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Assessment of Low-Cost Digital Camera with Fisheye Lens in Close-Range Photogrammetry for Indoor Building Dimensional Measurement

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Abstract: This paper examines the potential of using Samsung Gear 360, a low-cost consumer-grade spherical camera for indoor building dimensional measurement. The aims and objectives of this experiment are to assess the metric precision and accuracy level of detail that can be achieved from the Samsung Gear 360's fisheye lens coupled with digital modeling techniques based on close-range photogrammetry algorithms. Initial results indicated that the metric accuracy was relatively low while using the projection created directly from the mobile phone or even using the Gear 360 Action Direction desktop software for post-processing. To address this discrepancy, this paper proposed an alternative solution that was devised, involving the generation of equirectangular projections to resolve the inconsistency of accuracy caused by the original fisheye photos. For this, a calibration process was performed to gain insights into the intrinsic parameters of the two lenses of the camera and their relative orientation. As a result, new equirectangular projections were produced, leading to a significant enhancement in geometric accuracy. In conclusion, the study has demonstrated that the close-range photogrammetric technique with low-cost consumer-grade digital cameras has the potential for indoor building dimension measurement from spherical photographic panoramas to support strata surveying tasks in cadastral.

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Close-Range Photogrammetry, Fisheye Lens, 3D Dimensional Measurement, Low-Cost Digital Camera

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1. Introduction

Fisheye camera models for photogrammetric applications were extensively studied, tested, and validated in the first decade of the 2000s. Calibration procedures were presented by Abraham and Förstner (2005), Schwalbe (2005), Van den Heuvel (2006), and Schneider (2009), among others. Fisheye lenses allow users to capture a wide region of your surrounding space up to 180° in a single photo. They make it feasible to realize photos at very short distances, which may be very valuable in some engineering elaboration aspects.

The photogrammetric measurements of the interior of buildings, vaults, etc. often pose a problem. When the camera and the object are close together, more photographs or models are needed. The photogrammetric method can thus be ineffective. This problem can be overcome extensively by using fisheye lenses. The extreme angle of view in fisheye objectives usually covers the whole object. However, in contrast to the advantage gained through the utilization of the fisheye lens, there is a loss of the central perspective projection. Projection equations have to be determined as a result of this. A suitable method for assessing the calibration above all for the outer edges of the photograph has yet to be found.

The usage of fisheye lenses in photogrammetry is only worthwhile when used incorporation with analytical methods. Analog projection cannot be considered due to the extremely distorted values in the photographs. The paper investigates the use of the Samsung Gear 360 spherical camera for 3D documentation and the rapid identification of a room scene.

The aims and objectives of the research are:

(i) to study the performance and capability of digital camera with a fisheye lens in close-range photogrammetry for indoor building dimensional measurement and
(ii) to analyze the accuracy of indoor building 3D dimensional measurement between close-range photogrammetry and construction design drawing.

After a review of recent works of fisheye 3d indoor building documentation in Section 2, the project is introduced in Section 3, where the case study and the acquired data are described. An overview of the methodology applied for 3D geometry reconstruction and registration of process data is also given in Section 3, whereas results are analyzed in Section 4. Finally, a discussion and some concluding remarks are drawn in Section 5.

2. Literature

Digital panoramic cameras have found a growing interest in photogrammetry in the past few years. Originally primarily used for purposes such as web-based animation or surveillance, panoramic cameras have meanwhile reached a performance, which makes them an interesting data acquisition tool for verious applications in photogrammetry. New developments in sensor technology have enabled the acquisition of very high-resolution 360° panoramic images with an image format of up to almost one Gigapixel. Advances in display technology and computer graphics allow us to visualize images of this size dynamically. Especially for recording indoor scenes, the use of panoramic cameras has proven to be beneficial.

In order to use digital panoramic imaging devices for 3D measurement and object reconstruction, photogrammetrists have taken on the work of geometric modeling and calibration of those systems. Digital 360° panoramic photos have been produced using a variety of technologies:

1. Rotating linear array
2. Image stitching
3. Fisheye lens
4. Hyperbolic mirror
5. Multi-sensor systems

The biggest challenge with employing fisheye lenses is the increased likelihood of receiving inaccurate, subpar, and variable results. The inability to effectively manage the variables that can render the photogrammetry method useless appears to be the biggest disadvantage. When using the same consolidated pipeline made for rectilinear projection lenses with fisheyes, this can occur. Failure in the photogrammetric process could result from just thinking of them as wider FOV (Field of View) lenses. Understanding the distinctions between the various optical projections is crucial since a fisheye lens is not a rectilinear lens.

