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The flow of baseline estimation using a single omnidirectional camera

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ABSTRACT

Baseline is a distance between two cameras, but we cannot get information from a single camera. Baseline is one of the important parameters to find the depth of objects in stereo image triangulation. The flow of baseline is produced by moving the camera in horizontal axis from its original location. Using baseline estimation, we can determined the depth of an object by using only an omnidirectional camera. This research focus on determining the flow of baseline before calculating the disparity map. To estimate the flow and to tracking the object, we use three and four points in the surface of an object from two different data (panoramic image) that were already chosen. By moving the camera horizontally, we get the tracks of them. The obtained tracks are visually similar. Each track represent the coordinate of each tracking point. Two of four tracks have a graphical representation similar to second order polynomial.

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1. INTRODUCTION

Depth of objects can be estimated from stereo image. In previous research, stereo image was obtained by using two pocket cameras (with improper alignment-vertical error) [1] or two omnidirectional sensors [2]. Other research use two omnidirectional cameras (both of them are built in vertical) [3], combination of convex mirror and concave lens [4], two cameras with two convex mirrors [5, 6], double lobed mirror [7], and hyperbolic double lobed mirror [8]. In this research, we only employ a single omnidirectional camera with a hyperbolic catadioptric.

Catadioptric is one of the most important components of an omnidirectional sensor to produce an omnidirectional image. By using the catadioptric, all of the objects around the omnidirectional sensor can be seen in one omnidirectional image without any efforts to rotate the sensor. It means that this sensor has a wider field of view: 360°. There are many types of catadioptric and each catadioptric will give a different omnidirectional image. According to [9-15], the best type of catadioptric is catadioptric that has a hyperbolic shape.

There are many advantages using omnidirectional sensor in computer vision. Some of them are using for face detection [16], soccer robot (based on obstacle detection) [17], matching and localization [18]. In the conventional stereo image processing, baseline is one of the parameters to find the depth of objects. By using a pair of camera/omnidirectional camera/catadioptrics, baseline can be determined from the distance between cameras. Lukierski, Leutenegger, and Davison in [19] use an omnidirectional camera on mobile robot. Its baseline is determined by the length of the mobile robot's track and the length of its track will affect the depth estimation. In this research, our baseline estimation is not affected by the length of the track. When we try to obtain the depth and map, we should know about baseline. Using an omnidirectional camera with a hyperbolic catadioptric, there is no information about baseline. Depth map can be developed using stereo triangulation calculation. Our proposed method only focuses on determining the flow of baseline.

The flow of baseline in our method is estimated using panoramic image because next process is stereo triangulation calculation. The panoramic image is obtained by transformed the omnidirectional image into panoramic image. By using stereo triangulation and panoramic image, variable (x) should have a constant value in one axis [20] and the depth can be determined. This research produces images within different value in two axes (x,y). It shows that panoramic image, especially each pixel (of the objects) has a unique flow that represented a certain pattern.

From the unique flow of each pixel in the panoramic image, we can track each pixel using Lucas-Kanade's optical flow algorithm [21-23]. In order to that, we have to move the camera continuously in horizontal axis from its original location and use an object for detection to produce the desired tracks. As the result, we obtain coordinates shifting of the object that is saved into a file and transform it into graphs to get baseline estimation.

2. RESEARCH METHOD

Image that is captured using omnidirectional sensor is called as omnidirectional image. It has a black-circle in the center of the image. Objects around it will be reflected into the catadioptric mirror and the CCD sensor from the camera will capture the objects. The omnidirectional image is transformed into panoramic image before calibration process. Afterward, we can use the panoramic images to obtain flow of baseline estimation.

The structure of omnidirectional camera shown in Figure 1. The mirror or catadioptric should be put and centered on the upper of the camera. Uncentered mirror will cause a distortion in omnidirectional image transformation to panoramic image. To center the mirror to the camera, we use nuts, bolts, and springs that put in each corner of the mirror structure. In this research, we propose a method to estimate flow of baseline from omnidirectional images.

