AUGMENTED 3D VISION SYSTEM FOR OBJECT RECONSTRUCTION

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ABSTRACT:

In this paper the concept of combining two different imaging procedures and a laser scanning system is presented. The goal is to combine panoramic image with two co-centric image sequences and with laser scanning device creating an augmented 3D vision system. Solution will be sought to combine spherical image data with dissimilar geometry. The full 360° degree egocentric view from panoramic image and co-centric image sequence can be combined in order to form a stereoscopic view of the surrounding scene. In addition, the image sequences can be used for producing accurate 3D measurements. With this method it is possible to visualize the environment in a realistic way. Additional 3D data, like obtained by laser scanning, can be co-registered with the image data. The proposed approach can further be used as assistance when georeferencing additional data or information to common 3D coordinate frame.

1. INTRODUCTION

The management of image geometry in arbitrary conditions and applying consistent mathematical model is a demanding task. Imaging through a single perspective (*panoramic imaging*) or utilizing the geometry of multiple perspective images (*image blocks*) can be treated as alternative technical methods to record and acquire information from the surrounding scenery.

However, these two realizations are not mutually exclusive technical approaches to object recording or reconstruction. Combination of panoramic imaging and image block sequences can utilize benefits of both techniques. The full 360° degree egocentric view from a panoramic image gives realistic impression of the surrounding scene. On the other hand, an image sequence, which is acquired by moving the camera along a predefined trajectory covering as well the entire 360° degrees field of view, can yield the potentiality for obtaining comprehensive geometrical 3D information from the site. If the trajectory of the moving camera is a circle on an arbitrary plane, we can define and apply a mathematical model for it, like *circular imaging blocks* (Heikkinen, 2000;2004;2005). If the centre of a circular imaging block coincides with the perspective centre of a panoramic image, we can provide a *stereoscopic panorama* around this point.

Whenever object reconstruction is applied for surveying and mapping processes, the exact image registration or georeferencing becomes crucial. The modeling and solving the georeference, or image orientation, is one of the primary tasks of photogrammetry. The orientation can be defined with respect to a coordinate system or relative to other data e.g. from laser scanning. After the georeference is solved, images can be used for updating the geoinformation. This combination of different imaging sources can provide a tool for 3D data acquisition and visualization for number of applications from teleoperation to personal navigation. 3D vision compound with auxiliary 3D data is designated as an a*ugmented 3D vision system*.

1.1 Panoramic Imaging

Presentation of panoramic image mosaics may follow any mathematically defined map projection, like plane, cylindrical, conical, or spherical projection, to name only few. Panoramic images can be considered to be ideal media for acquiring images in the inside scene environment. The idea of panoramic images has been known over a century, but using this concept for measurements in close-range photogrammetry has only recently been of interest. Panoramic images can be obtained by merging multiple central projective frame images into a single panoramic image or by using cameras especially designed to acquire the intensity information with panoramic projection.

In order to acquire panoramic image information from multiple central projective frame images, it is necessary to have a single common projection centre that all images share. This can be accomplished by estimating mathematically the possible eccentrical difference between projection centres and taking into account this effect in constructing the panoramic image (Wester-Ebbinghaus, 1982; Hartley, 1993; Luhmann et al., 2002), or by trying to place the camera in a rotational mount piece (Figure 1) so that no eccentric difference exists between image perspective centres (Pöntinen, 1999; Kukko, 2004).

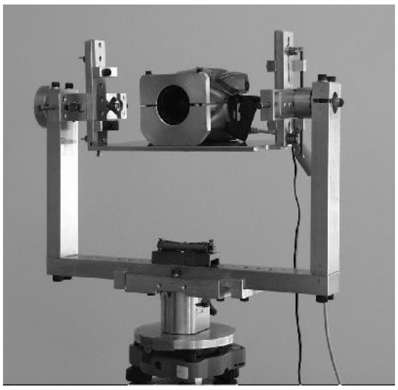

Figure 1: Rotation platform, the set-up for camera mounting.

