Projector Calibration for Pattern Projection Systems

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ABSTRACT
In this paper we proposed a method for geometric calibration of a projector. This method makes use of a calibrated camera to calibrate the projector. Since the projector works inversely with a camera i.e., it projects the image instead of capturing it, so it can be considered as a reverse camera. The projector is calibrated with the help of a calibrated camera using two types of chessboard, a printed chessboard and a projected chessboard by the projector. The object points of the projected chessboard pattern are measured with the help of calibrated camera and the image points are directly acquired from the chessboard pattern to be projected. Then using these object points and image points the projector is calibrated. Once the projector calibration is done, the transformation matrices (from projector to screen, from camera to screen and from camera to projector) are determined which are used for the reconstruction of the 3D geometry.

Keywords: calibration, extrinsic parameters, intrinsic parameters.

1. Introduction

The 3D shape measurement and reconstruction has become one of the hottest fields in computer vision and robotics during the past few years. Researchers from various fields like computer vision, robotics, mechatronics, intelligent manufacturing systems and applied optics have worked enormously to find more robust, less complex and faster techniques [1, 2]. These techniques are being adapted for medical, rapid prototyping, defense and other numerous industries. Based on their characteristics, these techniques are divided into two subgroups. The first one includes the use of stereovision system. This system makes use of two cameras to measure and recover the 3D geometry. The images of the objects are taken by both cameras from different positions and orientations simultaneously. Triangulation is then used to measure the 3D geometry. The bottle neck in the stereovision system is the correspondence. That is, to find the corresponding points in the projection of the scene in one camera to the points in the other camera. To cop with the correspondence problem, various image processing techniques are used. The correspondence problem is not involved in the second method. In this method the projector projects a structured light on a 3D geometry which is captured by a single camera. During the past few years a lot of work has been done on this technique and many people have come up with some very diverse ideas. This technique of reconstructing and measuring the 3D geometry is faster, robust and inexpensive; especially these days the decreasing prices of projectors and CCD camera has made it easy to have a 3D measurement system. But before doing any re-construction and measurement process the projector and the camera system must be calibrated. Researchers have investigated camera calibration deeply thus, there are different algorithms for this purpose.

For projectors there are two kinds of calibrations: The photometric calibration and the geometric calibration. The photometric calibration deals with the intensity values correspondence of the projected images and the images captured by the camera. This research focuses on the geometric calibration of the projector which deals with the calculation of the intrinsic and extrinsic parameters of the projector. Many researchers have worked on the geometric calibration of the projector.

Zhang and Huang [3] came up with the idea of capturing images with a projector. The projector is used to capture images like a camera, in this way the projector can be calibrated like a camera. The main difficulty lies in making the special setup of white and red light illumination. Apart from this detailed calculations, to find the absolute phase map make it a math heavy and time consuming method. Li and Shi [4] also proposed the calculation of the DMD image i.e., the image taken by the projector and make use of vertical and horizontal fringe patterns to recover the points seen by the projector, thus making it a time consuming method too. Gao and Wang [5] have done the projector calibration using homographies. That is a nice idea too but the problem is with the red and blue pattern they used like Zhang and Huang. They also use a very big chessboard pattern for which a camera with wide FOV is needed. A wide FOV results in the image distortion.

Because much work has been done, by researchers on camera calibration, in this work the projector calibration for the 3D measurement system is done based on the principles of the camera calibration.

The rest of the paper is arranged as follows; Section 2 describes the basic concept of camera calibration and how is it done in OpenCV. Section 3 sheds some light on projector calibration. Section 4 gives the 3D shape measurement system setup. Section 5 gives the results of experiments and their verification in OpenCV and finally the conclusion and future work are given.

2. System model

2.1 Problem statement

Let us consider a point $(m_{pro}, n_{pro})^T$ in the projector's plane. This point is projected on an unknown 3D point $(X_w, Y_w, Z_w)^T$ in the world plane. The camera then takes the image of this point and as a result the point $(m_{cam}, n_{cam})^T$ is obtained in the camera's image plane. It can be observed that the projector acts as a reverse camera. The camera takes an image of the unknown point on the screen while the projector projects the known point onto an unknown point. Here the divided and conquer rule can be applied to solve the problem. The whole process can be divided into two parts.

1) The projector to the screen

2) The screen to the camera

The medium between the camera and the projector will be a chessboard that is attached to a plane and light sheet of plastic. Here we use a chessboard an 8×8 black and white squares. The size of each black or white square of chessboard is 20 mm × 20 mm. For calibration, we used the OpenCV, which is an open source computer vision library. The camera calibration process in OpenCV follows the Zhang's method [4]. A brief description of this method is given below.

2.2 Zhang's method

A lot of work has been done on camera calibration during the past decades. The latest method that is used by most of the researchers is Zhang's. This method uses pinhole camera model, which has focal length, pixel size, and skews factor as intrinsic parameters and the translation and rotation of the camera reference frame with respect to the world reference frame as extrinsic parameters. The calibration is simply a process that finds the intrinsic and extrinsic parameters of the camera. A brief description of Zhang's method follows.

This method uses a regular shaped object e.g., a chessboard pattern. Let $q_{cam} = (m_{cam}, n_{cam}, 1)^T$ be the 2D point in the image plane and $Q_{cam}(X_{cam}, Y_{cam}, Z_{cam}, 1)^T$ be the corresponding 3D point in the screen frame of reference. According to the pinhole camera model

$$q_{cam} = sM_{cam}(R_{cam} \mid t_{cam})Q_{cam} \quad (1)$$

In Equation 1. M_{cam} is the set of intrinsic parameters and (R_{cam}/t_{cam}) is the set of extrinsic parameters. 's' is an arbitrary scaling factor. The set of intrinsic parameters is given as:

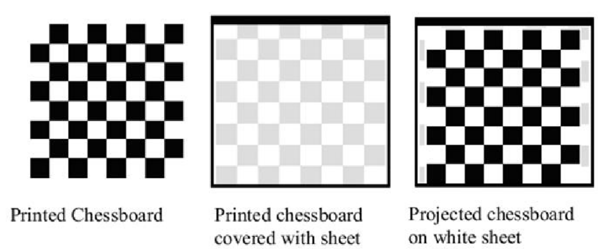

Figure1. Special chessboard setup