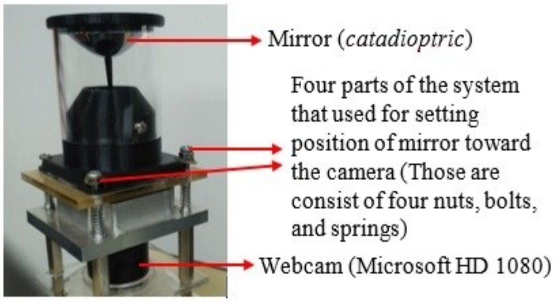


Figure 1. System's structure of our omnidirectional camera using webcam

2.1. The algorithm of estimation process

Figure 2 illustrates all the methods that used in the flow of baseline estimation process. There are three (3) process. The first process is loading live image, transform omnidirectional image to panoramic image, and calibration. Second process is object detection and tracking the object's points. The third process is to plot the points of the tracks into graphs, to find equation of baseline estimation's flow, and to determine the coefficient of the equation.

2.2. Modelling of hyperboloid mirror

The projection from hyperbolic catadioptric or hyperboloid mirror that produces an omnidirectional camera is shown in Figure 3. From Figures 3 and 4, the equation of hyperboloid mirror modelling is shown below.

$$\frac{R^2}{a^2}-\frac{(Z-h)^2}{b^2} = -1 \tag{1}$$

where: $a=\sqrt{c^2-b^2}$. So, the map for hyperboloid mirror can be calculate as follows:

$$Z = R\tan\alpha + c + h \tag{2}$$

Because all of the objects touch the field and given value, thus:

$$\tan\alpha = -\frac{c+h}{R} \tag{3}$$

From Figure 3, the equation is given, as follows:

$$\tan\theta = \frac{b^2+c^2}{\left(b^2-c^2\right)}\tan\alpha + \frac{2bc}{c^2-b^2}x\frac{1}{\cos\alpha} \tag{4}$$

$$\tan\alpha = \frac{f}{r} \tag{5}$$

To simplify, hence:

$$a_1 = \frac{b^2+c^2}{b^2-c^2}; \qquad a_2 = \frac{2bc}{c^2-b^2}; \qquad a_3 = (c+h) \tag{6}$$

focal point of the hyperboloid mirror is assumed on the principal point of the camera. So, (4) to (6) are simplified as follows:

$$\frac{f}{r} = a_1\tan\alpha + \frac{a_2}{\cos\alpha} \tag{7}$$

$$\frac{f^2}{r^2} - \frac{2a_1 f\tan\alpha}{r} + a_1\left(\tan\alpha\right)^2 = a_2^{\,2}\left(1+\left(\tan\alpha\right)^2\right) \tag{8}$$

By (3) and (8), the equation is given as follows:

$$\frac{f^2}{r^2} - \frac{2a_1 f\frac{a_3}{R}}{r} + \frac{a_1^{\,2}a_3^{\,2}}{R^2} = a_2^{\,2}\left(1+\frac{a_3^{\,2}}{R^2}\right) \tag{9}$$

$$(f^2 - r^2a_2^{\,2})R^2 - \left(2a_1a_3fr\right)R + r^2a_3^{\,2}\left(a_1^{\,2} - a_2^{\,2}\right) = 0 \tag{10}$$

where:
f = focal length of camera
r = radius in pixel
R = radius in world coordinate
$a_1a_2a_3$ = parameter of hyperboloid mirror