In the case of special panoramic cameras, the imaging is based on a single array sensor. The panoramic image is constructed while applying plane rotation for the vertically aligned sensor and acquiring the intensity information during rotation. The spatial resolution of the image is then dependent on a minimum rotational resolution in the horizontal direction, while, in the vertical direction, the number of sensor elements in the array limits the resolution. The sensor array is assumed to be perpendicular to the axis of rotation. There have been reports of this assumption having been found to be incorrect (Schneider et al., 2005). Also, there have been observations of uneven rotation of the sensor in the direction of rotation and of violations of a planarity constraint (Parian et al., 2004). By applying correction terms based on calibration, it has been possible to reduce the error of the single observation from 10 to 0.2 pixels (Schneider et al., 2005).

However, object reconstruction, based on the image ray intersection cannot be achieved from a single panoramic image. The image observations from a panoramic image can be equated with the horizontal and vertical angle observations from the theodolite. Consequently, to be able to measure 3D point location by means of image ray intersection, at least two panoramic images have to be created having a different centre of perspective. In order to have observational redundancy, three panorama sequences is the minimum. Before object reconstruction, images have to be relatively oriented or oriented with respect to a chosen coordinate system. With the use of photogrammetric bundle adjustment, the orientations can be computed in a rigorous way. Luhmann et al. have noted in their investigation that generally 5-7 tie points are sufficient for a complete room (Luhmann et al., 2002).

For object measurements, the corresponding image-point observations have to be made in the same way as when using central projective frame images. However, in contrast to frame images, the epipolar line, where correspondent points should coexist, is not a straight line but a sinusoidal curve. This is due to the presentation of the panoramic image projected on the surface of a cylinder. The benefit of panoramic images in the inside scene measurements by imaging outwards from inside is their coverage of full 360°. This means that an object point can possibly be seen in all panoramic images of the project. However, the image scale can vary largely from image to image. This is why, in many research projects, an image management and browsing system has had to be created in order to find all possible images where the object point can be seen (Luhmann et al., 2004; Chapman et. al., 2004). In complex environments, the image management system is a system component that is clearly crucial in getting the task accomplished (Chapman et. al., 2004).

1.2 Circular Imaging Blocks

Traditionally image based 3D measurements require at least two images to be taken with different views of perspective. So, the image sequence acquired for creating panoramic view does not fulfil the requirement just stated, since the projective centre will be convergent for all images by the definition. The imaging system developed for circumstances that would also be suitable for panoramic imaging has been created (Heikkinen, 2000; 2004; 2005). In this novel system camera is turned around a stationary point along circular trajectory. This imaging complies the principle of multiple perspective views and still covers the scenery of full 360°.

If two co-centric image sequences are created in such a way, that only the camera orientation respect to trajectory of rotation

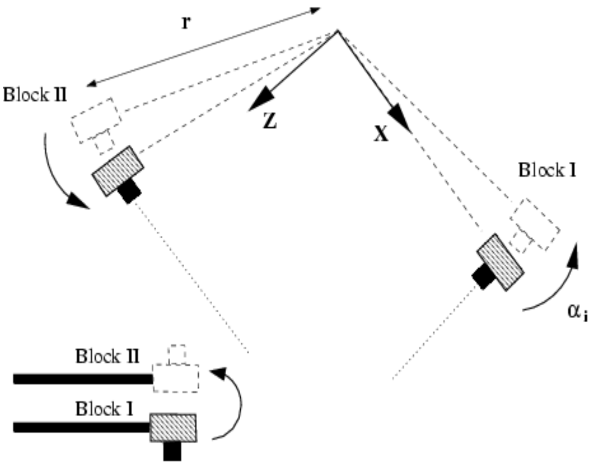

Figure 2: Two co-centric circular imaging blocks with convergent imaging property (Heikkinen, 2005).

differs, geometrically adequate imaging geometry can be achieved for 3D measurements. By applying two opposite camera orientations between image sequences (Figure 2), it has been verified that the accuracy of object measurements is around 1:2000, being the object measurement accuracy with respect to object size, in case where the radius of the rotation was r=0.45 m, and the distances to the object points varied between 2-15 m (Heikkinen, 2005).