A lens is not a fisheye just because it has a very wide FOV and a short focal length. The distinction is created by the unique relationship between focal length and field of view. The relationship between the two variables, which make up the optical function, determines the lens's characteristics. Each optical function has a unique relationship between field of view and focal length. For each accessible optical projection, a different FOV can be matched to the same focal length. The primary benefit of fisheye lenses is that, for a given focal length, they cause the incoming light beam to concentrate on a sensor circumference with a smaller radius than a rectilinear lens would.

The following are the primary categories of optical projections (Ray, 2002) (Kannala, 2006) that are available:

1. Rectilinear:
$$r = f \times \tan\theta \quad (1)$$

2. Equidistant:
$$r = f \times \theta \quad (2)$$

3. Equisolid:
$$r = 2f \times \sin\frac{\theta}{2} \quad (3)$$

4. Stereographic:
$$r = 2f \times \tan\frac{\theta}{2} \quad (4)$$

5. Orthographic:
$$r = f \times \sin\theta \quad (5)$$

Where
r = distance from the centre of the sensor
f = focal length
θ = angle of incidence of the light beams

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3. Methodology

This chapter covers the methods of work planning for producing 3D dimensional measurements for indoor building structures. The research methodology includes four steps:

1. Work Planning
2. Data acquisition
3. Processing

3.1 Work Planning

3.1.1 Study Area

The chosen area for this research is Officer Room, Wisma Tian Lock, District Survey Office Muar, Johor. Approximate 192 square feet (12 x 16 feet).

3.1.2 Non-metric Camera Samsung Gear 360

The Samsung Gear 360 Digital dual Fisheye Lens camera (Fig. 1) was used for data acquisition onto the indoor building structure at the site. This camera is known as a non-metric camera. The Samsung Gear 360 is the first 360-degree camera by Samsung Electronics.

The Samsung Gear 360 is a consumer-grade spherical camera able to capture photos and videos. The ultimate aim of this study is to assess the metric precision and achievable accuracy level of detail with the Samsung Gear 360 coupled with digital modeling approaches based on close-range photogrammetry and computer vision algorithms.

Fig. 1. - Camera Samsung Gear 360

3.1.3 Plan Layout during Construction Stage

For dimensional measurement comparison purposed, this study will use plan layout drawing during construction stage for the building structure as show at Fig. 2.

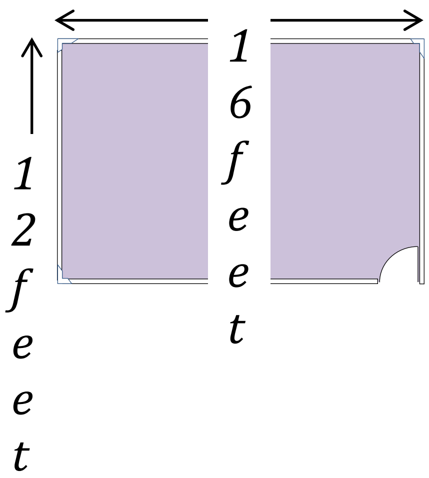

Fig. 2. - Layout drawing - Building Structure

3.1.4 Coded Target

PhotoScan Pro software supports the automatic detection of 12-, 16- and 20-bit coded targets. Cross and circle as well as non-coded targets can be used, although non-coded target detection is only possible after the camera has been aligned. Flat targets with no deformations should be used for coding. After printing the coded targets, arrange them in the scene or close to the object of interest such that they may be seen clearly in at least a few pictures.

Fig. 3 - Coded targets 12 bits

3.2 Data acquisition

With the Samsung Gear 360 camera, photograph was taken either horizontally, vertically or at some inclination using digital camera mentioned for the project. External controls are kept as simple as possible such as number of distances and the levelness of the camera. For easily doing the referencing process during process the image, marking sticker were installed at several locations at the surface of building structure.