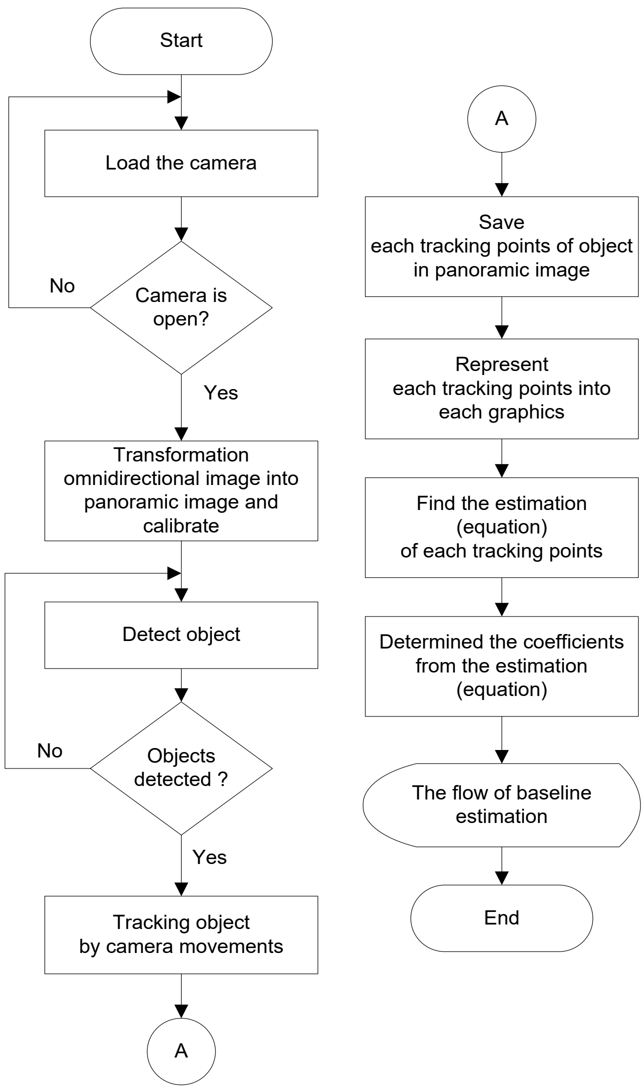


Figure 2. The flow of baseline estimation process

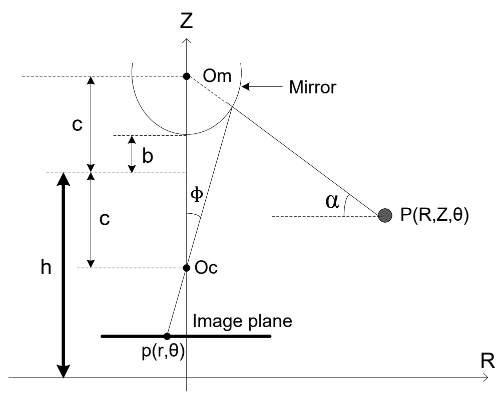


Figure 3. Geometry of hyperboloid catadioptric/mirror and projection of point from world coordinate on the image plane [24]

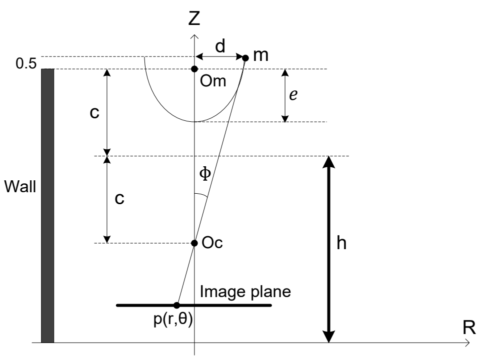


Figure 4. Installation specification of hyperboloid catadioptric/mirror with axis is laid on the field [24, 25]

2.3. Calibration method

When the omnidirectional sensor is employed, some distortion will appear due to its lens (improper position). Omnidirectional sensor parameters should be adjusted properly to minimize the distortion. All of the parameter's adjustment is called calibration. The calibration process is one of important step because the omnidirectional sensor is used to map objects inside a room. There are two parameters in a camera, extrinsic and intrinsic. Both of them describe the mathematical relationship between 3D coordinates of real word scene and the 2D coordinates of its projection onto the image plane. Specifically, the intrinsic or internal parameter is used to represent the pixel coordinates of image point with the corresponding coordinates in the camera reference frame. The extrinsic or external parameter of the camera is the parameter that defines the location and orientation of real world coordinates to camera coordinates. Focal length in pixel (f_x, f_y), principal point (c_x, c_y), pixel size, radial distortion (k_1, k_2, k_3) and tangential distortion (p_1, p_2) represent the intrinsic parameters. The camera matrix is represented in 3×3 matrix.

$$\text{camera matrix} = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \tag{11}$$

This is of radial distortion.

$$\begin{aligned} x \text{ disorted} &= y\ (1 + k_1 r^2 + k_2 r^4 + k_3 r^6) \\ y \text{ disorted} &= y\ (1 + k_1 r^2 + k_2 r^4 + k_3 r^6) \end{aligned} \tag{12}$$

And this is of tangential distortion.

$$\begin{aligned} x \text{ disorted} &= x + \left[2p_1 xy + p_2 \left(r^2 + 2x^2 \right) \right] \\ y \text{ disorted} &= y + \left[p_1 \left(r^2 + 2y^2 \right) + 2p_2 xy \right] \end{aligned} \tag{13}$$

Then, coefficient must be known is:

$$\text{Distortion coefficients} = \left(k_1\ k_2\ p_1\ p_2\ k_3 \right) \tag{14}$$

