3D Environment modeling using Stereo Panorama Method - State of the Art

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Abstract
A complete large scale city map which enables access to geometric as well as visual information is required by most organizations. There exist a number of problems such as moving the vehicle, moving objects and occlusions which affect the development of such maps. In this regard, the use of stereo panoramas is an image based solution which has attracted the developers and users of city maps. This is due to the fact that stereo panoramas besides offering a visual and complete view of surrounding static and moving are simple to create. There exist a number of techniques which are used to develop stereo panoramas. This paper, reviews these techniques from the projection as well as the geometrical stand points. The review includes systems offered for image acquisition, stereo panorama generation, registration, geometric measurement and representation.

1. Introduction

Today developments of models from city environments which allow the measurement of objects are of great interest. Such models can be used in different applications and disciplines including control and robotics (Cobez and Zhng, 2001), map completion (Micusik and Kosecka, 2009) and visualization (Shimamura et al., 2000), generation of intelligent decision support systems (Lin et al., 2008), games (Lippman, 1980) and navigation (Chen, 1995). There exist a number of problems such as moving the vehicle, moving objects and occlusions which affect the development of such models (Gledhill, 2004). 3D modeling techniques are either geometric or image-based (Moravec, 1993). In geometric based techniques, such as tacheometry and laser scanning geometric information including distance or coordinates are directly measured (Ayache and Faugeras, 1989) versus image-based techniques where an area is modeled through images. Geometric-based techniques are time consuming and can face serious problems in cities with moving objects and obstacles. In addition, they mostly operate in manual mode, require vast amount of processing and do not usually produce visual information. In contrast, image based techniques, offer comparably low cost solutions which also allow the visualization of objects (Huang and Hung, 1997). As source for image based techniques, a stereo panorama (figure 1) is 3D panorama which covers 360 degrees and can be used to obtained 3D measurements on the objects.

Figure 1: A stereo panorama (Amini, 2011)

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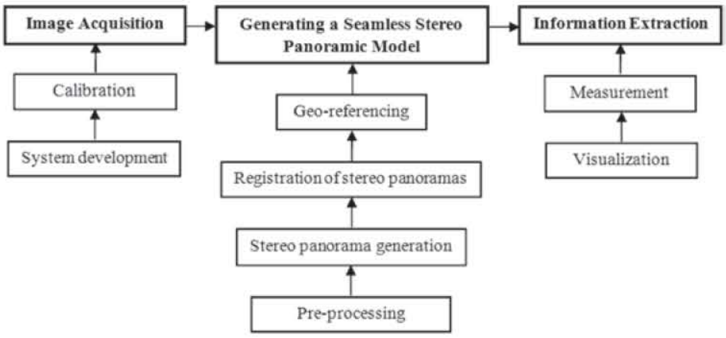

Figure 2: Steps of 3D environment reconstruction based on stereo panorama method

They are rich of visual information; thus in addition to being able to be produced at relatively low costs allow for simple identification of objects to be measured (Gledhill, 2004). It is also possible to configure the image acquisition system such that the stereo panorama is produced automatically (Varshosaz and Amini, 2007) and allow for geometric measurements of relatively homogenous accuracy (Amini, 2011). A 3D measuring system which uses stereo panorama as the source contains three main components (Figure 2) which are the image acquisition, stereo panorama generation, and 3D measurement systems. To design an image acquisition system, the required hardware need to be defined, configured to cover 360 degrees, and to be calibrated to allow for accurate 3D measurements. Once the images are acquired, they need to be corrected for geometric and radiometric effects and stitched together to form a panorama. Depending on the system configuration, the stereo panorama could be directly produced at this stage, or generated by combining a number of single panoramas. At last, the stereo panoramas should be registered together and to a local or global coordinate system to allow for 3D measurements. The measurements are carried out using the measurement component which should allow for visualization and measurement of objects either manually or automatically. There exist a number of solutions which can be used to design and implements a 3D panorama measurement system. This paper reviews these solutions in three separate sections. Section 2 concerns the systems developed for acquisition of stereo panorama images while Section 3 reviews stereo panorama generation techniques. Section 4 discusses methodologies which can be used to obtain geometric measurements from 3D stereo panoramas. Finally, Section 5 summarizes the systems and offers areas for future developments.

2. Stereo Panorama Data Acquisition

In order to acquire images required to form a stereo panorama, image acquisition hardware needs to be selected and a suitable calibration process to be designed. In the following each of these sections are discussed.