In this model the camera position in time of exposure is presented by polar coordinates and orientation is dependent by the plane-rotation respect to first camera position as depicted in equations (1) and (2).

$$\begin{cases} x = r \cdot \cos\alpha \\ y = constant \\ z = r \cdot \sin\alpha \end{cases} \qquad (1)$$

$$R_{\omega_i \phi_i \kappa_i} = R_{\omega_0 \phi_0 \kappa_0} \cdot R_{\alpha_i} \qquad (2)$$

In equation (2) the plane rotation is applied to first camera orientation matrix $R_{\omega_0 \phi_0 \kappa_0}$ in order to derive the rotation matrix of the individual camera position. The estimation model is based on tie point measurements on overlapping images. In order to solve unknown orientation parameters the LSQ-estimation is applied for over determined problem. If two circular imaging blocks are used, the estimation is applied for both blocks simultaneously. This will guarantee that the both blocks will be in same coordinate system. The coordinate system will be local, since only image observations are used in estimation. However, a scale in object space can be included in order to have measurements in metric system. The model is strictly depending on resumed imaging procedure, i.e. on plane rotation and static fixation of the camera at the end of the supporting bar. Few refinements have been made to the model in order to allow some variation of this strict assumption. More detailed description of the method can be found in (Heikkinen, 2004; and Heikkinen, 2005).

The configuration depicted here provides adequate imaging geometry for object measurements. The stereo viewing can also be generated from these two image sequences, but because two views are too wide apart, natural stereo view cannot be achieved. Therefore, a combination of panoramic image sequence with a circular imaging block is a well-grounded solution for creating augmented 3D vision system.

1.3 Stereo panorama

There have been few research projects where a stereo system with panoramic viewing capability has been investigated (Peleg et al., 1999; Seitz et. al., 2002). The construction of stereo panoramas or omni-vergent stereo is achieved from two image sequences. Image sequences are acquired in a way as was depicted in Figure 2. The aim has been to create a panorama image that consists of image strips from both image sequences. The image strip, a column, whose viewing angle is tangential to trajectory of the camera, is extracted on every image. For the purpose of stereo viewing, the image is projected onto a planar surface as a stereo pair with a chosen viewing direction. Neither of image image sequences has fulfilled the concentric panoramic imaging.

In these research projects, the aim has been to reduce redundant image information and only store those image rays that are necessary for creating a panoramic view. By storing image ray information so that image rays with the same horizontal angle are stored in the same image column, and image rays with equal vertical angles are stored on same row. This way epipolar lines will coincide scan-lines and the correspondence of image points can be found on the same row. This is a benefit when using standard stereo matching algorithms for object reconstruction. As the main goal has been only to create stereoscopic panoramic viewing, the image construction has not been geometrically adequate to provide precise measurements. However, attempts have been to accomplish object reconstruction by means of stereo matching as well (Seitz et. al., 2002). The main purpose of those projects has been to produce visualization tool, which can store the sufficient information for a 3D view. With the procedure of circular imaging block procedure, the redundant information is retained and the geometry of perspectively projected frame images with known camera calibration information are utilized to achieve accurate 3D measurements.

2. AUGMENTED 3D VISION

In this paper we present the idea to combine a true panoramic image from a single perspective with a concentric image sequence of circular imaging block. The new concept will accomplish a panoramic 3D object measuring and reconstruction system with stereo viewing.