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3.3 Data Processing

For data processing, the image data will process using Agisoft PhotoScan Pro software and Gear 360 ActionDirector. All the photos captured were further processed prior to the process of equirectangular projection (Software Gear 360 ActionDirector, Fig.4 & Fig.5). The steps of processing image involved marking the matching point between image (Fig.6, Fig.7 and Fig.8), referencing process, scaling process and rotation. For scaling process, the distance from point A to point B, where measured by total station, will be use as a scaling factor for the 3D model of bridge. After that, the 3D model generated can be edit to show the dimensional measurement for comparison purposed.

Fig. 4 - Gear 360 dual-fisheye output image (7776 x 3888 pixels). Left half: image taken by the front lens. Right half: image taken by the rear lens

Fig. 5 - The Samsung Gear 360 and its two circular images (top) turned into a single equirectangular projection (Gear360 ActionDirector)

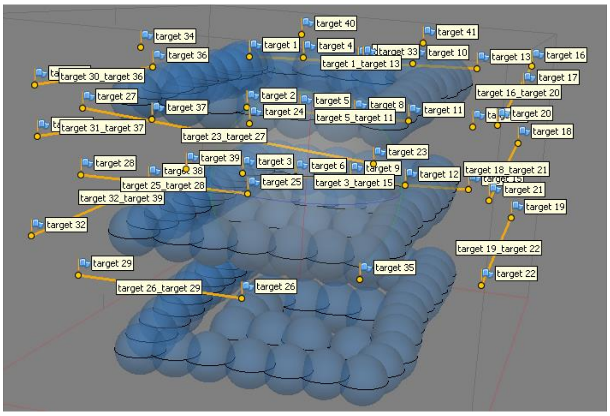

Fig.6 - All target markers in the object space

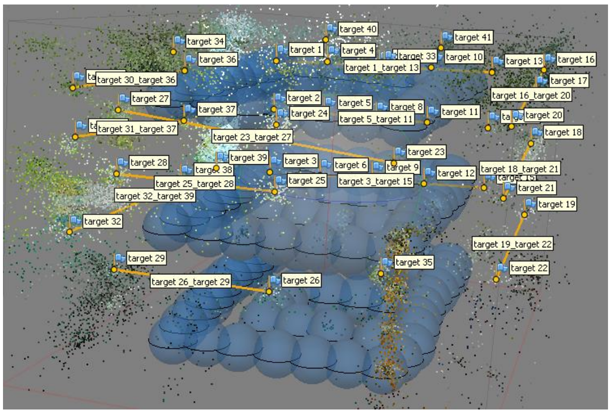

Fig.7 - 3D point coordinates of the tie points in the object space

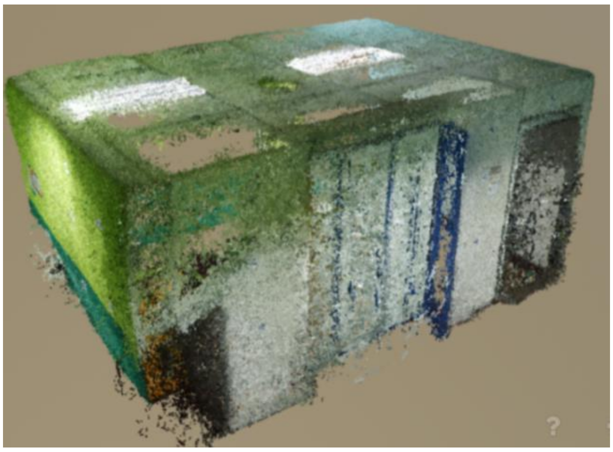

Fig.8 - Dense point cloud in the object space

4. Result And Analysis

One hundred twenty-six images were collected and used for the 3D modeling of the room using Agisoft PhotoScan Pro software. The CRP images were matched using 41 artificial black and white targets located on different parts of the room, such as wood edges and dots marking on the building materials, which were used for the accuracy assessment. However, in order to create a geo-registered 3D model, coordinates obtained from the Leica Smart-Station for twelve artificial targets were used during the image control point registration process.