2.1 The Stereo Panorama Image Acquisition Unit

In order to develop a stereo panorama two views are required one for the left eye and the other for the right. Depending on how these views are formed and combined a number of techniques have been proposed which are reviewed in this section. The most basic system used to develop a stereo panorama is to combine two panoramas obtained from adjacent camera stations (Varshosaz and Amini, 2007). For this, several images from two separate stations are taken and panoramas covering the same area are produced and used to produce an anaglyph stereo panorama. A system of such suffers from the difficulty in stereo viewing along the line connecting the two stations. Moreover, by the reason of difference in scale and viewing between two panoramas, the produced stereo panorama has not the appropriate quality. Peleg and Ben-Ezra (1999) proposed the idea of using a single camera to produce a stereo panorama. In his technique, the camera is rotated to take a number of images with large overlaps to cover the surrounding environment (Figure 3). A pair of thin strips is then extracted from the rear left and right parts of each images. The left parts are then stitched together to form the left panorama while the right strips form the right panorama. The stereo panorama is finally formed by combining the resulting left and right panoramas. In spite of being able to present a stereoscopic view of the complete 360 environment, this technique is time consuming, needs taking many images in a sequential mode in which static objects can only be modeled.

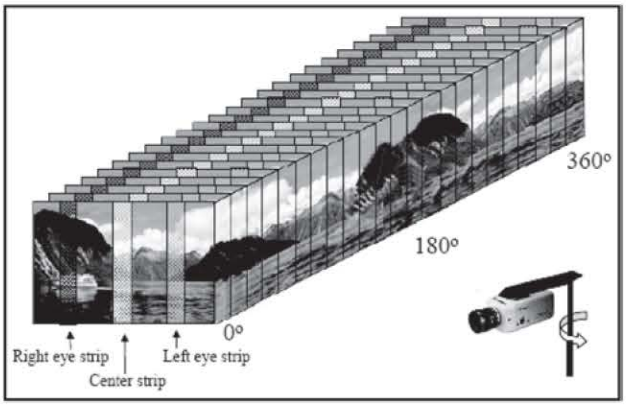

Figure 3: Left and right strips produced for two panoramas from a single camera (Peleg and Ben-Ezra 1999)

Figure 4: A stereo-bar camera (left) (Varshosaz and Amini, 2007) and a stereo-turn table camera (right) (Jiang et al., 2006)

In addition, instability of the rotating unit can reduce the quality of the result. Tzavidas and Katsaggelos (2005) extended the idea proposed by Peleg by replacing the rotating camera with a number of cameras positioned on a circular plate. This way, the problem of moving objects and the instability of the camera was resolved. However, in order to obtain a good quality stereo panorama, the number of cameras needs to be high, which in turn considerably increases the implementation costs and practically this idea, is not implementable. A common technique used to develop stereo panoramas is the use of two normal cameras which could be positioned either beside or one above the other (Gledhill, 2003). Examples of such systems are Huang and Hung (1997), Lin et al., (2008), Jiang et al., (2006), Qu et al., (2010), and Varshosaz and Amini (2007). In such systems, two single panoramas are produced using the left and right cameras and combined to form the final stereo panorama. Figure 4 shows the systems developed by Jiang and Varshosaz. Compared to the systems like that of Peleg and Ben-Ezra (1999) or Tzavidas and Katsaggelos (2005), such systems use fewer images to from the panoramas. However, they are not able to produce stereo panoramas from moving objects and are subject to instability of moving cameras. In addition, if the cameras are positioned vertically, the stereo viewing is not possible. Instead of normal cameras, linear array cameras (Li et al., 2008), (Benosman et al, 1996), (Benosman et al, 1998), cameras with fish-eye lenses (Hua et al., 2008), (Hall and Cao, 1986), and modular cameras (Kawanishi et al., 1998) can also be used. The use of cameras with fish-eye lenses allows for taking complete 360 degrees views instantly; thus the reducing the problem of moving objects and the instability of the acquisition unit when the images are captured. However, these lenses introduce large aberrations and lead to images having different resolution in the centre compared to the rear parts of the image. In systems that are based on the use of two linear array cameras, two complete panoramas are taken on a line by line basis. Although the quality of the resulting panoramas is good, the system cannot cope with moving objects. Moreover, the instability of the system during the image capture, may lead to a reduction in the quality of the resulting stereo panorama. As shown in figure 5, modular cameras are those constructed by fixing a number of cameras near each other so that a complete 360 degrees view is covered. Kawanishi et al., (1998) used two set of such cameras to produce a vertical stereo panorama imaging capture system. The result is a set of two single panoramas, which together can theoretically form a stereo panorama. Despite the possibility of making geometrical measurements, the stereo viewing is not possible. It is also possible to combine images taken from two omni-oirectional cameras to produce stereo panoramas (Figure 5). An omni-oirectional camera uses a parabolic mirror to capture the complete view surrounding the camera. Goshtasby (1993), Cabral et al., (2008) and Arnspang et al., (1995), Sung and Lu (2012) and Bo et al., (2011) used two cameras of such to form stereo panoramas. Despite being able to capture the whole view in a single snapshot, systems like this suffer from having large aberrations and low resolution. Various stereo panorama technologies and systems were introduced above. Some of these various technologies and their related researchers are presented briefly in table 1. By far no system has been developed to cover all needs of a stereo panorama image capturing system that allows for geometric measurements.