In addition, if the vision system is combined with other 3D measuring sources like terrestrial laser scanning, the system will become a mapping system, where advantages of laser techniques and image based methods can be utilized in object reconstruction. Also, if laser scanning is accomplished from the same location as panoramic imaging, visual inspection based editing of a 3D point cloud is essentially improved. The visual sight from the same viewpoint is an essential benefit in interpretation of laser point clouds and the capability to see data in 3D, takes the object data editing to the next level. The robustness of image registration and ability to project 3D elements precisely on top of the stereo view will together reproduce a mechanism to see the world in a realistic way in case of teleoperation, virtual museums, or in personal navigation systems.

2.1 Stereoscopic View and Panoramic Image

Our implementation of stereoscopic panorama differs from approach presented earlier (Peleg et al., 1999; Seitz et. al., 2002) as now the true panoramic image is included in generation of a stereo view (Figure 3). In stereo panorama (Peleg et al., 1999) and in omni-vergent stereo (Seitz et. al., 2002) the stereoscopic views have been constructed from two image sequences.

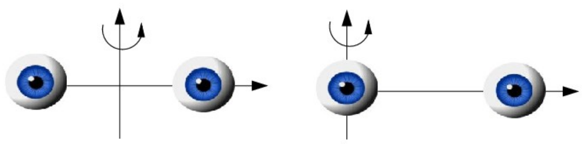

Figure 3: Stereo panorama (left) and stereoscopic panorama with true panoramic image (right).

The generation of panoramic stereo from two image sequences is a compromise of viewing convenience and geometrical measuring capability. If the trajectory of the image sequences is too much apart from the navel point, the stereoscopic viewing is not practical. On the other hand, if the radius is too short, the imaging geometry becomes poor and 3D measurements are trustworthy only within short distances.

However, if the other image is a true panoramic image and another image is extracted from image sequence, the same eye-base can be accommodated with one image sequence, where radius of the trajectory is two times as long as with previous construction. When circular imaging block procedure is followed in order to acquire 3D measurements, longer radius with imaging sequence can be used and better accuracy achieved in 3D measurements. Also, if stereoscopic panorama is created from panoramic image and both image sequences, we can have two stereoscopic panoramas with alternating viewpoints, one with left-eye and one with right-eye fixed to the navel point (Figure 4).

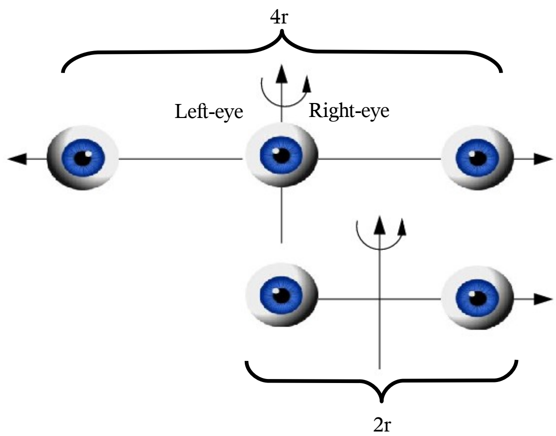

Figure 4: Comparison of the stereoscopic panorama.

2.2 Stereoscopic view generation

In order to generate stereo panoramic view from one full 360° panoramic image and a co-centric circular image block sequence, it is necessary to mount the camera, or cameras, on an imaging platform so that projection centres lie on same plane all the time. However, this is not a strict requirement. Small discrepancy can be compensated by means of mathematical transformation and by resampling of the image.

More comprehensive task is to verify that both image sequence and panoramic image really are co-centric in planimetry. The eccentrical difference can be taken into account mathematically when the stereopair corresponding the image of the image sequence is generated from the panoramic image. The eccentrical discrepancy is sensed as a varying length of the base vector. If the difference is concierable this will be annoying when watching a steroscopic streaming image sequence i.e. video sequence. However, the human eye can accomondate small variation of base vector quite well. As the stereo vision system is mainly used for visual intepretation and real measurements are going to be made from image sequences a small eccentrical discrepancy can be neglected.

