Investigating Effects of Stereo Baseline Distance on Accuracy of 3D Projection for Industrial Robotic Applications

Wutthigrai Boonsuk
Eastern Illinois University
wboonsuk@eiu.edu

Abstract

Stereo cameras have been used in robotic field for decades. With recent advances in sensor technology, they become one of the most prominent sensors for automation in robotic applications. Fulfilling the need for rapid detection and recognition of complex environment, stereo cameras allow robots to quickly sense an environment by reconstructing 3D scenes from disparity maps. Typical stereo cameras have fixed baseline, a distance between the cameras, which lessens quality of disparity maps when objects become closer to cameras. The baseline of stereo cameras needs to be adjusted to accommodate minimum range between cameras and the object. Accuracy of 3D surface can be essential for particular robotic tasks such as welding, riveting, measuring, and assembly. This study investigated the effects of different stereo camera's baseline on the accuracy of 3D projection generated from disparity maps. The results showed a correlation between baseline distances and valid surface areas of target object. This finding can be valuable for researchers who want to design and develop effective stereo camera system and improve the quality of 3D projection. Although the current study focuses on stereo vision system for industrial robotic purposes, the results may also be applied to other robotic applications such as navigational robot and autonomous vehicle.

Introduction

Although stereo cameras have been utilized in robotic field for decades, only recently they become one of the most prominent sensors for automated robot. Stereo cameras allow robots to sense an environment by reconstructing 3D scenes of the surroundings from disparity maps. Despite their wide use, typical stereo cameras have fixed baseline (Figure 1) separating the cameras resulting in less effective disparity maps when objects get too close to the cameras. In order to reduce this problem, the baseline of the stereo cameras needs to be shortened to accommodate the minimum range between camera and the object. This paper investigates the effects of baseline adjustment on the accuracy of 3D reconstruction of the scenes from disparity maps. This information is crucial to create an optimal baseline for fixed baseline stereo camera system and as a first step to develop flexible baseline system.

The main objective of this study is to investigate the relationship between stereo baseline distances and the accuracy of 3D scenes that are constructed from disparity map. This study focuses on stereo vision system for industrial robotic application. Several stereo vision parameters were examined including adjusting baseline distances to maintain the quality of

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disparity maps, and determining minimum and/or maximum effective ranges for different baseline distances.

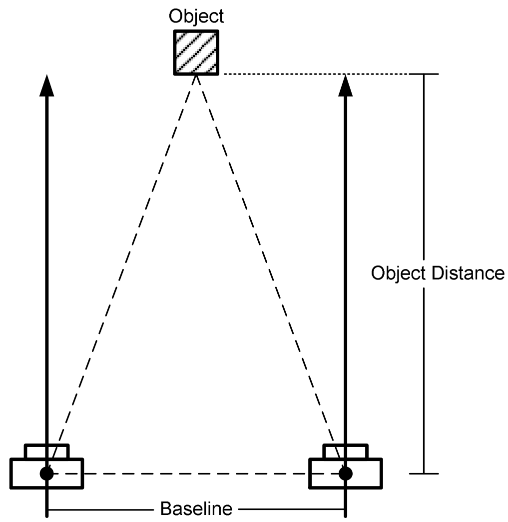

Figure 1: Stereo baseline

The accuracy of disparity map is crucial for building high quality 3D surface, particularly for robotic tasks that need high precision such as welding, riveting, measuring, and assembly tasks.The challenge in this study is that the cameras need a new calibration each time they are adjusted in order to obtain proper disparity maps. This can be troublesome as experimental design becoming more complex.

