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Full Length Research Paper

Evaluating a New Stereo Panorama System based on Stereo Cameras

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Abstract. Producing 3D urban models is required by most organizations. 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 offer complete viewing of the surroundings simply. There exist a number of techniques which are used to develop stereo panoramas and each structure has its own advantages and disadvantages. In this paper, a new stereo panorama system is presented which uses stereo cameras named "Stereo Panorama Modeler" that is patented. In addition to stereo viewing, other benefits of such a system are overcoming the effects of moving objects in images, increasing the automation of matching and stitching, and equal resolution on the whole stereo panorama. The paper describes the comparison between the proposed system and other stereo panorama systems. Moreover, the structure of the system, its components and applying stereo cameras in developing the stereo panorama system is studied. Finally, experiment carried out to evaluate the capability of the system in 3D city modeling. Evaluation results show that the system can produce suitable stereo panoramic models of the environment.

Keywords: Stereo Camera, Stereo Panorama, 3D Modeling,

1. INTRODUCTION

Today the development of models from city environments is of great interest. Such models can be used in different applications and disciplines including control and robotics (Cobzas and Zhang, 2001), map completion (Micusik and Kosecka, 2009) and visualization (Shimamura et al., 2000), generation of intelligent decision support systems and navigation (Lin et al., 2008). There exist a number of problems such as moving the vehicle or moving the objects and occlusions which affect the development of such models (Gledhill et al., 2007). 3D modeling techniques are either geometric or image-based (Moravec, 1990). In geometric based techniques such as tachometry and laser scanning, geometric information including distance or coordinates are directly measured, while in image-based techniques an area is modeled through images. Recently, image based techniques are most accepted due to their various benefits such as offering comparably low cost solutions and allowing the visualization of objects (Huang and Hung, 1997). As source for image based techniques, a stereo panorama is a 3D panorama which covers 360 degrees and can be used to obtain 3D models of the objects.

They are rich of visual information, thus can be produced at relatively low costs and allow a simple identification of objects (Gledhill et al., 2007). Figure 1 shows a stereo panorama. In order to develop a stereo panorama two views are required one for the left eye and the other for the right. Generally, stereo panorama generation is possible applying frame-based cameras, linear array sensors, fish-eye lenses, combination of cameras and parabolic mirrors, and modular cameras in the stereo panorama system. Depending on how these sensors are formed and combined, various methods for stereo panorama generation are obtained. 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 2). A pair of thin strips is then extracted from the rear left and right parts of each image. 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 and also requires taking many images in a sequential mode in which static objects can only be modeled. In addition, instability of the rotating unit can reduce the quality of the results. 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 et al., 2003). Examples of such systems are established by Qu et al. (2010), Lin et al. (2008), Varshosaz & Amini (2007), Jiang et al. (2006) and Huang and Hung (1997). In such systems, two single panoramas are produced-using the left and right cameras and combined to form the final stereo panorama. Figure 3 shows the systems developed by Jiang and Varshosaz. Compared to systems like that of Peleg and Ben-Ezra (1999), 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 (Amiri Parian and Grun, 2010, Li et al., 2008, Benosman et al., 1996, Benosman et al., 2001), 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 allow taking complete 360 degrees views instantly; thus eliminate 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 4, 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. In such system, the stereo viewing is not possible. It is also possible to combine images taken from two omni-directional cameras to produce stereo panoramas (Figure 4). An omni-directional camera uses a parabolic mirror to capture the complete view surrounding the camera. Sung and Lu (2012), Bo et al. (2011), Carbel et al. (2008), Arnspang et al. (1995), and Goshtasby and Grover (1993) 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.

Up to the present, no system has been developed to cover all needs of a stereo panorama image capturing system that allows geometric measurements. In this paper, we present the idea of developing a stereo panorama system based on stereo cameras which is named “Stereo Panorama Modeler” that is patented. This system can eliminate many problems related to producing a stereo panorama model from environment. In this regard, the structure of the system, its components is described. In this regard, applying off-the-shelf stereo cameras in development of the stereo panorama system is presented. Finally, practical experiments carried out and conclusions are made in the end.

