Introducing a New Radiation Detection Device Calibration Method and Estimating 3D Distance to Radiation Sources

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Abstract. Radiation detection devices; also known as particle detectors; are vastly used to track and identify radioactive sources within a given area. The 3D distance to such radioactive sources can be estimated using stereo radiation detection devices. In stereo vision, the devices have to be calibrated before they are used to acquire stereo images. In this work, we first introduce a new method to calibrate the stereo radiation detection devices using homography translation relationship. The radiation detection devices we have used in our approach are pinhole cameras. The calibrated pinhole cameras are then used to generate stereo images of radioactive sources using a pan/tilt device, and estimated the 3D distance using the intrinsic and extrinsic calibration data, and triangulation. Stereo vision cameras are used along with pinhole cameras to obtain coincident 2D visual information. We performed two experiments to estimate the 3D distance using different input image data sets. The inferred 3D distance results had around a 5~6% error which assures the accuracy of our proposed calibration method.

Keywords: Radiation detection devices, radioactive sources, Homography translation relationship, 3D distance, device calibration.

1 Introduction

Radiation has become one of the most widely discussed topics in around the world. Even though they are said to be having some negative corollaries, they play a significant role in many areas of science and industry including nuclear medicine, astronomy, environmental protection and nondestructive testing [1]. Many methods such as; conventional portable gamma cameras with various detectors and collimators have been introduced to acquire 2D images and information of radioactive sources in a particular area [2]. These images are processed to obtain the 3D position information along with image overlaying procedures to visualize the radioactive area in real world environments. Once the 3D distance to a radioactive source is estimated, the source activity (strength of the radiation source) can be estimated easily [2].

In 3D computer vision, device calibration is considered as the preliminary step to be followed. The necessity of device calibration is mostly encountered in many stereo-

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vision experiments. A proper calibration method always effects in higher accurate results. Many work related to camera calibration has been done throughout the past few decades [3, 4, 5, 6], [7, 8] but an accurate method to calibrate stereo radiation detection devices has not yet been introduced in computer vision society. Once the calibration relationship between radiation detection devices is known, 3D position information, 3D distance information, and homography matrices can be estimated accurately.

More accurate projector-camera calibration methods have been introduced in the recent past where the projector is considered as an inverse camera. In this inverse camera model, it is mentioned that a planar homography between the projector and the camera exists [6]. In this case, a separate calibration image; which is assumed to be the image obtained from the projector; can be generated. The generated image then satisfied with the homography translation relationship between the camera image and the projector image. A similar image acquisition method is used in this paper and the Zhang's method [3] is applied to calibrate stereo radiation detection devices.

The structure of this paper is as follows. Section 2 describes the pan/tilt scanning method used to generate radiation images. Section 3 comprehensively describes the method used to calibrate the devices along with the method used to find the homography translation relationships between radiation images and camera images. Two different experiments performed to estimate the 3D distance to radioactive sources are mentioned in section 4 which follows with the conclusion and future works.

2 Generating Radiation Images

In our approach, we have used a pan/tilt table to scan the area of the radioactive sources. The experimental setup is depicted in Fig.1. As it is mentioned in the figure, stereo pinhole cameras are mounted on the pan/tilt table. The rotation of the table in panning and tilting directions is simply controlled by a control board which is connected to a general purpose computer.

In our method, we followed two scanning procedures; a primary fast-scan to track the location of the radioactive source, and a secondary slow-precision scan to acquire the 2D information of radioactive sources within the region of interest (ROI). This procedure is depicted in Fig.2. The acquired information of radioactive sources are transmitted to the computer and radiation signal processing methods (filtering and quantizing) are applied to generate left and right stereo radiation images (Fig. 3). These generated radiation images are stored in the computer and sent for further image processing procedures.

We have used pinhole cameras as our radiation detection devices. Main reason is that pinhole cameras manage to produce radiographs and photographs of objects, which emit radiation and visible light. On the other hand, light is a form of radiation that spreads similar to gamma rays and other radiation sources. Considering it as a fact, we have used four bright LEDs (which are placed in the same plane) as our radioactive sources (Fig. 4).