Literature Review

The fundamental idea of this paper is influenced by active stereo vision approach [2], [4], and [3] which is a framework of stereo vision that manipulates camera parameters, light conditions, and motor controllers. Conventional stereo cameras for robot arm have fixed baseline [8] which can cause problem when the object is too close to the cameras. Multi-baseline stereo has been introduced in earlier research to gain advantage from a set of stereo cameras with different baselines [6]. By using multi-baseline and multi-resolution [1], the depth error can remain constant because the baseline and resolution can be varied proportionally to depth. Rather than capturing a series of images from stereo cameras, another approach [5] proposed stereo system that utilized high speed slider to adjust stereo baseline. Similar method for constructing stereo camera system was utilized in the present study. Related work by Rovira-Mas [7] identified the best combination of baselines and focal length lenses that is suitable for agricultural robot vehicles with working range of 6-12 meters. However, past studies have not examined the relationship between stereo baseline adjustment and the accuracy of the 3D projection, but rather pick the best combination from the pool. This paper sought to extend prior work by describing the relationship between stereo baseline distance adjustments and the accuracy of 3D reconstruction from disparity maps. The solution is aimed to be used for industrial robotic arm applications.

Method

In this project, the custom-built stereo camera rig consists of two Raspberry Pi cameras (5 Megapixels; focal length = 3.6 mm) were connected to two Raspberry Pi boards. The cameras were mounted on linear motor screws that allow for setting cameras apart from 30 mm (1.1 inches) to 120 mm (4.7 inches).

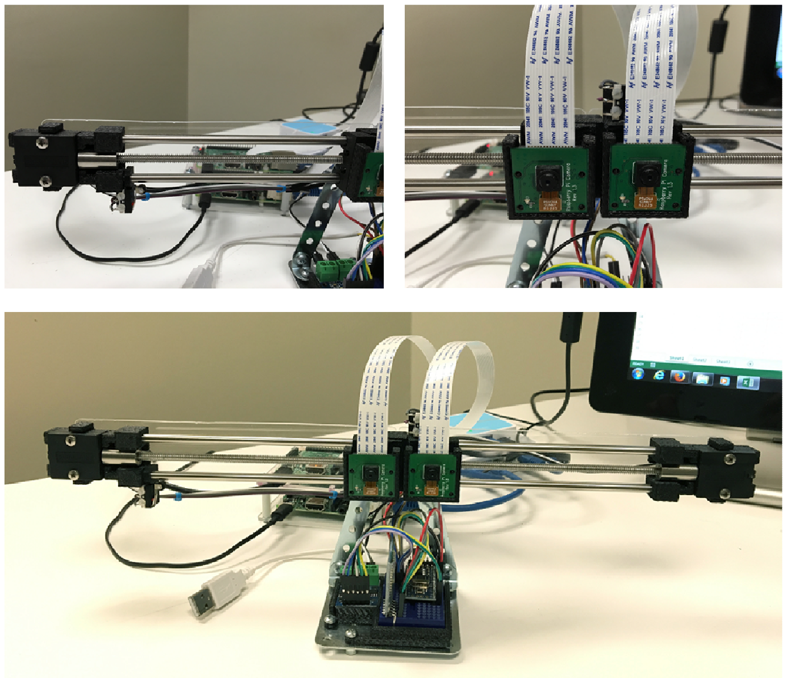

Figure 2: Stereo camera system

The stereo video signals were wirelessly transmitted through Wi-Fi connection. On desktop computer, OpenCV and Point Cloud Library (PCL) were used to analyze real-time video signals and to develop disparity maps using Semi-Global Block Matching (SGBM) algorithm. A set of experiments was conducted in the laboratory, as shown in Figure 3, the centers of cameras were set apart (baseline) at 15 mm increments (or 30, 45, 60, 75, 90, 105, 120 mm).