Fig. 1: A stereo panorama

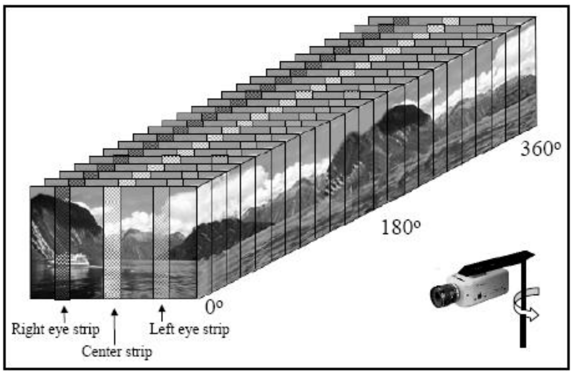

Fig. 2: Left and right strips produced for two panoramas from a single camera (Peleg and Ben-Ezra, 1999)

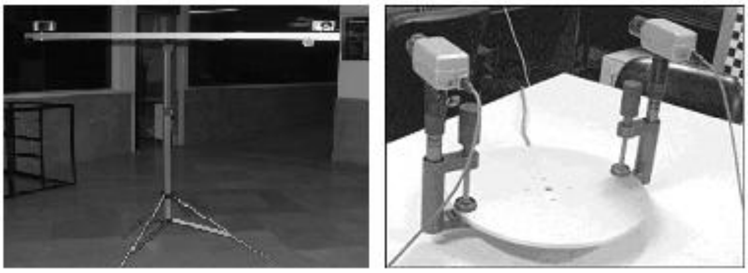

Fig. 3: A stereo-bar camera (left) (Varshosaz and Amini, 2007) and a stereo-turn table (right) (Jiang et al., 2006)

Fig. 4: Examples of modular camera (left) (Micusik and Kosecka, 2009) and omni-directional camera (right) (Gluckman et al., 1998)

2. STEREO PANORAMA MODELER IMPLEMENTATION

In a stereo camera, two cameras with the same brand are fixed in the form of a body and the position of the two cameras is stable related to each other. Figure 5 shows a Fuji W3 stereo camera.

In this paper, a horizontal stereo panorama system based on stereo cameras is proposed. In this system, several stereo cameras are placed on the circumference of a circular plate and all stereo cameras are symmetric and have the same distance from the center of the plate. In other words, the angle between each two consequent stereo cameras is the same.

In this system, there exists an overlap between stereo images so they can be stitched together and produce a horizontal stereo panorama. The system can cover the whole 360 degrees of the environment simultaneously; consequently the effects of vibrations of rotating systems and the effects of moving objects are eliminated in generating the stereo panorama model.

Moreover, due to the stability of the position of all stereo cameras related to each other, if relative orientation parameters between each two lenses of a stereo camera and also between stereo cameras are determined from the calibration procedure, they can be used to automate and simplify different stages of matching between images, image stitching and producing stereo panorama. According to 360 degree coverage of the environment and stability of stereo cameras in the system, general benefits of the proposed system can be mentioned as:

(a) Elimination of the effects of moving objects

(b) increased automation of image matching and stitching

(c) Elimination of vibration effects

(d) Possibility of stereo viewing

(e) Simultaneous 360 degrees coverage of the environment

(f) Equal resolution on the whole stereo panorama

According to the proposed structure of the system, designing and implementing of the system is introduced in continue.

Fig. 5: Fuji W3 Stereo camera

3. DESIGNING THE STEREO PANORAMA SYSTEM

Before applying stereo cameras, issues related to using the cameras in the implementing of the system should be investigated. These issues are as follows:

3.1. Minimum distance to provide the required coverage

In stereo image capturing, if minimum coverage between two stereo pairs needs to contain *p* percentage of the whole image, according to Figure 6, minimum distance of the stereo camera from objects (*H*) is obtained as:

$$H = \frac{b}{2.tg(\alpha/2).(1-p)} \qquad (1)$$

In equation (1), α is the horizontal viewing angle of the camera, *b* is the base-length of the stereo camera and *p* is the coverage percentage between stereo pairs. According to *p* percent coverage between stereo pairs and related computed distance (*H*), assuming an approximation, the angle that each camera includes *p* percentage of the coverage (α' in Figure 6) obtains:

$$\alpha' = 2Arctg(\frac{p.b}{2(1-p).H}) \qquad (2)$$

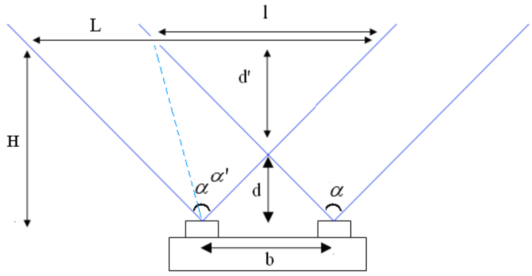

Fig. 6: Minimum distance of the camera from the objects to prepare *p* percent coverage between stereo pairs

3.2. Angles between stereo cameras and platform radius

In this section, hardware specifications of the system including the position of stereo cameras on the platform, angles between them and the radius of the platform is determined.