Matrix of rotation (R) and translation (T) are represented below.

$$R = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix} \tag{15}$$

$$T = \begin{bmatrix} t_1 \\ t_2 \\ t_3 \end{bmatrix} \tag{16}$$

2.4. Panoramic transformation

Omnidirectional image is transformed to be a panoramic image using Polar mapping. The Polar coordinate system is mapped into Cartesian coordinate system. Polar coordinate system is denoted by (r, θ) and in Cartesian coordinate system is denoted by (x, y). Coordinate center of polar sampling is calculated using (17) and (18).

$$\theta = \tan^{-1}\left(\frac{y}{x} \right) \tag{17}$$

$$r = \sqrt{x^2 + y^2} \tag{18}$$

Value of Cartesian coordinate (x,y) can be calculated from the Polar coordinate (r,θ) using trigonometry as follows.

$$x^2 + y^2 = r^2 \tag{19}$$

$$\begin{aligned} x &= r \cos\theta \\ y &= r \sin\theta \end{aligned} \tag{20}$$

So, the correlation of Cartesian coordinate system and Polar coordinate system with (x_c, y_c) is the center point of the coordinate of omnidirectional image (Polar coordinate system) and are given as follows.

$$\begin{aligned} x_0(r,\theta) &= r \cos\theta + x_c \\ y_0(r,\theta) &= r \sin\theta + y_c \end{aligned} \tag{21}$$

2.5. Optical flow

Intensity is one of the parameters in optical flow that used for representation the flow of every pixel in the image. Based on its characteristic, the track of each pixel can be estimated. We employ Lucas-Kanade's optical flow algorithm. This algorithm combines some information from several nearby pixels to resolves the ambiguity [21-22].

The Lucas-Kanade's optical flow algorithm work as a pyramidal structure within process from the highest layer until the lowest layer [21, 23]. This algorithm assumes the transfer of information in the image between two images (frames) is less and almost constant by considering pixels nearby of p coordinate. According to that, Lucas-Kanade assumes to maintain all pixels with a local window that is centered on p coordinate. The of its velocity are given as follows.

$$\begin{aligned} I_x(q_1)V_x + I_y(q_1)V_y &= -I_t(q_1) \\ I_x(q_1)V_x + I_y(q_1)V_y &= -I_t(q_1) \\ &\vdots \\ I_x(q_n)V_x + I_y(q_n)V_y &= -I_t(q_n) \end{aligned} \tag{22}$$

And (22) in matrix $Av = b$, is represented in (23).

$$A = \begin{bmatrix} I_x(q_1) & I_y(q_1) \\ I_x(q_2) & I_y(q_2) \\ \vdots & \vdots \\ I_x(q_n) & I_y(q_n) \end{bmatrix}, \quad v = \begin{bmatrix} V_x \\ V_y \end{bmatrix}, \quad b = \begin{bmatrix} -I_t(q_1) \\ -I_t(q_1) \\ \vdots \\ -I_t(q_n) \end{bmatrix} \tag{23}$$

Where:

$q_1, q_2, ..., q_n$ = pixels in the window (or local window)

$I_x(q_i), I_y(q_i), I_t(q_i)$ = partial derivatives of image I in accordance with the position (x, y) and the time (t) on pixel q_i at the time.

Lucas-Kanade's algorithm can be obtained using least square algorithm and it is called matrix system of 2×2

$$A^T A v = A^T b \quad \text{or} \quad v = \left(A^T A\right)^{-1} A^T b \tag{24}$$

Where, A^T is transpose of matrix A and represented in the (25).

$$\begin{bmatrix} V_x \\ V_y \end{bmatrix} = \begin{bmatrix} \sum_i I_x(q_i)^2 & \sum_i I_x(q_i) I_y(q_i) \\ \sum_i I_x(q_i) I_y(q_i) & \sum_i I_y(q_i)^2 \end{bmatrix}^{-1} \begin{bmatrix} -\sum_i I_x(q_i) I_t(q_i) \\ -\sum_i I_y(q_i) I_t(q_i) \end{bmatrix} \tag{25}$$

With the total summing are from $i = 1$ until n .