Figure 5: Instances of modular camera (left) (Micusik and Kosecka, 2009) and omni-directional camera (right) (Gluckman and et. al, 1998)

Table 1: Some of various stereo panorama technologies and their related researchers

Stereo panorama technology	Developer/s	Year
Obtaining two panoramas from adjacent camera stations	Varshosaz and Amini	2007
Using a single camera	Peleg and Ben-Ezra	1999
Extending using a single camera	Tzavidas and Katsaggelos	2005
Using two normal cameras	Huang and Hung	1997
	Gledhill et al.	2003
	Jiang et al.	2006
	Varshosaz and Amini	2007
	Lin et al.	2008
	Qu et al.	2010
Using linear array cameras	Benosman et al,	1996 1998
	Li et al.	2008
Using cameras with fish-eye lenses	Hall and Cao	1986
	Hua et al.	2008
Using omni-oirectional cameras	Goshtasby	1993
	Arnspang et al.	1995
	Carbel et al.	2008
	Boa et al.	2011
	Sung and Lu	2012
Using modular cameras	Kawanishi et al.	1998

Figure 6: A complete 360 degree test-field (Amiri Parian, 2007)

Figure 7: Two sequence images before (left) and after (right) radiometric correction (Gledhill, 2009)

2.2. System Calibration

To calibrate a stereo panorama image capturing unit, the internal and external parameters of all the cameras need to be defined (Gledhill, 2009). The calibration has the most important effect on the visual and geometrical quality of the result. This is especially true when either a rotating camera or a set of cameras are used to develop the stereo panorama. Fryer (1996), Pontinen (2002) and Amiri Parian (2007), Amiri Parian and Gruen (2004, 2010) have worked in this area. Taking into account the small movements and vibrations of the rotating cameras, Amiri Parian developed a new calibration model for the camera. He used a 360 degree test field that was made of targets fixed to the walls of a room (Figure 6). In systems where the position of cameras is fixed, the relative orientation of the cameras can be used an important data to link the images to produce the stereo panorama.

3. Production of a Seamless Stereo Panorama

This includes a number of steps including preprocessing, stereo panorama production, registration and geo-referencing. Once the images are taken their noise needs to be removed by applying some radiometric and geometric methods. The resulting images are then stitched together and complete stereo panorama is formed which enables the measurements in a local coordinate system. In order to obtain ground coordinates, the stereo panoramas produced at different stations need to be registered to each other and geo-referenced to the ground coordinate system.

Research conducted in each of the above steps is reviewed in the following sections.

3.1. Preprocessing

This includes radiometric and geometric corrections as well as noise reduction to prepare images series for stitching. As the captured images may have different tones, the stereo matching could well face problems. Gledhill (2009) compared a number radiometric transformation between homologous pixels including diagonal matrices, linear transformation and combination of each by an affine transformation. The results showed that linear transformation give better results. However, they are slower compared to diagonal matrices. In addition, adding an affine to the models, increases the accuracy, but reduces the speed of process. Therefore, selection of a suitable technique for radiometric corrections depends on the required speed and accuracy (Gledhill, 2004). Figure 7 shows two stitched images before (left) and after (right) radiometric correction. Geometric corrections are carried out to count for displacements due to perspective effects, system vibrations and so on Pontinen (2002), Amiri Parian (2007) and Griessbach et al., (2004) have worked in this area. For instance, Amiri Parian defined formulas containing additional parameters to reduce vibrations in his system that occurred due to rotation. Griessbach, too, used a Global Positioning System (GPS) and an Inertial Measurement Unit (IMU) to reduce displacement on images taken with a linear array camera mounted on a vehicle.

Figure 8 shows a distorted image and the corresponding image corrected for geometric errors.

