approximate orientations, i.e. the location with a hand-held GPS-receiver and the azimuth with a compass.

The panoramic photography has been done as stereoscopic image sequences (Figure 20). Each sequence consists usually of three single images. The base is generally about 15-20 meters forming an approximate base-to-distance ratio of between 1:10 or 1:15. The control points are selected using natural features, such as corners or edges of stones. The identification of the control points has been made in field, they are recorded by close-up photography, and their coordinates are measured with tacheometer. The survey group has made the archaeological identification of barrage systems and terrace walls on paper prints.

As far as it regards the exact orientation of the spherical images, we will use existing 3D data and apply the interactive orientation procedure described in Chapter 3.5. In addition to that, we will use the natural control points measured with tacheometer.

Figure 20. Panoramic image sequence of five images, seen from a building site, containing Wadi Araba in West, Jabal Haroun in North, and Petra in East. The images are original and not composed to a mosaic.

3.7 Discussion

Spherical images are optimal in photogrammetric applications primarily because of three reasons: They are metric images, they cover wide angle of scope, and they are high-resolution images.

We have collected and produced spherical images based on concentric image acquisition. The original images in a sequence are two-dimensional and the processing of the metric composition utilizes the internal geometric strength caused by concentricity. Also camera calibration can be included to the processing. The processing is high intensive but can be automated. The scope of spherical images varies from horizontal panoramic to full hemispheric and the resolution can be chosen according to application.

The number of images in a sequence can be considered as a practical limit. This is increased due to the required overlap between images, and will increase further, when long focal length optics is used for high-resolution image acquisition. Also the physical changes in the scene, e.g. due to the illumination or wind, or any movement of object, will cause problems in processing.

The ease of orientation is considered as major advantage of photogrammetric application of spherical imaging. The number of parameters in the physical model is minimal. It consists of three coordinates of the projection centre and two directions of the attitude, namely the horizon and the azimuth, or, the Zenith and North. We have utilized this feature especially in interactive relative orientation of spherical images either to three-dimensional feature data or laser point clouds.

The existing application software, e.g. the ones for data acquisition of digital surface models at stereo photogrammetric work stations, utilize epipolar images projected on planes. The projective resampling of images adjacent to the central one will result in reduced image resolution, and will thus cause deformations in the surface model. This can be avoided if the images are projected to cylinder. However, this is not included as option to ordinary mapping procedures available in photogrammetric work stations.

If we further consider stereoscopic visualization of spherical images, the question of projection becomes crucial. We have here introduced full-scale stereoscopy based on real imagery. As their perspectives define spherical images of real environment explicitly, the stereoscopy will cause obvious problems in case we change viewing directions. This problematic deserves further action in photogrammetric research. In immersive displays full-scale visualization is based on synthetic three-dimensional models and the perspectives are changed graphically.

4. CONCLUSIONS

In the paper, the concept of spherical imaging was introduced and its application to photogrammetry discussed. The practice and theory of producing spherical images was presented. Camera calibration was considered to be the primary photogrammetric application and it was shown that even with small concentric image blocks the calibration becomes feasible. The procedure of exterior orientation was experienced, as well as the procedures of data acquisition for digital surface models and of visualization of object models. These procedures are not yet complete and these experiences have initiated further research and development. As a new photogrammetric application full-scale stereo vision was introduced and discussed.

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