4.1 CRP Control Points Results

A relative orientation was first applied and then followed by the absolute orientation using 12 GCP and keeping the other four as checkpoints. The GCP target points were marked manually on the corresponding images which was probably a source of pointing error. The RMS errors using the CRP technique of the control points are listed in Table 1 below:

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Table 1 - Control points RMSE

Label	X error (cm)	Y error (cm)	Z error (cm)	Total (cm)
Target 5	0.8549	1.6598	4.0658	4.4740
Target 11	0.9064	2.9366	1.9657	3.6482
Target 18	4.4449	2.4991	2.8704	5.8517
Target 21	5.5217	0.0234	3.0131	6.2904
Target 25	1.2079	0.7595	0.2103	1.4423
Target 28	0.3935	1.8969	0.6792	2.0529
Target 31	6.6586	0.0517	3.2263	7.3993
Target 33	2.5384	1.1391	0.4668	2.8212
Target 34	1.5133	0.9238	1.8514	2.5635
Target 37	5.8379	0.7636	4.0411	7.1411
Target 40	1.1474	1.1466	0.7755	1.7980
Target 41	0.9980	0.3904	1.0041	1.4685
Total	**3.4506**	**1.4720**	**2.4189**	**4.4637**

The minimum RMSE of all the points is 0.000 m where the maximum RMSE reaches up to 0.067 m, resulting in an overall RMSE of 0.045 m.

4.2 CRP Check Points Results

Table 2 - Check points RMS

Label	X error (cm)	Y error (cm)	Z error (cm)	Total (cm)
Target 1	0.3940	0.6658	2.1627	2.2969
Target 2	0.4456	1.5985	3.8111	4.1567
Target 3	0.9411	2.8020	1.351	3.2500
Target 4	0.2789	0.5770	2.2875	2.3756
Target 6	0.7912	2.6004	0.7590	2.8221
Target 7	0.6606	0.6547	2.1191	2.3143
Target 8	0.1376	2.2636	4.8022	5.3107
Target 9	0.6164	3.9608	0.8953	4.1073
Target 10	1.4520	1.8353	2.5766	3.4808
Target 12	0.9301	4.6188	1.4163	4.9198
Target 13	1.1632	3.2935	4.0867	5.3760
Target 14	0.1648	3.8429	1.2190	4.0350
Target 15	1.8214	5.5564	2.1002	6.2131
Target 16	3.2288	2.2759	3.6273	5.3631
Target 17	4.7812	1.5371	1.6967	5.3011
Target 19	3.6989	3.5027	0.04684	5.0945
Target 20	4.7662	1.0600	0.1979	4.8867
Target 22	5.5753	0.8727	2.1630	6.0436
Target 23	2.8113	2.4635	1.7704	4.1360
Target 24	1.3159	0.7713	2.9937	3.3599
Target 26	1.5099	0.1581	4.3263	4.5850
Target 27	0.2242	2.0643	2.6021	3.3290
Target 29	0.7442	1.1508	3.4301	3.6937
Target 30	3.7626	1.6860	1.3471	4.3376
Target 32	3.6173	0.1875	1.4809	3.9132
Target 35	2.0049	2.5416	3.5775	4.8247
Target 36	4.4328	2.5123	0.1528	5.0976
Target 38	3.9329	0.3367	0.0660	3.9479
Target 39	3.6061	0.4719	0.7686	3.7172
Total	**2.6465**	**2.4235**	**2.4492**	**4.3447**

Results also show that the minimum errors of X, Y and Z are 0.001 m , 0.002 m, and 0.000 m, respectively; while the maximum error reaches 0.056 m, 0.056 m, and 0.048 m in the X, Y, Z directions.The minimum RMSE of all the points is 0.000 m where the maximum RMSE reaches up to 0.056 m, resulting in an overall RMSE of 0.043 m.

5. Conclusions

The close-range photogrammetric technique is expected the best method to replace the conventional technique survey for building dimensional measurement. This research has presented a close-range photogrammetric method for the semi-automatic extraction of 3D measurements from spherical photographic panoramas.

The technique can be both practical and economically feasible for dimensional measurement tasks. The development both of method and software approaches to implementing such applications is necessary to investigate the reduction of start-up costs, operating costs and equipment costs.

This work investigated the use of a low-cost imaging sensor, the Samsung Gear 360 spherical camera, combined with the adoption of algorithms for image pre-processing, photogrammetric 3D reconstruction, data registration and analysis, all implemented in software solutions. The contribution of the paper is twofold.

First, it evaluated the performance of the tested system for the rapid 3D reconstruction of a room scenario, both qualitative analysis (i.e. visual inspection of reconstructed objects) and quantitative evaluation (i.e. best fitting plane analysis on various surfaces) showed a good potential of the method for the 3D documentation of the room. A dense 3D point cloud (mean spatial resolution in the range of 2.297 to 6.263 cm) locally characterized by limited plane fitting RMSE (always below 4.345 cm, when the pre-processing is performed) is indeed achieved.