Stereopair generation basicly means converting the cylidrical projection of the panoramic image to image projected on plane. The plane should be the same as the frame image selected from the sequence. The task is to generate that projection from a small section of panoramic image which shares the same view than the frame image. Which part of the image is then equivalent has to be solved by image registration. The procedure should be equivalent to image sequence image registration, with exception that the image geometry is different.

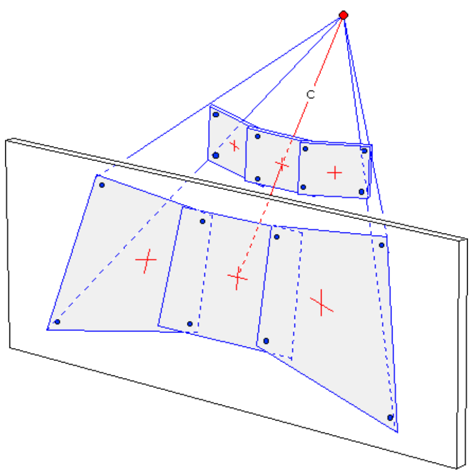

Figure 5: Projective rectification of co-centric images.

In this implementation the other image, from left or right, will be from image sequence and is originally a frame image. So this can used as a reference image for creating a stereo pair for specific viewing direction. However, a plane-to-plane transformation might be needed in some cases. The frequency of stereo pairs is much dependent on the number of images taken in image sequence. So, in order to have smooth representation for stereoscopic panorama the number of images needed is rather significant. The increase of number of images puts some pressure on developing automatic image registration.

2.3 Laser point cloud registration with image data

To be able to project precisely the 3D point cloud measured by laser scanning device on top of the images, the data has to be co-registered. The measurements obtained from laser scanner are based on angular observations or angular and distance observations depending on whether device is utilizing triangulation or laser ranging technique. Regardless of laser used, point clouds can be projected and viewed from a single perspective point. Therefore combining a stereo panoramic image with laser measurements taken from the same point location is a sensible solution.

When viewing directions are nearly the same, the co-registering of laser point cloud with the panoramic image becomes feasible. The intensity image received from laser scanner can be used for computation of coordinate transformation between laser point coordinates and panoramic image coordinate system (Wendt, 2004). The fact that laser intensity and range images are from the same perspective view improves the robustness of the correspondence matching. Since the stereo-panoramic image measurement system consisting of circular imaging block and co-registered panoramic image is capable of producing accurate 3D measurements, the 3D measurements can be used for co-registering laser points into same coordinate system and improve the overall performance. After all, the measurements given by laser scanning device are three-dimensional coordinates of laser points. The task is then to extract and match 3D features of both data sets.

In laser scanning projects the problem how to co-register the data from separate measurements accurately has come up quite frequently (Sequeira, 1999; Rönnholm, 2003). Inaccuracy increases when laser beam hits the surface in smaller incidence angles. Those critical surfaces are hard to detect directly since the data obtained from laser device are mearly point coordinates. With help of stereo view, co-registering can be facilitated and even it is possible to locate the errorness measurements of laser device from the data. It has also been proven that using image data for assistance can really improve the accuracy of laser data georeferencing (El-Hakim et. al., 2002). So, a good option would be to use image based observation to create coordinate frame for the measurements and assist in co-registering the data. Also, edge type object feature are better to be acquired from image data while laser measurements are used to reconstruct smooth surfaces and more detailed object structures.

3. CONCLUSION

In this paper a new concept to create stereoscopic panoramic view is presented. The suggested system is constructed from one true panoramic image and a concentric circular imaging block. The system will provide a panoramic system, which can be used also for accurate 3D measurements. This system, if combined with a laser scanner, can create augmented 3D vision, where 3D editing based on visual inspection can be performed on both photogrammetric and laser point cloud image observations. Also, some aspects appearing in co-registering different images have been discussed and strategies suggested to overcome obvious problems.

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