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Development of Easy Camera Calibration Tool under Unified World Coordinate System Using Online Three-dimensional Reconstruction

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Abstract: Three-dimensional position information is essential in order to give appropriate support for human beings in an intelligent space. Distributed cameras in an intelligent space have to be calibrated for acquisition of three-dimensional position. Since calibration of many cameras is time-consuming, camera calibration method for easy construction of an intelligent space is needed. This paper proposes automatic camera calibration method based on image features and 3D information of minimal calibrated cameras. Image features and 3D positions are shared with uncalibrated cameras via network, and these cameras are calibrated with common image features. In this paper, the first experimental results with SIFT (Scale-Invariant Feature Transform) as image features are shown.

Keywords: camera calibration, stereo camera, 3D reconstruction, mobile robot, intelligent space

1 INTRODUCTION

In recent years, there are many studies on intelligent spaces [1]. Fig.1. shows a concept of the intelligent space for acquiring information on positions and states of robot and person by distributing various sensors and networked cameras in the environment. It is necessary to know three-dimensional geometric relationship between networked cameras and environment in order to achieve various applications based on object positions in intelligent space. In other words, networked cameras must be calibrated geometrically in unified world coordinate system fixed to the environment.

Tsai's calibration method [2] needs to know several corresponding points between three-dimensional world coordinates and two-dimensional coordinates in image plane. Then, these must be measured manually in advance. Zhang's calibration method [3] needs artificial checker pattern. In this method, each camera is calibrated in the different world coordinate system. That is not enough for geometrical calibration of distributed cameras in unified world coordinate system. Since the calibration has to be performed for every camera, it is very time-consuming that human operators calibrate many cameras distributed in the environment with corresponding points or a plane checker pattern as usual. Even if intelligent space is large area, many cameras in the environment are desirable to be calibrated with small manual operation. These cameras must be also calibrated under unified world coordinate system. Camera calibration in unified coordinate system with cooperative positioning system [4] was proposed as a solution of such a problem. In this method, two robot-groups measure three-dimension position each other and move while measuring the other robot positions. On the other hand, geometrical relationship between cameras and environment can be also acquired with Structure from Motion (SFM), such as Parallel Tracking and Mapping (PTAM)[5].

This study introduces a calibration system under unified world coordinate system of networked cameras distributed in the intelligent space. The system uses a portable stereo camera and a mobile robot for calibration. World coordinates of natural corresponding points based on SIFT (Scale-Invariant Feature Transform) [6] are calculated according to localization of the portable stereo camera installed on the mobile robot. The detailed approach is as follows.

Self-position estimation of the mobile robot is used for localization of the portable stereo camera. World coordinates of natural feature points in stereo camera images are calculated using localization results. World coordinates of natural feature points are shared with the uncalibrated network cameras for calibration. However, camera calibration with natural corresponding points based on SIFT often fails. It is caused by that natural corresponding points are concentrated locally and that natural corresponding points include many mis-matched points.

It is desirable that successful calibration is distinguished from unsuccessful one easily by the human operator. In this study, the system for checking calibration conditions online is developed. This system includes matching of SIFT features, calculation of camera parameters, optimization of camera parameters and showing three-dimensional grids for representing calibration results online. Especially, matching of SIFT features take much processing time. In this study, online three-dimensional reconstruction of image features is achieved by fast calculation and matching of SIFT features with GPU.

Accordingly, the human operators of calibration system can calibrate the network cameras distributed in the intelligent space easily by moving the stereo camera on the mobile robot to front of uncalibrated network cameras. In this paper, detailed system configuration and performance of the system will be described.

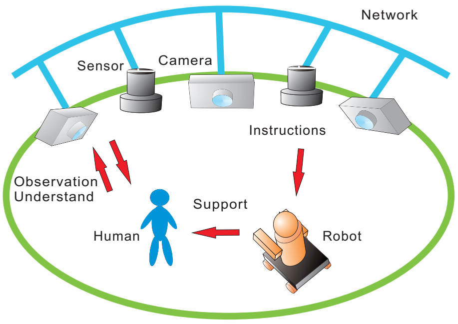

Fig. 1. The concept of the intelligent space

2 EASY CAMERA CALIBRATION SYSTEM

2.1 Proposed System

Fig.2. shows a flow chart of the proposed method. In this study, three-dimensional feature points measured by a portable stereo camera are used for calibration of networked cameras distributed in the intelligent space.