3.2 Production of the Stereo Panorama

Development of the stereo panorama includes two important phases which are the production of single panoramas and then the registration of the adjacent panoramas. Research conduction in both areas is reviewed in the following lines: Production of single panoramas: To produce a single panorama there are mainly four steps to be considered (Gledhill, 2009):

1. Selection of features on individual images: these features need to be invariant with respect to scale and rotation. Corners and junctions are among proper examples of such.
2. Matching of homologous points in adjacent images
3. Definition of a proper transformation algorithm
4. Resampling and stitching the images: once the images are resampled, some gaps are created in the images due to the change in scale and rotation which need to be overcome using a suitable refining algorithm. A common technique used is to fill in the gaps by interpolation (Gledhill, 2009). Figure 9 shows these steps.

Stereo matching: By far, there have been numerous algorithms developed to define how matching between overlapping images is to be done. For instance Bao and Xu (1999), Kim et al., (2000), Mann and Picard (1994), Kourogi et al., (1999) and Zhu.et al., (1999) developed algorithms to stitch panorama images while Trucco and Verri (1998), Zhang (2001), Super and Klarquish (1997), Borga and Knutsson (1999) and Luong and Faugeras (1996) studied the role of epipolar lines in improving the quality and speed of stereo matching. Today, these techniques are mainly grouped into Area-Based and Feature-Based (Gledhill, 2009). A hybrid technique that could overcome the dependence on scale and orientation was developed by Lowe (1999, 2004) and is named SIFT (Scale Invariant Feature Transform). Min et al., (2012) used SIFT algorithm in matching procedure of consequence panoramas. Surf (Speeded-Up Robust Features) is another useful robust local feature detector algorithm for matching developed by Bay et al., (2008). It should be noted that Ransac (Random Sample Consensus) algorithm proposed by Fischler and Bolles (1981) is a good method to remove inappropriate matched points. It is an iterative method to estimate parameters of a mathematical model from a set of observed data which contains outliers. Wang offered a feature-based algorithm that incorporated techniques developed by Lucas and Kanade (1981) and Shi and Tomasi (1994) in order to carry out matching between images taken on the move. Remondino and Borlin (2004) proposed transformations used in between images taken with a rotating data acquisition unit. He added a few additional parameters to a polynomial to model systematic distortions of the images. This technique allowed for defining the relation between homologous points in consequent images without the need to any 3D information of the area.

Figure 8: Original image (left) and motion corrected image (right) (Griessbach, 2004)

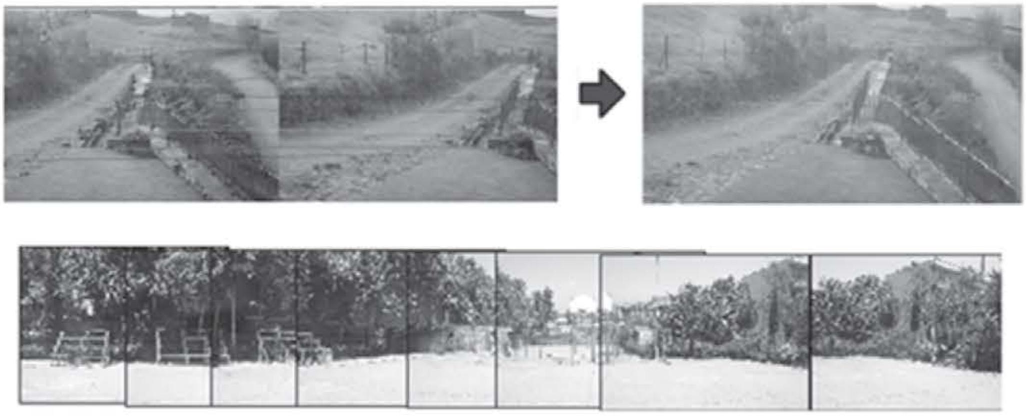

Figure 9: Steps of producing a single panorama (Gledhill, 2009)

