Increased Automation in Stereo Camera Calibration Techniques

Brandi House and Dr. Kevin Nickels
Department of Engineering Science, Trinity University
San Antonio, TX 78212, USA

ABSTRACT

Robotic vision has become a very popular field in recent years due to the numerous promising applications it may enhance. However, errors within the cameras and in their perception of their environment can cause applications in robotics to fail. To help correct these internal and external imperfections, stereo camera calibrations are performed. There are currently many accurate methods of camera calibration available; however, most or all of them are time consuming and labor intensive. This research seeks to automate the most labor intensive aspects of a popular calibration technique developed by Jean-Yves Bouguet. His process requires manual selection of the extreme corners of a checkerboard pattern. The modified process uses embedded LEDs in the checkerboard pattern to act as active fiducials. Images are captured of the checkerboard with the LEDs on and off in rapid succession. The difference of the two images automatically highlights the location of the four extreme corners, and these corner locations take the place of the manual selections. With this modification to the calibration routine, upwards of eighty mouse clicks are eliminated per stereo calibration. Preliminary test results indicate that accuracy is not substantially affected by the modified procedure. Improved automation to camera calibration procedures may finally penetrate the barriers to the use of calibration in practice.

Keywords: Camera, Calibration, Stereo Vision, Robotics

1. INTRODUCTION

Robotic vision has very promising implications in both research and industry. Among the benefits derived from this technology is the ability to have a robot recognize objects and determine the objects' relative locations. Depth perception can be especially useful in mobile robots and in robots requiring hand-eye coordination. To facilitate the task of object detection, a pair of cameras can be used to implement stereo vision, in which triangulation between the two cameras and the object determines the location of the object relative to the cameras' internal coordinate systems. A system capable of using vision much like that of humans, though perhaps even more precise, opens worlds of possibilities. However, the practical applications of robotic vision are still quite limited, due in part to imperfections in system design, process implementation, and analysis software.

Two of the biggest flaws encountered are distortion in the lenses or other internal devices and errors in the system's view of the location of these cameras in the workspace. Intrinsic parameters are used to model the imaging process, and extrinsic parameters are used to model the camera's location in its environment. Camera calibration for stereo pairs of cameras determines values for both intrinsic and extrinsic parameters, and then uses software in the processor to internally correct the errors. Without calibration, the image delivered to the robot may be inaccurate, and the robot's response is likely to be proportionally skewed. Therefore, it is important to implement an accurate calibration method before stereo vision is used in robotic applications. There are many calibration methods currently available, with varying degrees of accuracy. However, the most thorough and accurate calibrations are also the most tedious and time consuming to perform. This research seeks to automate the most labor intensive aspects of a popular calibration technique developed by Jean-Yves Bouguet at the California Institute of Technology [4], as more automated calibration procedures are necessary to commoditize stereo vision and broaden its application for robotic systems.

2. EXISTING CALIBRATION SYSTEMS

Many researchers have spent countless hours developing accurate calibration procedures for cameras. Among these researchers are Zhengyou Zhang [5], Janne Heikkilä [3], and Jean-Yves Bouguet [4]. Each individual has contributed much to the field of camera calibration, and each has developed a toolbox that allows others to implement calibrations that involve algorithms related to their personal research. Although each procedure is relatively accurate, Bouguet's toolbox was chosen for this work due to its ease of use and well developed user interface.

In Bouguet's calibration technique, several images of checkerboards in various positions are captured by each camera simultaneously and then loaded into Matlab. The extreme corners of each of the checkerboard patterns are located manually with four mouse clicks, and the toolbox finds the locations of the corners of internal squares of the checkerboard. At this point other options can be selected to improve the results of the calibration, such as changing the value of the radial distortion coefficient such that the internal squares can be located more accurately. See Figure 1 for an example of such a modification.

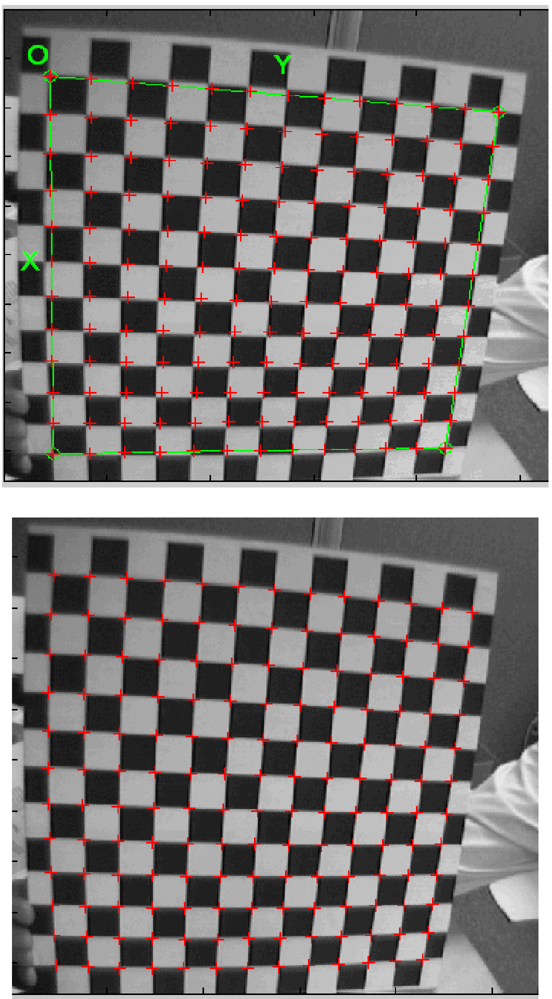

Figure 1: Example of improved corner extraction due to altered distortion coefficient [4]. The hash marks in the bottom image are much closer to the corners of the internal squares after the distortion coefficient has been altered.