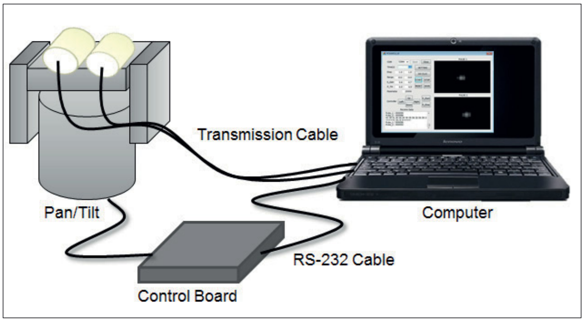

Fig. 1. The pan/tilt table with stereo pinhole cameras and the main control board connected to a pc via RS-232 cable

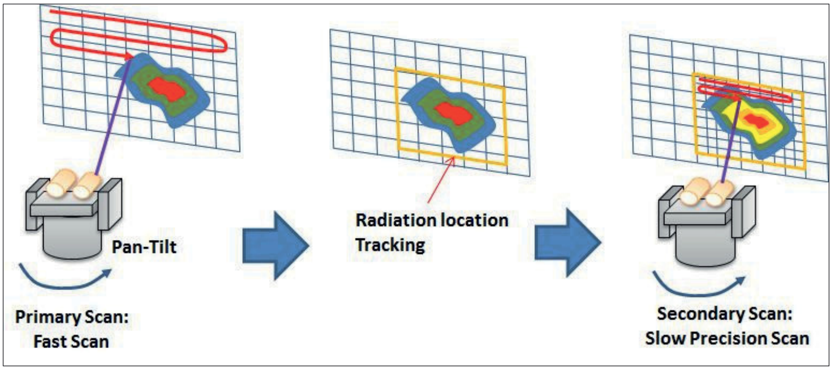

Fig. 2. Primary fast scan and secondary slow-precision scan used to track and acquire 2D information of radioactive sources. Yellow rectangle represents the ROI area

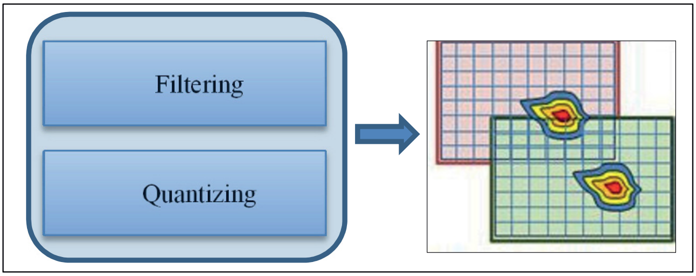

Fig. 3. Left and right radiation images are created from the processed scanned data. Filtering and Quantizing are the used signal processing methods.

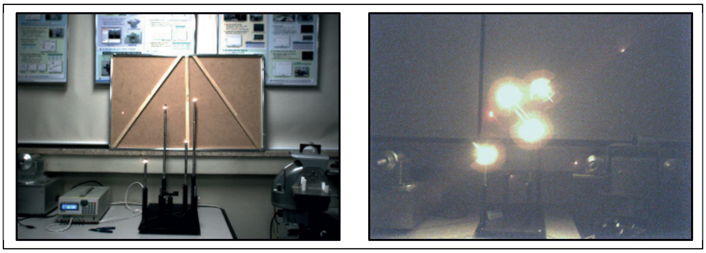

Fig. 4. Four LED lights on the same plane are displayed and used as radioactive sources

3 Calibrating Radiation Detection Devices

In device calibration, sets of left and right calibration pattern images are required. The quality of pinhole camera images compared to camera images is considerably low and consequently; they cannot be used directly to capture images of a calibration pattern image. Due to this fact, we have come-up with an idea to generate pinhole calibration pattern images using vision camera images. The same scanning method introduced in section 2 is used to generate pinhole camera images of 4 LED spots as mentioned in Fig. 4, and additional CCD cameras are mounted in-between pinhole cameras to capture vision images simultaneously (Fig. 5).

First we calculate the left and right homography relationships - H_{crl} , H_{crr} respectively- between vision and pinhole camera sets using these images. Fig. 6 depicts the setup used to calculate the homography translation relationships. These homography relationships are then applied to a separate set of vision camera images (images of a calibration pattern image taken according to Fig. 7), and generate a new set of virtual pinhole camera images. These virtual images are assumed as calibration pattern images obtained from pinhole cameras. Finally; the Zhang's camera calibration method [3] is applied on the virtual images to calibrate stereo pinhole cameras.