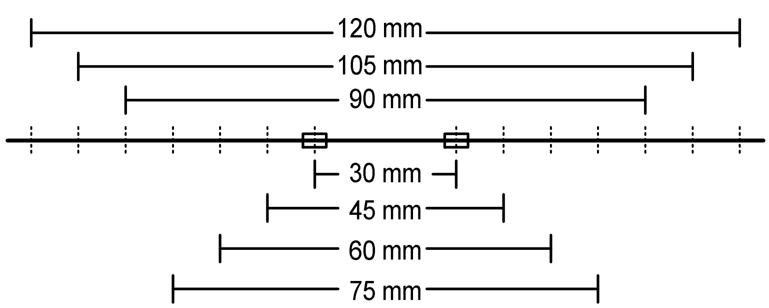

Figure 3: Baseline adjustment for the stereo camera system

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This camera system is planned to be implemented on a FANUC LR Mate 220iC which has maximum arm reach of about 700mm (27 inches). Thus, the object was first placed at 700 mm from the cameras and moved closer to the cameras in 100 mm increment (Figure 4: 700, 600, 500, 400, 300, 250 mm).

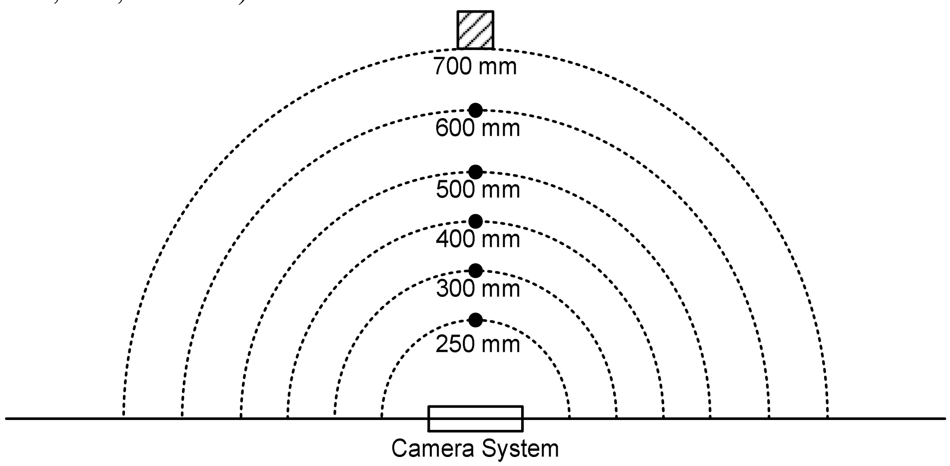

Figure 4: Target distances from the camera system

The target object is a 30 x 30 mm plastic cube with a 20 mm diameter through hole (Figure 5). This target is typically used for robot gripping test in the lab and was chosen to test the accuracy of the disparity map. The disparity map is generated for each pair of baseline and object distance. The 3D scene is reconstructed and analyzed for its accuracy.

