Improving 3D Measurement Accuracy in Epipolar Directions via Trinocular Spherical Stereo

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***Abstract*—Spherical cameras are suitable for all-round 3D measurement due to their wide field of view. When performing 3D measurement using binocular spherical stereo, the areas in the epipolar directions cannot be reconstructed accurately due to the low measurement confidence in the epipolar direction. By adding one more spherical camera, perpendicular to the epipolar direction, to the binocular spherical stereo to form a trinocular spherical stereo, all-round 3D measurement can be achieved. In this paper, we propose a method to improve the 3D measurement accuracy by minimizing the overall reprojection error. Effectiveness of the proposed method is verified through experiments.**

Keywords—3D measurement, spherical cameras

I. Introduction

3D measurement with cameras is important in robot teleoperation and navigation, especially in an unpredictable disaster environment. 3D models help in motion planning and visualization. One of the common used 3D measurement methods with the camera is the stereo system[1][2]. The regular binocular stereo system is implemented by two perspective cameras with a limited field of view (FoV). Thus, the 3D measurement can only cover a limited area.

Different from perspective cameras, spherical cameras have an all-round FoV which is 360-degree in all directions. In order to make use of the wide FoV to perform all-round 3D measurement, binocular spherical stereo was proposed. However, the measure confidence keeps decreasing while getting closer to the epipolar direction. Li[3] proposed a trinocular spherical stereo setup with two baselines perpendicular to each other. The method to achieve all-round measurement with this setup is the combination of two sets of binocular stereo based on the geometry information. Though it can obtain the all-round measurement result, the weak epipolar constraint in this method lowers the overall measurement accuracy.

The method proposed in this paper aims to improve the accuracy of the all-round measurement using the trinocular spherical stereo. The algorithm of the method is introduced, and experiments show superior accuracy in epipolar directions.

II. Proposed Approach

Since there are three spherical cameras in the trinocular spherical stereo as shown in Fig. 1, each pair of cameras can generate a depth map of the environment, besides the points at epipoles, each point in the environment may have multiple distance values generated due to the errors in the measurement and depth map generation. However, there is only one true position of a point. The reprojection error is zero if the point is at its true position. The method is proposed based on the physical constraint that one point can only have one position in the 3D space, which is missing in previous research.

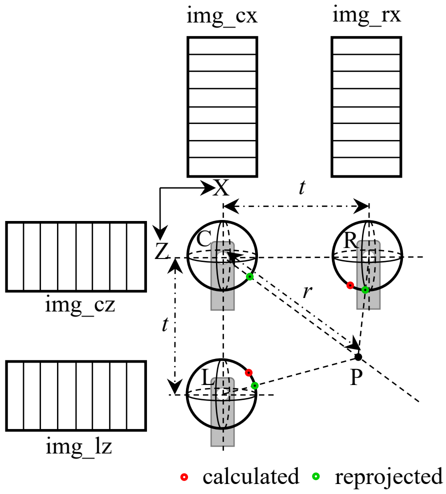

Fig. 1. Trinocular spherical stereo and setup of the method.

A. Setup and Image Configuration

The setup of the cameras of the proposed method is shown in Fig. 1, where there are two pairs of binocular spherical stereo with a common camera C, right camera R and lower camera L. The baselines are both of length t and are perpendicular to each other. The common camera C is identified as the reference camera in this paper, and the spherical image C taken by camera C, which the image plane is a sphere surface, is projected into two equirectangular images, img_cx and img_cz along x-axis and z-axis respectively. The spherical image R and L taken by camera R and L are projected to equirectangular img_rx and img_lz. In this configuration, the epipolar lines are straight and aligned with the epipolar direction[4] so that the disparity map can be generated easily. For any arbitrary point P in the 3D space, we denote the distance from the center of camera C to point P as r.