References

[1] Atkinson, K. B. (ed) (1996). Close Range Photogrammetry And Machine Vision. Whittles Publishing. Scotland, UK.

[2] Briggs, A., Li, Y., Scharstein, D. & Wilder, M. (2006) Robot navigation using 1D panoramic images. In Proceedings of the 2006 International Conference on Robotics and Automation (ICRA

2006). 2679–2685. DOI: 10.1109/ROBOT.2006.1642106.

[3] Brown, D.C. (1984) A Large Format Microprocessor Controlled Film Camera Optimized for Industrial Photogrammetry. International Congress of Photogrammetry and Remote Sensing, Rio de Janiero

[4] Brown, D.C. (1987) Autoset, an Automated Monocomparator Optomized for Industrial Photogrammetry. International Conference and Workshop on Analytical Instrumentation, Phoenix, AZ, 2-6 November.

[5] C. Hughes, M. Glavin, and E. Jones (2011) Simple fish-eye calibration method with accuracy evaluation, Electronic Letters on Computer Vision and Image Analysis, vol.10,no.1,pp.54-62,2011.

[6] C. Hughes, P. Denny, E. Jones, and M. Glavin (2010) Accuracy of fish-eye lens models, Applied Optics, vol. 49, no. 17, pp. 3338-3347, 2010

[7] C. Hughes, P. Denny, M. Glavin, and E. Jones (2010) Equidistant Fish-eye calibration and rectification by vanishing point extraction, IEEE Transactions on Pattern Analysis and Machine Intelligence,vol. 32, no. 12, pp. 2289-2296, 2010

[8] C. Hughes, R. McFeely, P. Denny, M. Glavin, and E. Jones (2010) Equidistant Fish-eye perspective with application in dis-tortion centre estimation, Image and Vision Computing, vol.28, no.3,pp.538-551,2010.

[9] Cramer, M., Haala, N. (2009) DGPF project: Evaluation of digital photogrammetric aerial bases imaging systems-overview and results from the pilot centre. In Proceedings of the ISPRS Hannover Workshop, Hannover, Germany, June 2-5, 2009.

[10] Creagh, H. (2003) CAVE Automatic Virtual Environment. In Proceedings of the 2003 IEEE Electrical Insulation Conference and Electrical Manufacturing

[11] D. Schneider and E. Schwalbe (2008) Integrated processing of terrestrial laser scanner data and Fisheye-camera image data, in Proceedings of the 21st ISPRS Congres, pp. 1037-1044, Beijing, China, July 2008

[12] D. Schneider, E. Schwalbe, and H.-G. Maas (2009) Validation ofgeometric models for Fisheye lenses, ISPRS Journal of Photogrammetry and Remote Sensing, vol.64,no.3,pp.259-266,2009

[13] Estrela, C., Bueno, M.R., Leles, C.R., Azevedo, B. & Azevedo, J.R. (2008) Accuracy of cone beam computed tomography and panoramic and periapical radiography for detection of apical periodontitis. Journal of endodontics. 34(3):273–9. DOI: 10.1016/j.joen.2007.11.023.

[14] Faugeras, O., Benosman, R. & Kang, S.B. (2013) Panoramic vision: sensors, theory, and applications. Springer Science & Business Media.

[15] Fraser, C. S & Brown, D.C. (1986). Industrial Photogrammetry: New Developments and Recent Applications. Photogrammetry Record, 12(68): ms 197-217

[16] Fraser, C.S. (1997). Industrial Measurement Application. dlm. Atkinson. K.B. (ed). Close Range Photogrammetry and Machine Vision. Whittles Publishing, Caithness, Scotland, U.K.

[17] Fraser, C.S. (2001). Automated Digital Close Range Photogrammetry: New Development and Application. International Symposium & Exhibition on Geoinformation 2002, Kuala Lumpur. October 22-24.

[18] Fraser, C.S. (2006). Developments in Close Range Photogrammetry for 3D Modeling: The iWitness Example. International Workshop: Processing & Visualization using High-Resolution Imagery, Thailand,18-20 November.