Once the corners have been extracted for all right camera and left camera images, the algorithms in the toolbox calibrate each camera separately and then as a stereo pair. The stereo calibration produces two sets of intrinsic parameters (one for each camera), and one set of extrinsic parameters. The intrinsic parameters include values for the focal length of the lens, the principle point, the skew coefficient, and the distortion coefficient [2]. These values define internal imperfections of each camera that can be corrected by software. The extrinsic parameters include values for the rotation and translation of the right camera with respect to the left camera. Figure 2 was produced using Bouguet's toolbox, and it depicts a graphical representation of the extrinsic parameters produced by a stereo calibration.

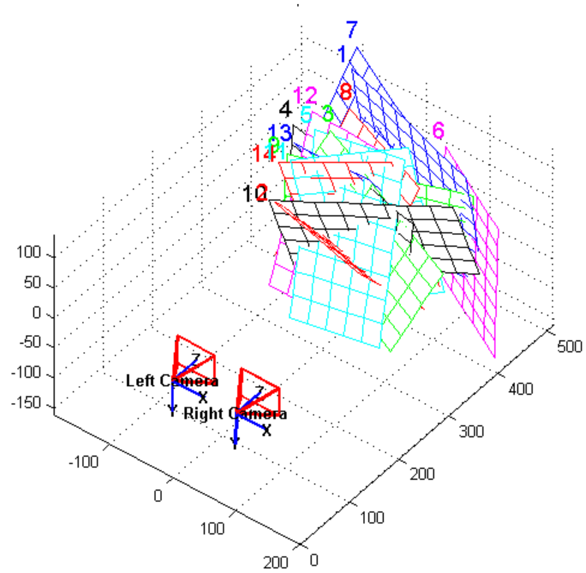

Figure 2: Graphical representation of extrinsic parameters [4]

Bouguet's calibration technique is widely accepted. However, it requires upwards of eighty very precise mouse clicks per stereo calibration. This can cause the process to be too tedious for regular use in industry and perhaps even in research that is not focused on calibration.

3. MODIFICATION TO CALIBRATION ROUTINE

As seen in Bouguet's procedure documented in the previous section, the most tedious aspect lies in the corner extraction. The modification attempted in this research seeks to eliminate the need for mouse clicks by embedding light emitting diodes (LEDs) in the four extreme corners of the checkerboard pattern to act as active fiducials, meaning that they serve as artificial points of reference to define the calibration area. The image acquisition algorithms used to take the pictures are modified to activate the LEDS, capture an image, deactivate the LEDs, and capture a second image, all in rapid succession. By allowing the two images to be taken almost instantly, image differences are minimized. A Matlab program subtracts the unlit images from the lit images and locates the four brightest spots remaining. Figure 3 shows the result of the image subtraction. Circles are added to these images to emphasize the location of the LEDs.

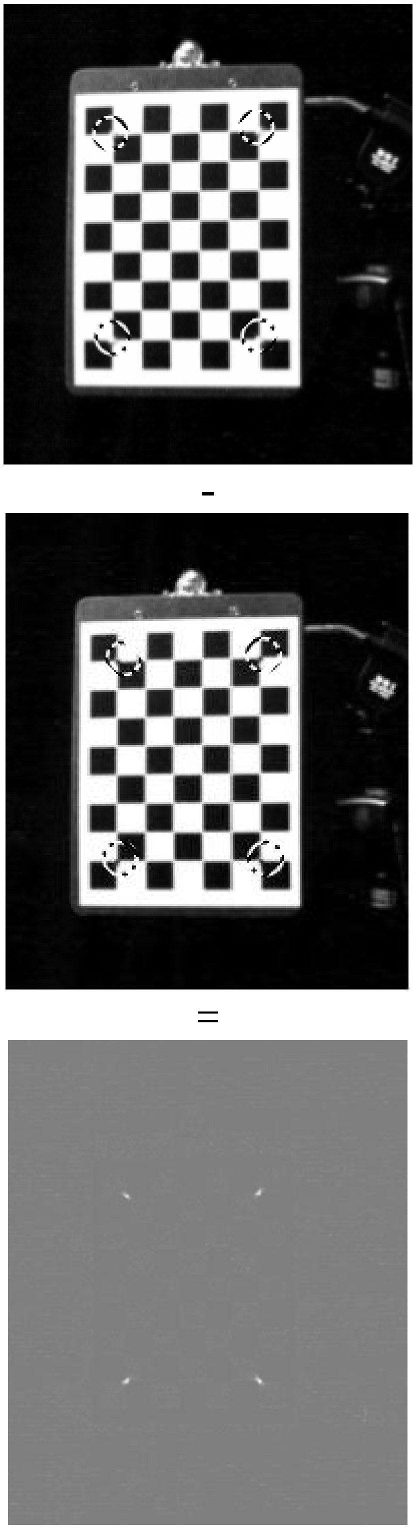

Figure 3: Image subtraction: 'LEDs On' (top) – 'LEDs Off' (middle) = '4 bright spots' (bottom)