Usually, it needs minimum 20% coverage between consecutive images in order to stitch. For minimum imaging distance (*H*) computed from equation (1) and coverage angle (*α'*) computed from equation (2), the value of the arc opposite *α'* (*c* in Figure 7) and related radius (*r*) can be computed as:

$$r = H / \cos(\frac{\alpha'}{2}) \qquad (3)$$

$$c = r.\alpha'.\pi / 180$$

As there is a minimum need of 20% coverage between consecutive images (*c'*) and the length of each stereo camera (*B*), to compute the angle between two stereo cameras on the platform (γ) and the radius of the platform (*R*) (Figure 7), the two following equations with two unknowns must be solved together.

$$tg(\gamma/2) = \frac{B}{2R} \qquad (4)$$

$$(r+R).\gamma.\frac{\pi}{180} = (c/2 + c/2 - 0.2c)$$

In equations (4), values of *r* and *c* have been obtained from equation (3).

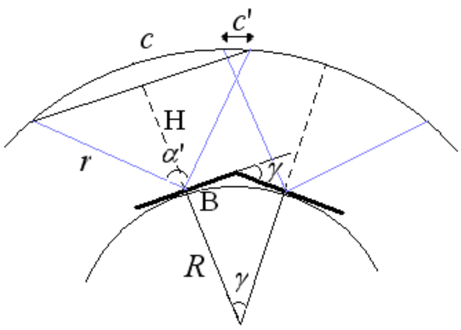

Fig. 7: Determining the angle between consecutive stereo cameras on the plate of the system

3.3. Implementing Stereo Panorama Modeler

In order to implement the proposed stereo panorama system, several Fuji W3 stereo cameras are used. The specifications of this stereo camera include 15 mm nominal focal length for each lens, 2 µm pixel size, 54 degrees horizontal viewing angle and 124 mm camera length. Figure 8 shows the system. According to the specifications of the Fuji W3 stereo camera and subjects of previous section, designing values for stereo panorama system is obtained as follows:

In order to determine the minimum distance of the stereo cameras to the object to achieve the needed coverage between stereo pairs, if 95% coverage is required, according to equation (1), the system must be placed at least 1.48 m far from objects.

Horizontal angle (*α’*) that Fuji W3 stereo camera views 90% coverage is estimated 51.68 degrees according to equation (2).

Considering 180 mm space legth for each stereo camera (for camera length and transmission wires), according to equations (3) and (4), the circular radius of system on platform is computed 291 mm and the angles between stereo cameras is calculated about 36.27 degrees if at least 20% coverage is needed to between stereo models to stitch together.

Finally, minimum required stereo cameras to cover all around 360 degrees can be computed as *360/γ,* consequently for such system 10 stereo cameras are needed.

In the stereo panorama system implementation, an electronic control unit is in order to control the stereo camera synchronization and remote commands are also possible. Figure 9 shows the electronic control unit of Stereo Panorama Modeler.

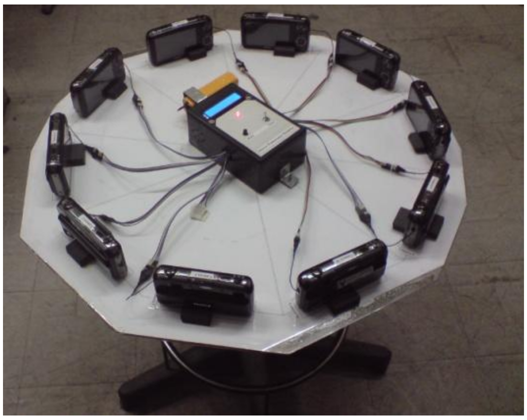

Fig. 8: Stereo Panorama Modeler System

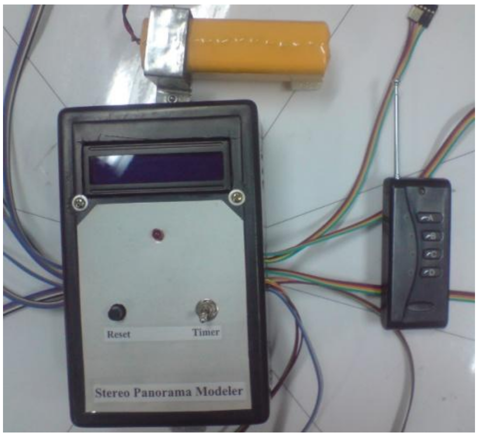

Fig. 9: The electronic control unit, batterry and remote controler of the stereo Panorama Modeler

4. STEREO PANORAMA MODELER CALIBRATION

Proper calibration is an important part of using any image capturing instrument. For the proposed system, this affects the quality of the resulting stereo. The calibration is carried out in three main stages: interior orientation of individual camera lenses, determination of the relative orientation between the lenses of each stereo camera, and alignment of adjacent stereo cameras.