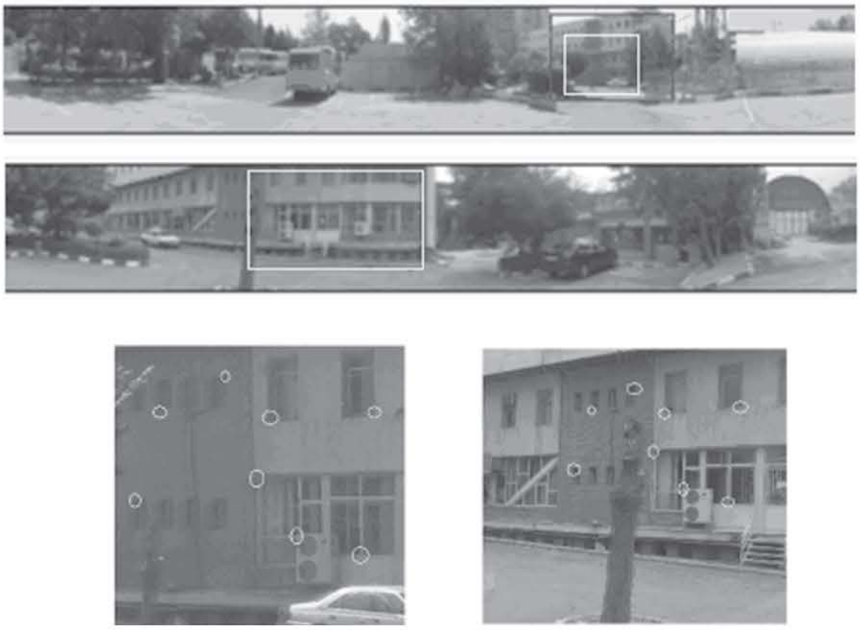

Figure 10: Registration between two stereo panoramas using common points (Amini, 2011)

3.3 Registration between Single Stereo-Panoramas

The next step in the formation of a complete stereo panorama is the registration between stereo panoramas, which (as shown in figure 10) need to be done from the geometry as well as the color point of views (Remondino and Borlin, 2004). It should be noted that the registration of stereo panoramas is much more complex than that of single images. In addition to moving objects, the difference between viewing angle, object scales and the radiometric effects are among major problems which make the registration a challenging task. Zitora (2003) investigated completely on various registration methods and compared them. One of the most common methods of registration between two or three-dimensional spaces and is widely applied in registration of panoramic images named ICP (Invariant Closest Points) presented by Besl and McKay (1992). The method handles the full six degrees of freedom and is based on the iteration which requires a procedure to find the closest point on a geometric entity to a given point. The ICP algorithm converges monotonically to the nearest local minimum of a mean square distance metric. Liang et al., (2012) proposed a new technique to register panorama images.

In his method, appropriate features are detected using Surf algorithm. Afterwards, matching process is done using nearest-neighbor method. Finally, Ransac is applied to remove inappropriate matched points. Kawasaki et al., (2000) used building edges to register images taken with an omni-directional camera. Akbarzadeh (2006) developed a viewpoint-based method applied to depth maps to register the images taken with a system made of four cameras mounted on a car. Shunyi et al., (2008) used a three dimensional conformal transformation to register adjacent point clouds in local coordinate systems. Aliaga and Carlbom (2001) tried to connect adjacent three dimensional models, but failed to do so and could only develop a visual product.

3.4 Geo-Referencing

In order to be able to make ground measurements in a stereo panorama, the relation between its coordinate system and that of the ground must be established. The coordinate systems involved in this process are image, cylindrical and ground coordinate systems (Luhmann and Tecklenburg, 2004)). Geo-referencing can be done either indirectly using ground control points or directly using a combination of a Global Positioning System (GPS) and an Inertial Navigation System (INS). Haggren et al., (2004) used control points to geo-reference panorama images. The accuracy of this technique is dependent on the accuracy and the distribution of the control and tie points. Some like Micusik and Kosecka (2009), Havlena (2007) and Clipp et al., (2008) are among those who used the GPS/INS combination. In contrast to ease of use, systems of such suffer from having low accuracy in real-time on the road applications. In addition the connection between a GPS and its satellites is frequently lost, especially in narrow alleys.

4. 3D Measurements

Once the stereo panorama is formed, it can be used for both visual and geometrical applications. The visualization of a stereo panorama can be done using a number of techniques the most common of which is the Anaglyph Stereo viewing method due to its simple algorithm and low cost. Szeliski and Shum (1997) and Lee et al., (1999) studied the rendering process of panoramic models. In addition to visualization, the ability to measure points on the resulting stereo panorama is an important issue which is favored by most applications which require geometrical measurements. Once registered to the ground coordinate system, the stereo panorama can be used as an intermediate media to measure distances and define the coordinate of objects on the ground. This can greatly improve the ability of map completion and reduce the time required to do so in this area.