The location of these four points is imported into Bouguet's corner extraction sequence as the location of the four corners to replace the manual selection. These points should be as accurate if not more accurate than those provided by manual selection, as human error is less likely to occur. Further automation could be added through the use of a robotic arm to move the checkerboard pattern to its various positions. However, this addition is beyond the scope of the current project. These proposed modifications would make Bouguet's calibration procedure much simpler, less labor intensive, and less time consuming.

4. RESULTS

As this research is still in progress, some aspects have not yet been accomplished. At this point, the corner extraction sequence has been modified, and the image subtraction technique is functioning properly; however, the LEDs must be turned on and off manually as the pictures are taken. Due to the time delay between the two pictures, some errors occur in photo differencing. Objects in the background may move slightly when there is a multiple second delay as opposed to a microsecond delay. Figure 4 depicts an image where the photo differencing and corner extraction would produce errors, as an object below the checkerboard pattern moved slightly or was illuminated differently between the two frames.

Figure 4: Erroneous image subtraction due to movement below the checkerboard.

To mitigate these problems, a black curtain is installed behind the checkerboard pattern, so that less movement between images. The final task required to fully accomplish the research goals is the automation of the LED activation and image captures.

Preliminary experiments are conducted to ensure that the accuracy of the modified procedure matches that of Bouguet's original method. To accomplish this comparison, experiments are run using the same pair of cameras in different settings. The first set of data is produced using Bouguet's original calibration method without any LEDs embedded in the checkerboard pattern. The second set of data is also acquired through

Bouguet's original method, except that the images contain unlit LEDs embedded in the checkerboard pattern. The third and final set of data is acquired through the modified calibration procedure by using the same images as the second set of data in addition to a set of images with lit LEDs. Although the first set of data uses different images than the second two sets, the results should still be very similar, as the same cameras and settings were maintained during all image captures. Table 1 compares the values of focal length and distortion coefficient found for the left camera in each method and Table 2 compares the values of rotation and translation for the pair of cameras in each method.

Table 1: Intrinsic Parameter Comparison (all units in pixels)

	Original Method: No LEDs	Original Method: with Unlit LEDs	Modified Method: with LEDs
Focal Length:	749.52	755.99	743.95
Distortion:	-0.190	-0.174	-0.201

Table 2: Extrinsic Parameter Comparison (all units in pixels)

	Original Method: No LEDs	Original Method: with Unlit LEDs	Modified Method: with LEDs
Rotation:	0.00	0.01	0.00
Translation:	162.07	163.65	162.50

As seen in Table 1 and Table 2, the results of each calibration are very similar, so this preliminary testing shows that the modified calibration system increases the automation of Bouguet's procedure without sacrificing its original accuracy.

5. CONCLUSIONS

The modified calibration technique discussed in this paper requires further development to improve its accuracy and convenience. Preliminary results show this calibration method to be substantially equal in accuracy to Bouguet's original method. This method's attempt to combine accuracy and efficiency to facilitate high quality stereo vision is very close to success. A calibration method that is extremely accurate but is not used does not benefit an operational robotic system. Improved automation may finally penetrate the barriers to the use of calibration in practice.

6. ACKNOWLEDGEMENTS

The authors of this paper wish to express their appreciation to the Trinity University Herndon Fund for Undergraduate Research and the Engineering Science Department at Trinity University for financial support of this work. We also recognize NASA for their donation of the Biclops seen in Figure 5 that was used as a camera mount. This paper was presented in part at the National Conference for Undergraduate Research, Virginia, April 2005.

Figure 5: Picture of Biclops used in research

7. REFERENCES

[1] Berthold K. Horn, *Robot Vision* (Cambridge: The MIT Press, 1986), 299.
[2] Hartley, Richard and Zisserman, Andrew, *Multiple View Geometry* (Cambridge: University Press, 2003), 153.
[3] Janne Heikkilä, "A Four Step Camera Calibration Procedure with Implicit Image Correction," *Infotech Oulu and Department of Electrical Engineering*, http://www.vision.caltech.edu/bouguetj/calib_doc/papers/heikkila97.pdf.
[4] Jean-Yves Bouguet, "Camera Calibration Toolbox for Matlab," Intel Corp, 2004, http://www.vision.caltech.edu/bouguetj/calib_doc/.
[5] Zhengyou Zhang, "Flexible Camera Calibration by Viewing a Plane from Unknown Orientations," *Microsoft Research*, http://www.vision.caltech.edu/bouguetj/calib_doc/papers/zhan99.pdf.