In a typical calibration, to define the interior parameters of a camera, a number of images are taken from a test-field. By utilizing a standard bundle adjustment not only the interior but also the exterior parameters of the camera at each imaging station are obtained. For a single stereo camera, these include the internal and external parameters of each camera lens. Relative orientation parameters between two lenses of the stereo camera can be calculated using exterior orientation parameters (3 position and 3 rotation elements). As two bundles of corresponding points on images of two lenses are related to the unique point of the object, Equation (5) can be written for them:

$$R_{left} \cdot \begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix}_{left} + T_{left} = R_{right} \cdot \begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix}_{right} + T_{right} = \begin{bmatrix} X_i \\ Y_i \\ Z_i \end{bmatrix} \quad (5)$$

In Equation (5), x,y,z are image coordinates, X,T,Z are object coordinates, T_{left} and R_{left} are the translation and rotation matrix of the left lense and T_{right} and R_{right} are the translation and rotation matrix of the right lens respectively. Relative orientation parameters between the two lenses can be calculates as below:

$$\begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix}_{left} = R^t_{left} \times R_{right} \begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix}_{right} + R^t_{left} \times (T_{right} - T_{left}) \quad (6)$$

In Equation (6), R^t_{left}*$\mathrm{R_{right}}$ is the rotation matrix and $R^t_{left}*(T_{right}-T_{left})$ is the translation matrix between the two lenses of the stereo camera.

To calibrate the system, a test-field with including a number of scale bars measured with a caliper having a nominal precision of 0.01mm was used (Figure 10). The calibration was performed in three steps, at first; the interior orientation parameters of the individual lenses were calculated. Next, relative orientations of the left lens with respect to the right lens of each stereo camera were derived. Finally, the relative orientation of the left lens of any stereo camera with respect to the left lens of its subsequent one was computed.

From the calibration procedure, the average accuracy of relative orientation parameters computation was determined as shown in Table 1.

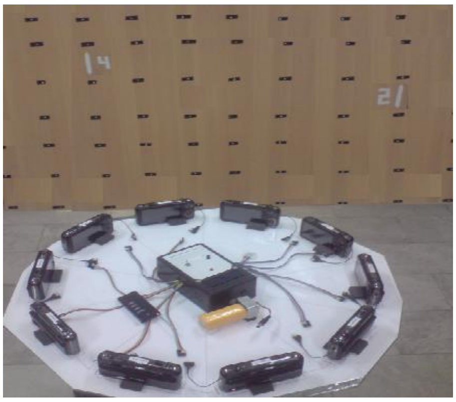

Fig. 10: Calibration of stereo panorama system using a test-field

Table 1: Accuracy of the relative orientation parameters derived from system calibration

Parameters	*RMSE*
ΔΩ (degree)	0.021
ΔΦ (degree)	0.011
ΔΚ (degree)	0.002
ΔX (mm)	0.146
ΔY (mm)	0.145
ΔZ (mm)	0.119

5. STEREO PANORAMA GENERATION

The images taken by each stereo camera are used to form anaglyph stereo models. The models are then stitched together to generate a complete stereo panorama. Image stitching is the process of combining multiple photographic images with overlapping fields of view to produce a segmented panorama or high-resolution image. To create the individual models, the left and right images of each stereo camera are matched. For this, SIFT (Scale Invariant Feature Transform) was used which is developed by Lowe (1999) and is one of the most promising techniques in matching. This algorithm is proved to be invariant to changes in scale, illumination, and small changes in a camera viewpoint (Lowe, 2004). In order to reduce the number of wrong matches, we used Ransac (RANdom SAmple Consensus), an algorithm proposed by Fischler and Bolles (1981).