5. Conclusions

Stereo panorama is a new tool which offers rich visual information of 3D environments especially in urban areas. Some important applications of such technologies can be named as 3D environment reconstruction, city modeling, control and robotics, map completion and visualization, generation of intelligent decision support systems, games and navigation. This paper reviewed the state of the art in the development of stereo panoramas used for visualization and making measurements in urban areas. As stated, the main stages of forming a stereo panorama with the capability of making 3D geometric measurements are image acquisition, stereo panorama production, registration, visualization, and coordinate measurements. The image acquisition stage includes selection of the hardware and the system calibration while the model formation deals with the radiometric and geometric corrections, image stitching to form single stereo panoramas at individual stations followed by a registration process to form an integrated stereo panorama covering the whole area of interest. The visualization and measurement provides an environment whereby a user can visualize the model and make accurate measurements. Having reviewed the research conducted in all of the above, it was observed that the availability of an image acquisition unit which could deal with moving the vehicle, moving objects in city areas, covering whole 360 degree of environment simultaneously, automatic reconstruction, and stereo visualization is a vital part that needs attention in the future research. In order to achieve geometric information of the environment, it is necessary to geo-referencing the stereo panorama model. On-line geo-referencing of the stero panorama system can improve and prompt 3D environment reconstruction. Future research can be performed about combining of the stereo panorama system and GPS/INS system for on-line geo-referencing and the calibration of such combined system. Another challenging area is the registration between single stereo panoramas which are captured in various stations. In order to cover a large area completely, it needs many stereo panorama acquisition stations. As these models are different in scale, viewing angle and contrast, registration between these models cannot be performed easily. Consequently, this issue can be considered as an important future research subject.

References

Akbarzadeh, A., 2006, Towards Urban 3D Reconstruction from Video. *Third International Symposium on 3D Data Processing, Visualization and Transmission, Chapel Hill.*

Aliaga, D. and Carlbom, I., 2001, Plenoptic Stitching: a Scalable Method for Reconstructing 3D Interactive Walkthroughs. *28th Annual Conference on Computer Graphics and Interactive Techniques, Los Angeles,* 443–450.

Amini, A. Sh., 2011, Development of a New Stereo Panorama System for Environmental Geometric Reconstruction. *PhD Proposal Thesis, K. N. Toosi University of Tehran, Iran.*

Amiri Parian, J., 2007, Sensor Modeling, Calibration and Point Positioning with Terrestrial Panoramic Cameras. *PhD Thesis for the degree of Doctor of Sciences, Swiss Federal Institute of Technology (ETH) Zurich.*

Amiri Parian, J. and Gruen, A., 2004, A Refined Sensor Model for Panoramic Cameras. *ISPRS Workshop, Germany.*

Amiri Parian, J. and Gruen, A., 2010, Sensor Modeling, Self-Calibration and Accuracy Testing of Panoramic Cameras and Laser Scanners. *ISPRS Journal of Photogrammetry and Remote Sensing,* 65, 60-76.

Arnspang, J., Nielsen, H., Chritensen, M. and Henriksen, K., 1995, Using Mirror Cameras for Estimating Depth. *6th Conference on Computer Analysis of Images and Patterns, Springer Heidelberg,* 711–716.

Ayache, N. and Faugeras, O. D., 1989, Maintaining Representation of the Environment of a Mobile Robot. *IEEE Transactions on Robotics and Automation*, 5, 804–819.

Bao, P. and Xu, D., 1999, Complex Wavelet-Based Image Mosaics using Edge Preserving Visual *Perception Modeling. Computers and Graphics,* 23, 309–321.

Bay, H., Ess, A., Tuytelaars, T. and Van Gool, L., 2008, Speeded-Up Robust Features (SURF). *Computer Vision and Image Understanding,* 110, 346:359.

Benosman, R., Maniere, T. and Devars, J., 1996, Multidirectional Stereovision Sensor, Calibration and Scenes Reconstruction. *13th Internatinoal IEEE Conference on Pattern Recognition, Austria,* 161-165.

Benosman, R., Maniere, T, and Devars, J., 1998, Panoramic Stereovision Sensor. *14th International IEEE Conference on Pattern Recognition, Australia,* 767-769.

Besl, P. J. and McKay, H. D., 1992, A Method for Registration of 3D Shapes. *Pattern Analysis and Machine Intelligence,* 14(2), 239-256.

Bo, Z., Haitao, X., Lulu, L., Jun, J., Jianyue, Z. and Yiping, T., 2011, Development of Coordinate-machine of the Scene of Road Traffic Accident based on Binocular Stereo Omni-Directional Vision Sensors. *Procedia Engineering,* 24, 262 – 266.

Borga, M. and Knutsson, H., 1999, Estimating Multiple Depths in Semi-transparent Stereo Images. *Proceedings of the 11th Scandinavian Conference on Image Analysis.*

Cabral, E. L. L., Oliveira, P. R. G. and Junior, J. C. S., 2008, An Omnidirectional Stereo Vision System. *ABCM Symposium Series in Mechatronics,* 643-652.

Chen, S. E., 1995, QuickTime VR – An Image-Based Approach to Virtual Environment Navigation. *22nd Annual Conference on Computer Graphics and Interactive Techniques, SIGGRAPH 95,* 29-38.