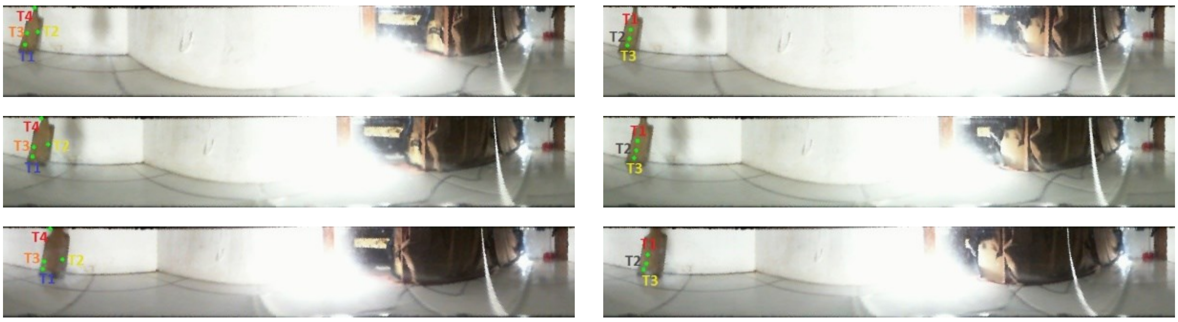
3. RESULTS AND ANALYSIS

The sample of image that was captured using our omnidirectional camera is shown in Figure 5. The omnidirectional image must be transformed into panoramic image in order to be processed using stereo triangulation. Figure 6 shows the result of panoramic image that was produced using polar mapping algorithm. The baseline estimation was calculated using coordinates shifting of an object in panoramic image. Coordinates shifting were obtained by moving the camera from one location to another location. Each coordinate is an image's pixel that was represented by a point (green circle) in panoramic image. Each point was assigned on the surface of the object in panoramic image. We assign three and four (4) points in the detected object for different length of track (94 cm and 129 cm) and both of them is shown in Figures 6 (a) and (b). The points were used as tracking points in Lucas-Kanade's optical flow algorithm. Figure 7 shows detection points in the board were successfully detected in three different image. Those images were captured from a different timestamp.

Figure 5. Omnidirectional image

(a)
(b)
(c)

Figure 6. Panoramic image that was captured in a room within length of track; (a) 94 cm and (b) 129 cm, (c) Panoramic image that was captured in laboratory



(a) (b)

Figure 7. Four detected points (a) on length of track 94 cm and three detected points (b) on length of track 129 cm in the object and the flow of them from the current frame to the next frame

The coordinates of tracking points were saved into a file in *.txt file format. The saved coordinates in the file were transformed into graph for each point. After the graphics were obtained for each point, the flow of baseline estimation was calculated. The data is tested in various conditions based on track's length and horizontal distance of camera's movement. Several data from tracking points are shown in Figures 8 and 9. Two of the tracks in both graphs obtain similar flow and the other tracks show an improper flow. The improper flow of the tracks occurs because of the difference light intensity in the panoramic image. This phenomenon occurs because of the points detection process use Lucas-Kanade's optical flow algorithm.