The matched points are then used to determine a homography matrix. Called homography in computer vision (Faugeras, 1993), this matrix is a 3 ×3 linear projective transformations which is used here to transform the coordinates of the left image to the right image by:

$$\lambda \begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} = \begin{bmatrix} H_{1,1} & H_{1,2} & H_{1,3} \\ H_{2,1} & H_{2,2} & H_{2,3} \\ H_{3,1} & H_{3,2} & H_{3,3} \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} \qquad (7)$$

In Equations (7), x, y and x', y' are the image coordinates of left and right images respectively. Once H is found, the anaglyph models are produced from the green and blue channels of the left image and the red channel of the right image. In a similar procedure H is defined between consecutive stereo models and the final stereo panorama is generated. Finally, the resulting stereo panorama is projected on a cylinder to allow for more realistic visualization. Figure 11 shows matching procedure between images for stereo panorama generation.

6. EXPERIMENTS

To evaluate the Stereo Panorama Modeler system, it was used in 3D reconstruction of some places for instance in the university area and in the street. These areas were containing of moving vehicles and peoples. Figure 12 shows the application of the system in 3D modelling of the university and the street. The images captured at each position were processed as described above. The individual stereo camera models were produced and stitched together to form the stereo panoramas at each station. Figure 13 shows the resulting stereo panoramas produced in various environment. As can be seen in Figure 13, The generated stereo panorama models is stereo, have well quality, continuous, and the resolution on the whole stereo panorama is equal. Moreover, since the stereo cameras are synchronized and cover the whole 360 degree of the environment simultaneously, there is no need to rotate the system like usual systems and consequently the effects of vibration of the system is eliminated. In addition, the effect of the people and moving objects does not affect the generated model.

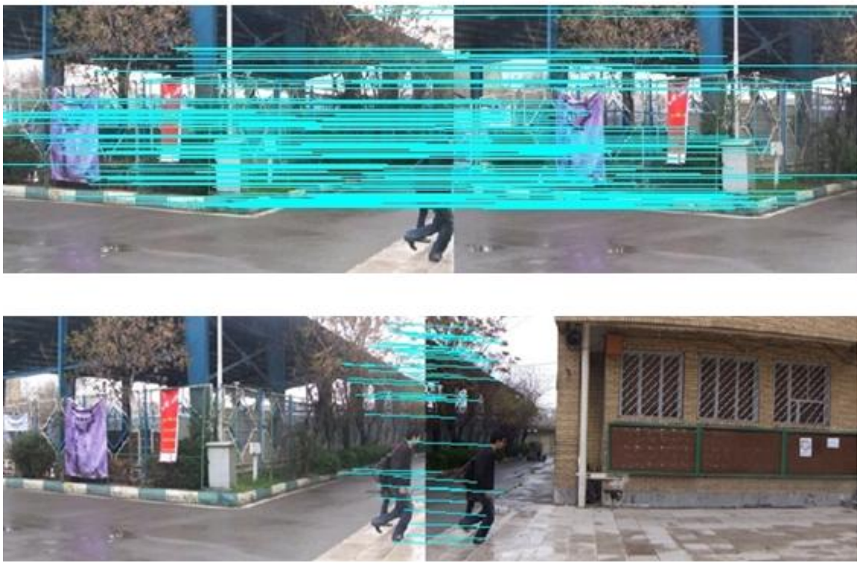

Fig. 11: Matching between stereo pairs (top) and matching between two consecutive stereo models (down)

Fig. 12: Evaluating the Stereo Panorama Modeler in 3D reconstruction of the environment in the area of the university (left) and in a street (right)

Fig. 13: The stereo panoramas generated from various environment

7. CONCLUSION

Producing a complete large scale environment model which enables access visual information is required by most organizations. In this regard, the applied method and system in 3D modeling of the environment is an important subject. In this paper, we present a new stereo panorama system which is names Stereo Panorama Modeler that is patented. The system enjoys a number of benefits such as 3D viewing, 360 degree covering the environment, overcoming the effects of moving objects on a stereo panorama, increasing automation of matching and image stitching, and having equal resolution on the whole stereo panorama. In this regard, first, the structure of the system, its components is described. Next, applying off-the-shelf stereo cameras in development of the stereo panorama system is presented. In order to evaluate the system in 3D urban reconstruction, the system was applied in modelling of some places for instance in the university area and in the street. These areas were containing of moving vehicles and peoples.The result of experiments showed that the generated stereo panorama models is stereo, have well quality, continuous, and the resolution on the whole stereo panorama is equal. Moreover, since the stereo cameras are synchronized and cover the whole 360 degree of the environment simultaneously, there is no need to rotate the system like usual systems and consequently the effects of vibration of the system is eliminated. In addition, the effect of the people and moving objects does not affect the generated model. Consequently, the proposed system is a useful method for 3D reconstruction of the urban areas and can be applied by many organizations.

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