Clipp, B., Raguram, R., Frahm, J. M., Welch, G. and Pollefeys, M., 2008, A Mobile 3D City Reconstruction System. *IEEE VR Workshop on Cityscapes.*

Cobez, D., and Zhang, H., 2001, Mobile Robot Localization using Planar Patches and a Stereo Panoramic Model. *Vision Interface,* 94-99.

Fischler, M. A. and Bolles, R. C., 1981, Random Sample Consensus: A Paradigm for Model Fitting with Applications to Image Analysis and Automated Cartography. *Communications of the ACM,* 24(6), 381–395.

Fryer, J. G., 1996, Single Station Self-calibration Techniques. *ISPRS Conference of Photogrammetry and Remote Sensing,* 178-181.

Gledhill, D., 2009, 3D Panoramic Imaging for Virtual Environment Construction. *PhD Thesis for the degree of Doctor of Philosophy, School of Computing and Engineering, the University of Huddersfield.*

Gledhill, D., Tian, G. Y., Taylor, D. and Clarke, D., 2003, Panoramic Imaging—a Review, *Computers & Graphics,* 27, 3435-3445.

Gledhill, D., 2004, Tian, G. Y., Taylor, D. and Clarke, D., 3D Reconstruction of a Region of Interest using Structured Light and Stereo Panoramic Image. *IEEE Eighth International*

Conference on Information Visualization, 1007-1012.

Goshtasby, A., 1993, Grover W. Design of a Single-Lens Stereo Camera System. *Pattern Recognition,* 26, 923–937.

Griessbach, D., Borner, A., Scheele, M., Scheibe, K. and Sujew, S., 2004, Line Scanner in Combination with Inertial Measurement Unit. *ISPRS Workshop, Germany.*

Haggren, H., Hyyppa, H., Jokinen, O., Kukko, A., Naikka, M., Pitkanen, T., Pontinen, P. and Ronnholm, P., 2004, Photogrammetric Application of Spherical Imaging. *ISPRS Workshop, Germany.*

Hall, Z. and Cao, E. L., 1986, Omnidirectional Viewing Using a Fisheye Lens. *SPIE Optics, Illumination, and Image Sensing for Machine Vision,* 728, 250–256.

Havlena, M., 2007, Automated City Modeling from Omnidirectional Image Sequences. *PhD Proposal Thesis, Czech Technical University.*

Hua, S., Huanga, Q., Zhang, A. and Qiaoa, J., 2008, 3D Measurement, Reconstruction and Navigation through Panoramic Photography. *International Conference of Photogrammetry, Remote Sensing and Spatial Information Sciences,* China.

Huang, H. C. and Hung, P., 1997, SPISY: The Stereo Panoramic Imaging System. *Third Workshop on Real-Time and Media Systems, Taiwan,* 71-78.

Jiang, W., Okutomi, M. and Sugimoto, S., 2006, Panoramic 3D Reconstruction using Rotational Stereo Camera with Simple Epipolar Constraints. *IEEE Computer Society Conference on Computer Vision and Pattern Recognition,* 371–378.

Kawanishi, T., Yamazawa, K., Iwasa, H., Takemura, H. and Okoya, N., 1998, Generation of High-Resolution Stereo Panoramic Images by Omnidirectional Sensor Using Hexagonal Pyramidal Mirrors. *14th International Conference of Pattern Recognition,* 485-489.

Kawasaki, H., Ikeuchi, K. and Sakauchi, M., 2000, Automatic 3D City Reconstruction using Omni Camera. *IEEE International conference on Multimedia and Expo, USA,* 1653-1656.

Kim, H. S., Kim, C. H., and Lee, W. K., 2000, Stitching Reliability for Estimating Camera Focal Length in Panoramic Image Mosaicing. *15th International Conference on Pattern Recognition,* 596–599.

Kourogi, M., Kurata, T., Hoshino, J. and Muraoka, Y., 1999, Real-time Image Mosaicing From a Video Sequence. *IEEE International Conference on Image Processing,* 133–137.

Lee, K., Fung, Y., Wong, K., Or, S. and Lao, T., 1999, Panoramic Video Representation using Mosaic Image. *International Conference on Imaging Science, Systems, and Technology (CISST),* 390-396.

Li, R., Yan, L., Di, K. and Wu, B., 2008, A New Ground-Based Stereo Panoramic System. *ISPRS Congress, China.*

Liang, Y., Li, Q., Lin, Z. and Chen, D., 2012, A Panoramic Image Registration Algorithm Based on Surf. *Springer Publishing.*

Lin, T. T., Hsiung, Y. K., Hong, G. L., Chang, H. K. and Lu, F. M., 2008, Development of a Virtual Reality GIS Using Stereo Vision. *Computers and Electronics in Agriculture,* 63, 38–48.