B. 3D Model Generation

The proposed method follows the procedures below.

a) Disparity map: Generate the disparity maps for the stereo pairs along x-axis using img_cx and img_rx, and along z-axis using img_cz and img_lz using DeepFlow.

b) Approximated unoptimized distance: Calculate the distance values from the two disparity maps for each point using (1) [4]. Combine the results for unoptimized distance by taking the average of two distance values of the point.

$$r = t \times \frac{\sin(\omega + d)}{\sin(d)}, \tag{1}$$

where t is the length of the baseline, d is the disparity value and ω is the position of the point from epipolar direction in rad.

c) Calculated point: For each point on spherical image C, calculate the corresponding point on spherical image R and L using the disparity maps, as the red points in Fig. 1.

d) Reprojected point: For each point on spherical image C, reconstruct the point to an assumed point P, with assumed r value and reproject the assumed point P to spherical image R and L, as the green points in Fig. 1.

e) Reprojection error: For each point on spherical image C, calculate the geodesic reprojection error e_x and e_z between the calculated point and the reprojected point on spherical image R and L respectively.

f) Optimization: Levenberg-Marquardt approach is applied to get the optimal value of r by (2), and the approximated unoptimized distance calculated in *b)* is used as the initial value for the optimization.

$$r = \text{argmin}(e_x(r) + e_z(r)). \quad (2)$$

The smaller the reprojection error, the more accurate the measurement is. Ideally it is zero at the true position. This improves accuracy, especially in the epipolar directions by considering the measurement result of three cameras at the same time.

III. Experiment

The trinocular spherical stereo is placed inside an indoor classroom model in Blender, with camera C and camera L align vertically (global z-axis) and camera C and camera R align horizontally (global x-axis). In this setup, as shown in Fig. 2, two out of four walls as well as the ceiling and the floor of the classroom contains the area in the epipolar direction.

In order to test the proposed algorithm, three equirectangular images of size 1000 pixel×500 pixel is rendered in Blender with a 360˚×180˚ FoV spherical camera at three different positions accordingly. Transformation is applied to images generated by camera C and camera R to make the epipolar lines straight and align with the epipolar directions. The environment model used for the experiment and preprocessed input images are shown in Fig. 2.

Since the confidence of the result at epipolar direction is extremely low, the approximated unoptimized distance is inaccurate. The target of the experiment is to improve the 3D measurement accuracy of the areas in the epipolar directions.

The experiment result using the input images in Fig. 2 is shown in Fig. 3. The point cloud in blue is generated from the approximated unoptimized distance and the green one is generated from the optimized distance using the proposed method.

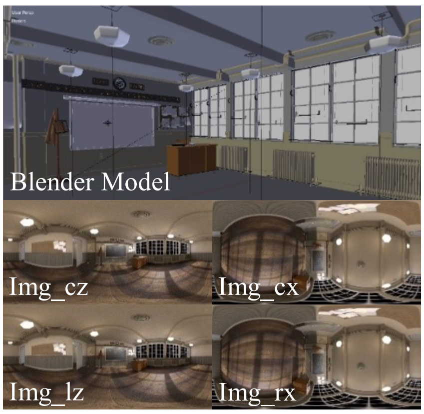

Fig. 2. Experiment environment and input images.

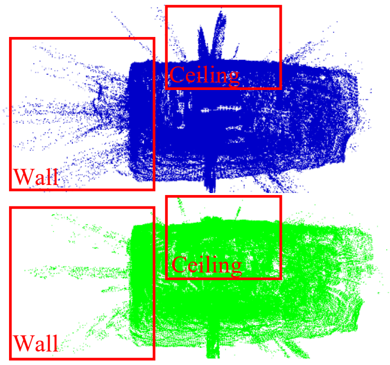

Fig. 3. Experiment result. Blue point cloud: before optimization; Green point cloud: after optimization.

TABLE I. Measurement Error Analysis

	Ceiling Area		Wall Area	
	Mean (%)	*SD*	*Mean (%)*	*SD*
Unoptimized	16.25	15.01	9.81	6.96
Optimized	6.48	5.23	7.17	4.47

The measurement result in the boxes in Fig. 3, which are the areas in the epipolar directions are analyzed. From the mean and standard deviation value shown in Table 1, it can be clearly seen that the accuracy in the areas along the epipolar directions in the ceiling and on the wall is improved. The error and distortion of reconstruction is eliminated.

IV. Conclusion

In this research, a novel method was proposed to improve the 3D measurement accuracy in the epipolar directions. With the three input images including errors, the proposed method can successfully eliminate the error in the output measurement result. Since the accuracy of the distance from two sets of binocular stereo is very different in the area along epipolar directions and it is not clear that which one is more accurate, the proposed method leads to a better result than taking the weighted average.

We intend to extend this method to the all-round 3D measurement. Besides the area in epipolar directions, the accuracy is expected to be improved in the area where the results of two sets of binocular stereo do not agree. We plan to introduce more factors to the optimization cost function and evaluate the accuracy improvement with quantitative evaluation for better accuracy and smoother reconstruction.

References

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