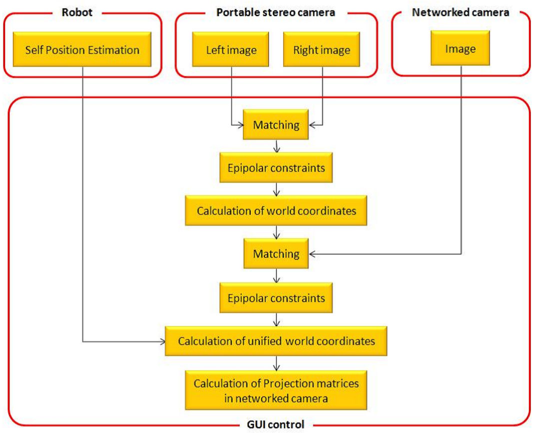

Fig. 2. Flow char t of the proposed method

2.2 Position Estimation of Portable Stereo Camera

A mobile robot with the portable stereo camera is manually controlled so that the view of a stereo camera can overlap with the view of a networked camera. Positions and orientations of the mobile robot are calculated by applying any self-position estimation algorithms of a mobile robot. Then, positions of the portable stereo camera in the unified world coordinate system can be obtained.

2.3 Matching of Feature Points

Matching points between images of a portable stereo camera and an image of a networked camera are calculated using SIFT features. Examples of many matched future points are shown in Fig.3..

However, several mis-matched points are found. These mis-matched points make an accuracy of estimating camera parameters of the networked camera worse. These mis-matched points are removed by a method based on epipolar restraint. Fig.4. shows results of removing mis-matched points in Fig.3..

Fig. 3. Matching of feature points among three images

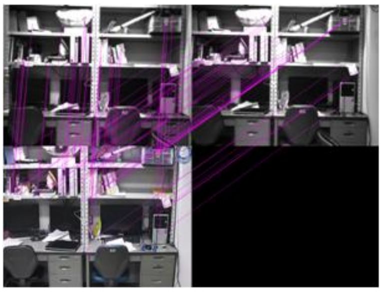

Fig. 4. Matching removed noise among three images

2.4 Positions in Unified World Coordinates

Fig.5. shows a method to calculate three-dimensional positions by the stereo camera in the camera coordinate system. Common feature points extracted by SIFT and epipolar constraints. Then, three-dimensional positions of feature points are calculated from stereo camera images. Of course, a geometrical relationship between left and right cameras of stereo camera is known.

Camera coordinates in the stereo camera must be transformed to unified world coordinate system. Fig.6. shows relationship between the camera coordinate system and the unified world coordinate system. Position estimation results of the mobile robot are applied.

2.5 Calculation of Camera Parameters

Camera parameters of the uncalibrated networked camera are calculated according to unified world coordinates of corresponding feature points between the networked camera and the stereo camera. However, camera parameters calculated

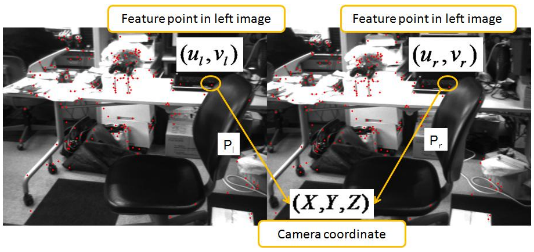

Fig. 5. Position calculation with stereo matching

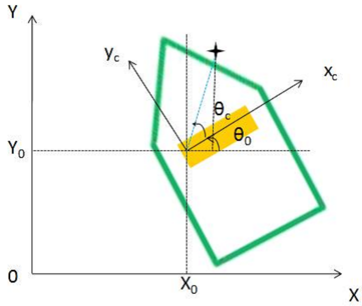

Fig. 6. Transformation between coordinate systems

in this level cannot reconstruct an accurate world coordinate system. Nonlinear optimization called Levenberg-Marquardt algorithm [7] is applied to optimize camera parameters. Details are shown in [8].