Lippman A., 1980, Movie-Maps: An Application of the Optical Videodisc to Computer Graphics. *ACM SIGGRAPH Computer Graphics,* 14, 32-42.

Lowe, D. G., 1999, Object Recognition from Local Scale-Invariant Features. *Proceedings of the International Conference on Computer Vision,* 1150–1157.

Lowe, D. G., 2004, Distinctive Image Features from Scale-Invariant Keypoints. *Computer Vision,* 60, 91–110.

Lucas, B. D. and Kanade, T., 1981, an Iterative Image Registration Technique with an Application to Stereo Vision. *In Proceedings of IJCAI,* 674-679.

Luhmann, T. and Tecklenburg, W., 2004, 3D Object Reconstruction from Multiple-Station Panorama Imagery, *ISPRS Workshop, Germany.*

Luong, Q. T. and Faugeras, O. D., 1996, The Fundamental Matrix: Theory Algorithms and Stability Analysis. *Computer Vision,* 17, 43–75.

Mann, S. and Picard, R. W., 1994, Virtual Bellows: Constructing High Quality Stills from Video. *IEEE International Conference of Image Processing,* 363-367.

Micusik, B. and Kosecka, J., 2009, Piecewise Planar City 3D Modeling from Street View Panoramic Sequences. *IEEE Conference on Computer Vision and Pattern Recognition, Miami,* 2906-2912.

Min, Z., Jiguo, Z. and Xusheng, X., 2012, Panorama Stitching Based on SIFT Algorithm and Levenberg-Marquardt Optimization. *Physics Procedia,* 33, 811–818.

Moravec, H. P., 1993, The Stanford Cart and the CMU Rover. *IEEE Proceedings,* 71, 872 – 884.

Peleg, S., and Ben-Ezra, M., 1999, Stereo Panorama with a Single Camera. *IEEE Conference on Computer Vision and Pattern Recognition,* 395-401.

Pontinen, P., 2002, Camera Calibration by Rotation. *ISPRS Conference of Photogrammetry and Remote Sensing,* 585-589.

Qu, Y., Khoo, W.L., Molina, E. and Zhigang, Z., 2010, Multomodal 3D Panoramic Imaging using a Precise Rotating Platform. *IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM),* 260-265.

Remondino, F. and Borlin, N., 2004, Photogrammetric Calibration of Image Sequences Acquired with a Rotation Camera. *ISPRS Workshop, Germany.*

Shi, J. and Tomasi, C., 1994, Good Features to Track. *IEEE Conference on Computer Vision and Pattern Recognition (CVPR'94),* 593-600.

Shimamura, J., Takemura, H., Yokoy, N. and Yamazawa, K., 2000, Construction and Presentation of a Virtual Environment Using Panoramic Stereo Images of a Real Scene and Computer Graphics Models. *IEEE International Conference on Pattern Recognition*, 4463.

Shunyi, Z., Ruirui, W., Changjun, C. and Zuxun, Z., 2008, 3D Measurement and Modeling Base on Stereo Camera. *ISPRS Congress, China.*

Sung, C. K. and Lu, C. H., 2012, Single-Camera Panoramic Stereo Model Based on Skew Ray Tracing. *Optic*, 123, 594-603.

Super, B.J. and Klarquish, W. N., 1997, Patch-based Stereo in a General Binocular Viewing Geometry. *Pattern Analysis and Machine Vision,* 19, 247–253.

Szeliski, R. and Shum, H., 1997, Creating Full View Panoramic Image Mosaics and Environment Maps. *International Conference on Computer Graphics and Interactive Techniques,* 251–258.

Trucco, E. and Verri, A., 1998, *Introductory Techniques for 3D Computer Vision,* (Prentice Hall Publishing).

Tzavidas, S., and Katsaggelos, A. K., 2005, A Multicamera Setup for Generating Stereo Panoramic Video. *IEEE Transactions on Multimedia,* 7, 880-90.

Varshosaz, M. and Amini, A. Sh., 2007, Stereo Panoramas: Problems and Solutions. *XXI International CIPA Symposium, Athens.*

Zhang, L., 2001, Hierarchical Block-Based Disparity Estimation Using Mean Absolute Difference and Dynamic Programming. *VLBV01: International Workshop on Very Low Bitrate Video Coding,* 114–118.

Zhu, Z., Hanson, A. R., Schultz, H., Stolle, F. and Riseman, E. M., 1999, Stereo Mosaics from a Moving Video Camera for Environmental Monitoring. *First International Workshop on Digital and Computational Video*, 45–54.

Zitora, B. and Flusser, J., 2003, Image Registration Methods: A Survey. *Image and Vision Computing,* 21, 997-1000.