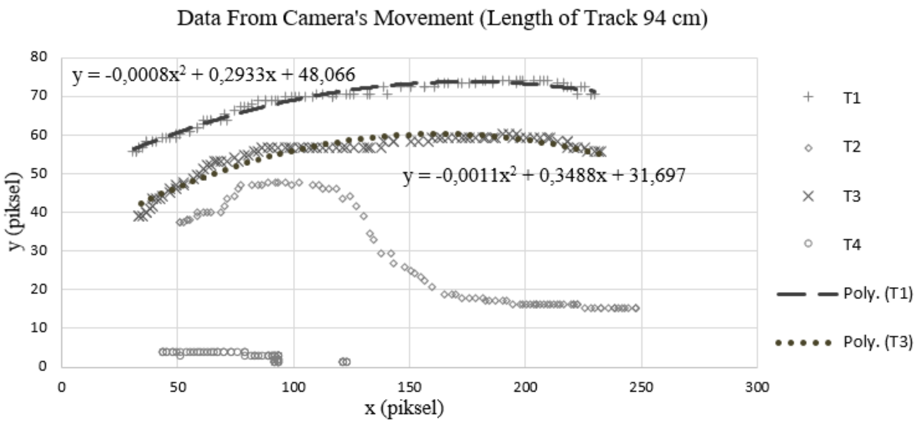


Figure 8. The tracking flow of detected points from 94 cm camera's movement

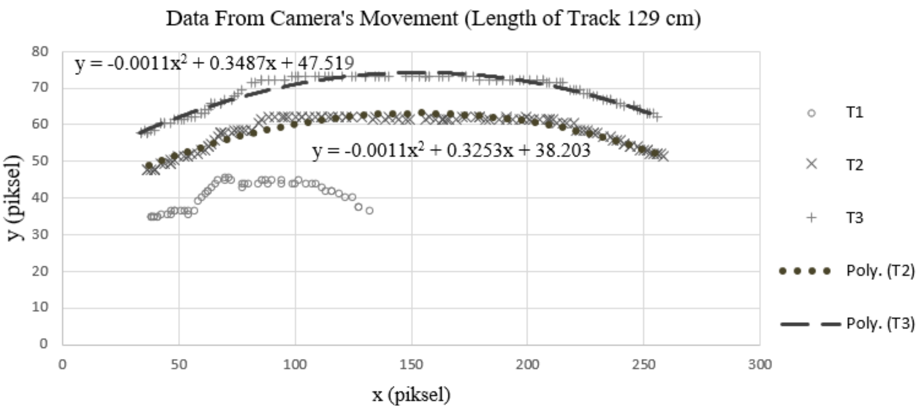


Figure 9. The tracking flow of detected points from 129 cm camera's movement

After we compute the estimation graphs, the coefficients of its are given as follows.

$$a = 0.001$$
$$b = 0.349$$

The flow of baseline estimation is given as follows:

$$y = -0.001x^2 + 0.349x + c \quad (22)$$

After we get the baseline estimation, that equation was tested by tracking object in a different length and different area Figure 6 (c). The result shows the track that was produced has similar flow. The value of c also different because it depends on the initial position of the tracking points that are not always the same.

4. CONCLUSION

The proposed method to estimate the flow of baseline from a single omnidirectional camera is achieved. From the detected object, we choose three and four points to track and two of the tracking points have a similar flow. The flow of baseline estimation method that is obtained in this research shows a second order polynomial equation with value of $a = 0.001$ and value of the $b = 0.349$. The constant value of c depends on the initial position of the tracking points. From several experiments that were conducted, we conclude that the equation of baseline estimation is not affected by length of tracking points. It is indicated by the same coefficient values of a and b. The equation of baseline estimation that was obtained will be used for the matching process in panoramic image.

REFERENCES

[1] J. Mrovlje J and V. Damir, "Distance Measuring based on Stereoscopic Pictures," *Proceeding of 9th International PhD Workshop on Systems and Control: Young Generation Viewpoint*, Izola, Slovenia, Ljubljana: Institut Jožef Stefan, 2008.

[2] O. M. M. K. Fouad, "Position Estimation of Mobile Robots Using Omni-Directional Cameras," M. S. *thesis*, Mechanical Engineering, Carleton University, Ottawa, Ontario, Canada, 2014.

[3] Z. Zhu, "Omnidirectional Stereo Vision," *Proceeding of the Workshop on Omnidirectional Vision, the 10th IEEE ICAR*, Budapest, Hungary, 2001.

[4] S. Yi and N. Ahuja, "An Omnidirectional Stereo Vision System Using a Single Camera," in *Proceeding of International Conference on Pattern Recognition*, pp. 861-865, Hong Kong, August 2006.

[5] J. Gluckman, S. K. Nayar, and K. J. Thoresz, "Real-Time Omnidirectional and Panoramic Stereo," in *Proceedings of the 1998 DARPA Image Understanding Workshop, IUW'98*, Monterey, California, 1998.

[6] T. Svoboda and T. Pajdla, "Epipolar Geometry of Central Catadioptric Camera," *International Journal of Computer Vision*, vol. 49, no. 1, pp. 23-37, August 2002.

[7] D. Southwell, *et al*., "Panoramic Stereo," in *Proceedings of 13th International Conference on Pattern Recognition*, Vienna, Austria, pp. 378-382, 1996.

[8] E. L. L. Cabral, J. C. de Souza Junior, and M. C. Hunold, "Omnidirectional Stereo Vision with a Hyperbolic Double Lobed Mirror," in *Proceedings of the 17th International Conference on Pattern Recognition*, pp. 1-9, Cambridge, UK, August 26, 2004.

[9] T. Sato and N. Yokoya, "Efficient Hundreds-baseline Stereo by Counting Interest Points for Moving Omni-directional Multi-camera System," *Journal of Visual Communication and Image Representation*, vol. 21, no. 5-6, pp. 416-426, July-August 2010.