[19] Gaspar, J., Winters, N. & Santos-Victor, J. (2000) Vision-based navigation and environmental representations with an omnidirectional camera. IEEE Transactions on Robotics and Automation. 16(6):890–898. DOI:10.1109/70.897802.

[20] Held, C. (2012) Creating 3D models of cultural heritage sites with terrestrial laser scanning and 3D imaging.

[21] Honey, O.B., Scarfe, W.C., Hilgers, M.J., Klueber, K., Silveira, A.M., Haskell, B.S. & Farman, A.G. (2007) Accuracy of cone-beam computed tomography imaging of the temporomandibular joint: Comparisons with panoramic radiology and linear tomography. American Journal of Orthodontics and Dentofacial Orthopedics. 132(4):429–438. DOI: 10.1016/j.ajodo.2005.10.032.

[22] Huang, F., Klette, R. & Scheibe, K. (2008) Panoramic Imaging: Sensor-Line Cameras and Laser Range-Finders. John Wiley & Sons.

[23] K. B. Johnson (1997) Development of a versatile wide-angle lens characterization strategy for use in the OMNIster stereo vision system [M.S. thesis], University of Tennessee, Knoxville, Tenn,USA

[24] K. Miyamoto (1964) Fish eye lens"Journal of the Optical Society of America, vol.54, no.8, pp.1060-1061

[25] Klette, R. & Scheibe, K. (2005) Combinations of range data and panoramic images - New opportunities in 3D scene modeling. In Proceedings of the Conference on Computer Graphics, Imaging and Vision: New Trends 2005. V. 2005. 3–12. DOI: 10.1109/CGIV.2005.26.

[26] Lothridge, K., 2013. A Guide for Law Enforcement, https://www.nist.gov/sites/default/files/documents/forensics/Crime-Scene-Investigation.pdf

[27] Luhmann, Th., (2004): A historical review on panorama imagery. International Archives of Photogrammetry and Remote Sensing, Vol. 34, Part 5/W16

[28] McBride, B. (1994) A Timeline of Panoramic Cameras. Available: http://www. panoramicphoto.com/timeline.htm.
[29] Morisse, D. (2012) World Wonders Project : Click to explore a World Heritage site with Google. Available: whc.unesco.org/document/122289
[30] Newton, I. & Mitchell, H. L. (1996). Medical Photogrammetry. In: Atkinson, K. B. ed. Close Range Photogrammetry and Machine Vision. Latheronwheel: Whittles Publishing. 303 –324.
[31] Oettermann, S. (1997) The Panorama: History of a Mass Medium. V. 21. Zone books New York.
[32] S. Parhizgar (2014) An evaluation of an omni-directional (fisheye)vision sensor for estimating the pose of an object [M.S. thesis],University of Regina, Master of Applied Science in Software Systems Engineering University of Regina, Saskatchewan, Canada,2014
[33] Sequeira, V. & Goncalves, J.G.M. (2002) 3D reality modelling: photorealistic 3D models of real world scenes. In Proc. First International Symposium on 3D Data Processing Visualization and Transmission. 776–783.
[34] Shoval, S., Borenstein, J. & Koren, Y. (1994) Mobile robot obstacle avoidance in a computerized travel aid for the blind. In Proceedings of the 1994 IEEE 114 International Conference on Robotics and Automation. IEEE Comput. Soc. Press. 2023–2028. DOI: 10.1109/ROBOT.1994.351166.
[35] Shuai Liu, Lingli Zhao1 and Junsheng Li (2016). Panorama Measurement Based on Spherical Projective Geometry
[36] Thibault, S. (2007) Enhanced surveillance system based on panomorph panoramic lenses. In Defense and Security Symposium. T.T. Saito, D. Lehrfeld, & M.J. DeWeert, Eds. International Society for Optics and Photonics. 65400E–65400E–8. DOI: 10.1117/12.719495.
[37] Wolf, P.R & Dewitt B. A. (2000). Elements of Photogrammetry with Applicatin in GIS (3rd Edition). McGraw-Hill, New York.
[38] Wolf, P.R. (1983). Elements of Photogrammetry. McGraw-Hill Inc. New York.
[39] Wong, W.K., Liew, J.T.Y., Loo, C.K. & Society, I.C. (2009) Omnidirectional Surveillance System for Digital Home Security. In Proceedings of the 2009 International Conference on Signal Acquisition and Processing. IEEE. 8–12. DOI: 10.1109/icsap.2009.13