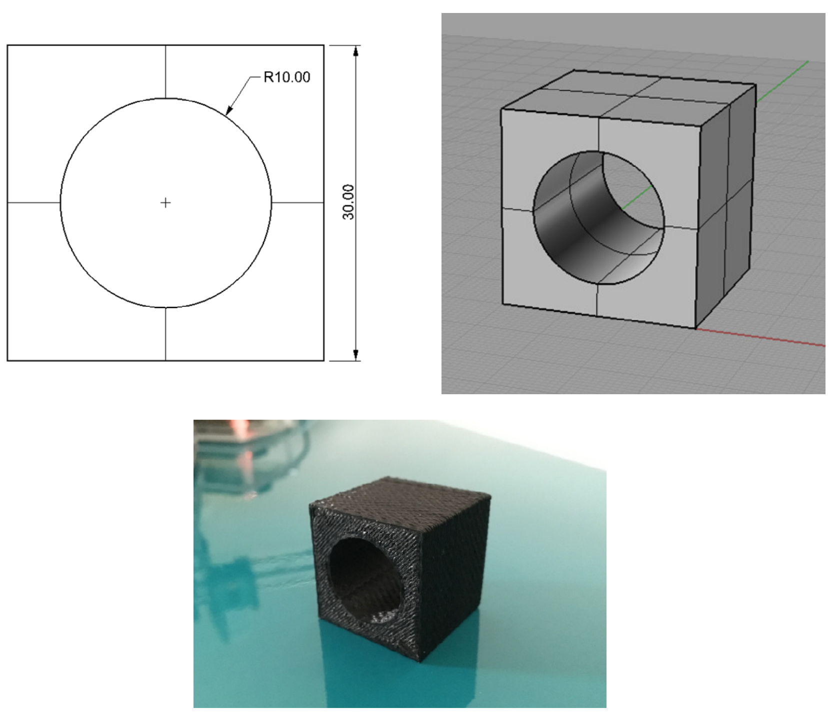

Figure 5: Target object

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Experiments and Results

At the beginning of the experiments, camera system was calibrated using checker board as shown in Figure 6. A recalibration was performed for each baseline distances. After the calibration process, camera matrixes were generated and stored as text files which later were used to compute disparity maps and generate surface point clouds of the target object.

Figure 6: Camera calibration process

The position of the target and camera's baseline distance significantly affected quality of the disparity map. It is found that at the baseline distances of 90 mm and above, disparity maps from the stereo camera generated extreme surface errors throughout all target distances, implying that the base line distances of 90 mm and above are not suitable to detect objects in the range under 700 mm. Thus, the results of this study will be discussed based on the baselines of 30, 45, 60, and 75 mm for stereo camera settings.

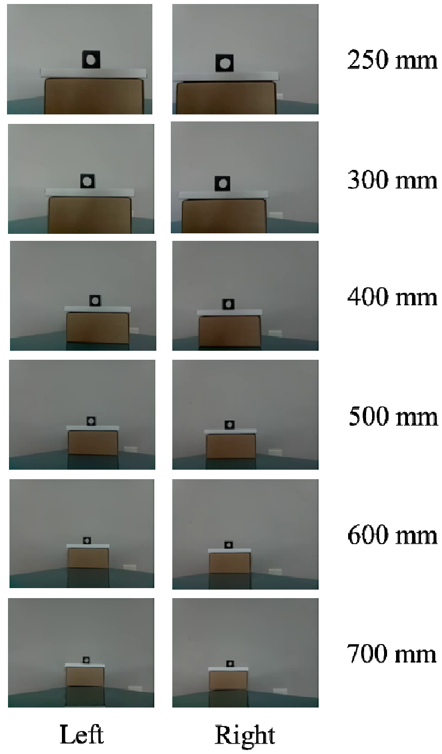

Figure 7: Stereo images for the baseline of 45mm

For each baseline setting, the target object was moved from 700 mm to 250 mm as shown in Figure 7. Disparity maps and point clouds were then generated.

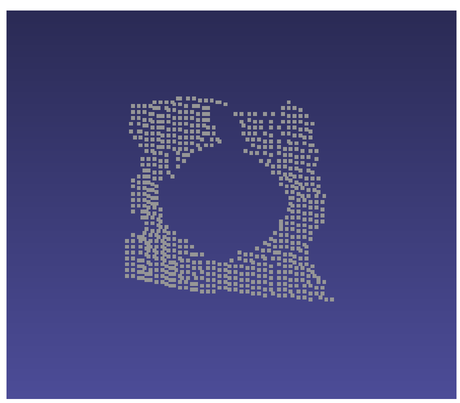

Figure 8: Example point cloud of target object

Three dimensional surfaces of the target were subsequently generated from these point clouds. Post processing processes were required on point clouds to remove noises and irrelevant points in the scene. The surface areas (square millimeters) were calculated to compare the ability of stereo camera with different baselines to pick up the surface of target object. It is hypothesized that the higher surface areas, the more effective the baseline on that specific distance.