[10] K. Yang Tu, "Analysis and Comparison of Various Shape Mirrors Used in Omnidirectional Cameras with Parameter Variation," *Journal of Information Science and Engineering*, vol. 25, no. 3, pp 945-959, May 2009.

[11] M. Yachida, "Omnidirectional Sensing and Combined Multiple Sensing," in *Proceedings of IEEE and ATR Workshop on Computer Vision for Virtual Reality Based Human Communications*, pp. 20-27, Bombay, India, January 1998.

[12] K. Yamazama K, Y. Yagi, and M. Yachida, "Omnidirectional Imaging with Hyperboloidal Projection," in *Proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS '93)*, pp. 1029-1034, Yokohama, Japan, July 1993.

[13] J. Gaspar, *et al.*, "Constant Resolution Omnidirectional Cameras," in *Proceeding of OMNIVIS'02 Workshop on Omni-directional Vision*, pp. 27-34, Copenhagen, Denmark, June, 2002.

[14] T. L. Conroy and J. B. Moore, "Resolution Invariant Surfaces for Panoramic Vision Systems," in *Proceedings of the Seventh IEEE International Conference on Computer Vision*, pp. 392-397, Kerkyra, Greece, September 20-27, 1999.

[15] S. K. Nayar, "Catadioptric Omnidirectional Camera," *Proceeding of IEEE Computer Society Conference on Computer Vision and Pattern Recognition*, pp. 482-488, San Juan, USA, June 1997.

[16] A. L. C. Barczak, J. Okamoto Jr., and V. Grassi Jr., "Face Tracking Using a Hyperbolic Catadioptric Omnidirectional System", *Research Letters in the Information and Mathematical Sciences*, vol. 13, pp. 55-67, January 2009.

[17] J. Silva, *et al*., "Obstacle Detection, Identification and Sharing on a Robotic Soccer Team," *Proceeding of Portuguese Conference on Artificial Intelligence (EPIA 2009)*, pp. 350-360, Aveiro, Portugal, 2009.

[18] D. Michel, A. A. Argyros, and M. Lourakis, "Horizon Matching for Localizing Unordered Panoramic Images", *International Journal of Computer Vision and Image Understanding*, vol. 114, no. 2, pp. 274-285, January 2010.

[19] R. Lukierski, S. Leutenegger, and A. J. Davison, "Rapid Free-Space Mapping from A Single Omnidirectional Camera," in *Proceeding of the European Conference on Mobile Robots (ECMR)*, pp. 1-8, Lincoln, UK, September 2015.

[20] OpenCV Dev Team, "Depth Map from Stereo Images," OpenCV 3.0.0-dev documentation: Camera Calibration and 3D Reconstruction, Nov 10, 2014. [Online]. Available from: https://docs.opencv.org/3.0-beta/doc/py_tutorials/py_calib3d/py_depthmap/py_depthmap.html. [Accessed November 9, 2015].

[21] R. Sigit, *et al*., "Improved Echocardiography Segmentation Using Active Shape Model and Optical Flow," *International Journal of Telkomnika telecommunication computing electronic and control*, vol. 17, no. 2, pp. 809-818, April 2019.

[22] A. A. Pratiwi, *et al.*, "Improved Ejection Fraction Measurement on Cardiac Image Using Optical Flow," in *Proceeding of 2017 International Electronics Symposium on Knowledge Creation and Intelligent Computing (IES-KCIC) IEEE*, pp. 295-300, September, 2017.
[23] U. Umar, R. Soelistijorini, and H. A. Darwito, "Tracking Arah Gerakan Telunjuk Jari Berbasis Webcam Menggunakan Metode Optical Flow," in *Proceeding of the 13th Industrial Electronics Seminar 2011 (IES 2011)*, pp. 249-254, October, 2011.
[24] M. Jamzad, A. R. Hadjkhodabakhshi, V. S. Mirrokni, "Object Detection and Localization Using Omnidirectional Vision in the RoboCup Environment," *International Journal of Scientia Iranica*, vol. 14, no. 6, pp. 599-611, November 2007.
[25] A. K. Mulya, F. Ardilla, and D. Pramadihanto, "Ball Tracking and Goal Detection for Middle Size Soccer Robot Using Omnidirectional Camera," *Proceeding of International Electronics Symposium (IES)*, pp. 432-437, September 2016.

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