3 SYSTEM PERFORMANCE

3.1 Experimental Environment and Systems

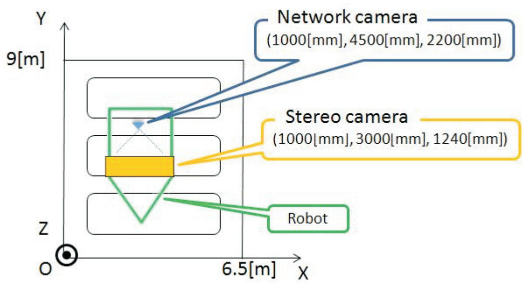

Fig. 7. Experimental environment

Position estimation of a moving stereo camera and calibration of networked cameras in the unified world coordinate system are performed as experiments. Bumblebee2 by Point Grey Research Inc. was used as the stereo camera. Canon VB-300 network camera was arranged in the intelligent space as the uncalibrated cameras for calibration experiment. Pioneer3-DX by MobileRobots Inc. was used as a mobile robot to mount the stereo camera. The stereo camera was calibrated using Zhangfs calibration method. All image sizes of cameras are 640 [pixel] 480 [pixel]. Fig.7. shows a sketch map of experimental environment. The Coordinates (1000[mm], 4500[mm], 2200[mm]) and the coordinates (1000[mm], 3000[mm], 1240[mm]) mean unified world coordinates of networked camera and stereo camera. Fig.8. shows the connection diagram of this system with RT middleware. All modules of the system are implemented as RT components. A matching component is implemented with GPU processing. Since it achieves high speed matching, it enables to estimate camera parameters online. Camera parameters calculation in the developed system became faster around 30 times than a system with a normal CPU.

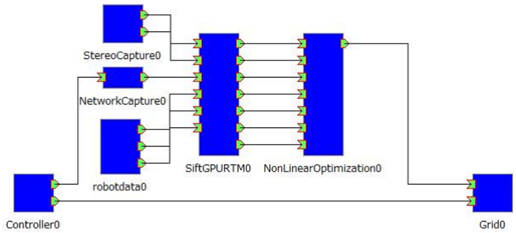

Fig. 8. Connection diagram of the system

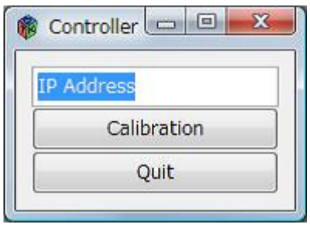

Fig. 9. GUI tool for calibration

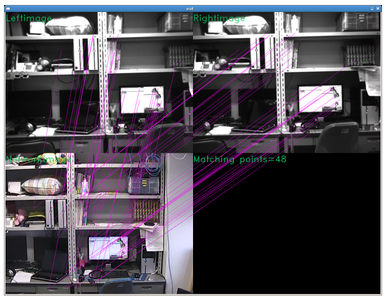

Fig. 10. Matching results

Fig. 11. Result of camera calibration

3.2 Calibration of Networked Cameras

A human operator controls the mobile robot to front of the target camera for making overlaps between the view of a stereo camera and the view of the networked camera. On a screen of computer, matching among the images of stereo camera and the image of networked camera, and three-dimensional reconstruction results are always displayed on-line. The human operator uses GUI shown in Fig.9. Calibration command is executed with this GUI when the accurate three-dimensional reconstruction results are displayed. Fig.10. shows results of matching. Fig.11. shows an example of three-dimensional reconstruction with calibration results.

3.3 Evaluation Experiment

Fig.12. shows an image of the target networked camera. In this figure, red points are selected and world coordinates of red points in the actual environment are measured manually for evaluations of calculated camera parameters. Green points represent the points projected using the world coordinates of red points and calibrated camera parameters. Errors between red points and green points are calculated. 1. shows the result of evaluation experiment. According to Table 1., there is the great difference between point where an error is small and point where an error is big. It is considered that is caused by that matching points concentrate locally. It can be used for the application like easy Augmented Reality (AR) which does not require highly precise camera calibration. There is room for improvement of this system. Concrete solution is introducing dynamic conditions so that matching points may be dispersively acquired according to a situation.

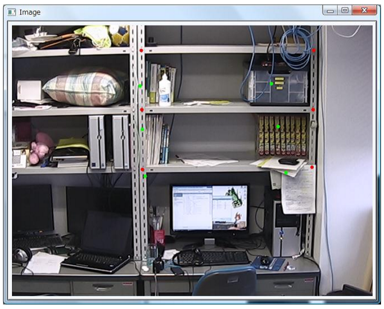

Fig. 12. Points for accuracy evaluation

Table 1. Result of evaluation experiment

Unified World Coordinates			Red		Green		Error
X[mm]	Y[mm]	Z[mm]	u	v	u'	v'	e
1040	470	1300	236	267	231	255	13.00
40	470	1300	486	261	532	251	47.07
1040	470	1650	231	184	230	149	35.01
40	470	1650	472	179	534	149	68.88
1040	470	2000	227	107	229	44	63.03
40	470	2000	460	103	535	44	95.43

4 CONCLUSION

This study proposed the camera calibration system in the unified coordinate system. The camera calibration method is based on estimating the position of the portable stereo camera and matching the feature points between the stereo camera and networked cameras.

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