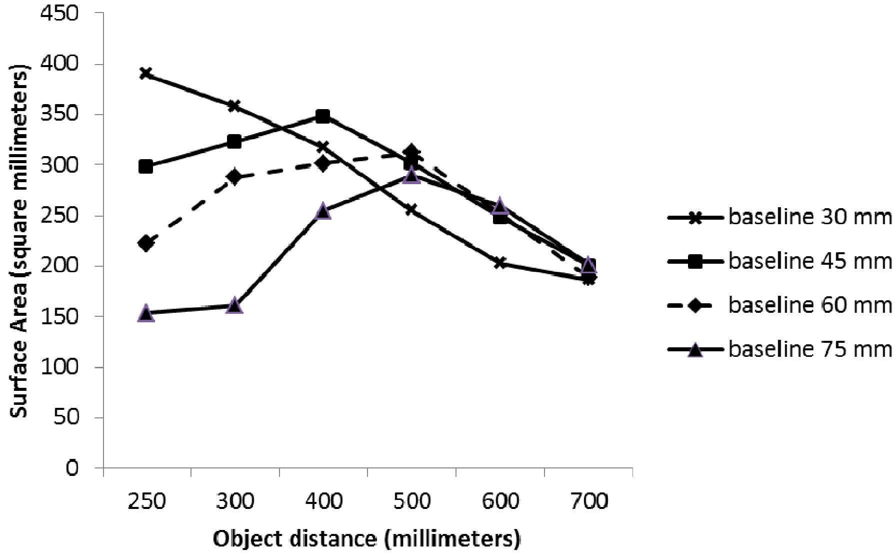

Figure 9: Chart of surface area of target object

Figure 9 and Table 1 present the results of the experiments. As displayed on Figure 9, stereo camera with 30 mm baseline was able to pick up most surfaces of the target at 200 mm and 300 mm from the target. At 400 mm distance, the baseline of 45 mm captured more surfaces than other baselines. At 500 mm and 600 mm distances, the camera with baseline of 45, 60, and 75 mm had very similar results, but they were all better than the baseline of 30 mm. At 700 mm distance, all baselines yielded similar results.

Table 1: Surface areas of target object

Object Distance	Surface Areas (Square Millimeters)			
	30 mm	45 mm	60 mm	75 mm
250 mm	389.32	298.61	222.57	153.36
300 mm	357.21	322.54	287.54	161.24
400 mm	316.47	347.93	301.26	254.87
500 mm	254.32	301.59	312.25	289.65
600 mm	201.97	247.63	251.27	259.31
700 mm	185.68	199.87	188.63	201.23

Discussion

Results from the experiments showed that stereo baseline distance can affect 3D projection of target object in different distances. In general, shorter baseline distances performed better at shorter distances, whereas longer baseline distances tend to perform better at longer distances. In addition, each baseline seemed to have its own peak spot where it can perform best at specific distance. There are several factors that might need to be considered before implementing this system, including calibration parameters, size of object, and light condition.

Obtaining optimal calibration parameters for camera system is challenging. These parameters appeared to be unique for each baseline distance. Future experiments can extend this study by identifying the relationship between baseline and the parameters, as well as creating an automatic system that can adjust without the need of recalibration each time. In this study, the size of the target object remained constant throughout the experiments. Providing various sizes of object may help identify the effectiveness of the 3D projection for larger baseline distances. Finally, light condition can influence the performance of the camera system in the experiment, especially when target object is placed further away from the camera. Future research can manipulate the lighting condition to confirm the results of this study.

Conclusion

In summary, this preliminary research implements stereo vision system for industrial robot. The results of this study suggest that adjusting the baseline distance of stereo camera can influence the accuracy of 3D projection from disparity maps. An optimal stereo system should have dynamic baseline adjustment, depending on the distance of target object.

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Biography

WUTTHIGRAI BOONSUK is an Assistant Professor of Applied Engineering and Technology at Eastern Illinois University. He earned his master and doctorate in Industrial and Manufacturing System Engineering and a master in Human Computer Interaction from Iowa State University. His work has focused on 3D stereoscopic applications, Manufacturing Systems, Rapid Prototyping, Robotic and Controller Systems, Virtual Reality, and Geographic Information System (GIS). He can be reached at wboonsuk@eiu.edu