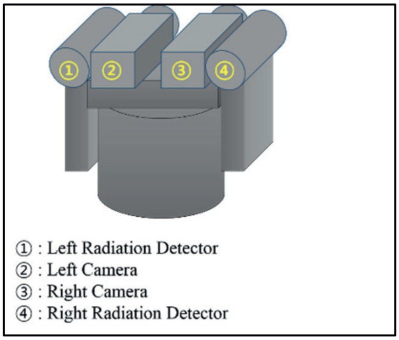

Fig. 5. Mounting additional stereo CCD cameras in-between pinhole cameras

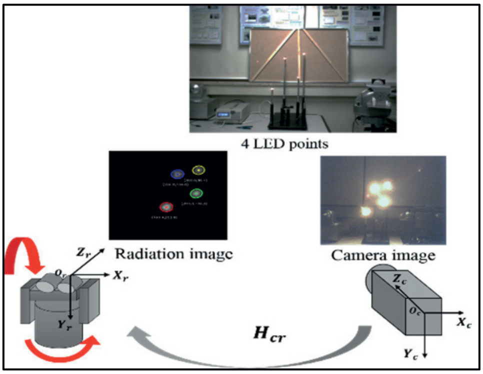

Fig. 6. Experimental setup used to calculate homography translation relationships. Pinhole cameras are mounted on the pan/tilt table.

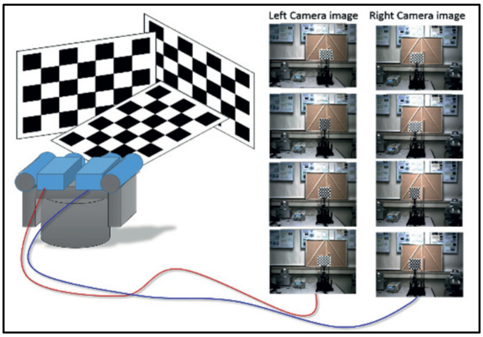

Fig. 7. Capturing images of calibration pattern image shown at a few different orientations using vision cameras

4 Experiments and Results

4.1 Estimating 3D Position

After device calibration; the intrinsic and extrinsic camera parameters can be obtained and they are used to calculate left and right perspective projection matrices (PPM). Fig. 8 shows a set of left and right stereo radiation images where image processing methods such as adaptive thresholding, contour detection and ellipse fitting are applied to find the center points $((u, v)\ and\ (i, j))$ of each radiation (LED) spot. Essential and Fundamental matrices can also be calculated using the camera parameters according to equations (1) and (2) and the Epipolar geometry is applied to identify the corresponding matching points of left and right radiation images. These correspondences are represented with identical colors in Fig. 8.

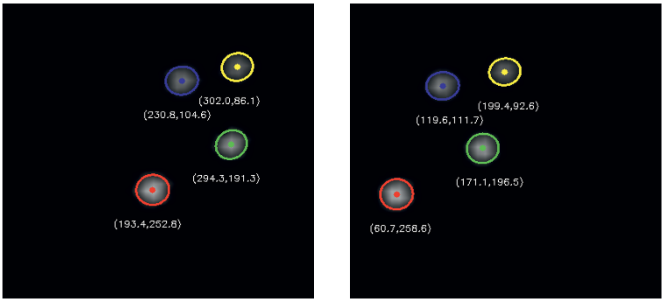

Fig. 8. Representing corresponding matching points found using Epipolar geometry

$$\mathrm{E} = \mathrm{R}\ [t]_x \tag{1}$$

$$\mathrm{F} = K'^{T^{-1}} E\, K^{-1} \tag{2}$$

E and F represent Essential and Fundamental matrices respectively. R $[t]_x$ is the cross product of extrinsic camera parameters whereas K' and K represent intrinsic parameters of right and left cameras respectively. The 3D coordinates ($W\ (X, Y, Z)$) for each matching point set can be calculated using linear equation (3).

$$\mathrm{AW} = \mathrm{Y} \tag{3}$$

Here A represents a 4×3 matrix, and Y represents a 4×1 matrix.

$$PPM^L = \begin{bmatrix} (a_1)^T & a_{14} \\ (a_2)^T & a_{24} \\ (a_3)^T & a_{34} \end{bmatrix} \qquad PPM^R = \begin{bmatrix} (b_1)^T & b_{14} \\ (b_2)^T & b_{24} \\ (b_3)^T & b_{34} \end{bmatrix}$$

$$A = \begin{bmatrix} (a_1 - ua_3)^T \\ (a_2 - va_3)^T \\ (b_1 - ib_3)^T \\ (b_2 - jb_3)^T \end{bmatrix} \qquad Y = \begin{bmatrix} (a_{14} - ua_{34}) \\ (a_{24} - va_{34}) \\ (b_{14} - ib_{34}) \\ (b_{24} - jb_{34}) \end{bmatrix}$$

The inverse of matrix A is calculated using singular value decomposition (SVD) method. Fig. 9 shows an example of how 3D coordinates are estimated for a one matching set. The same procedure is repeated to estimate the 3D coordinates of all the rest corresponding sets.

4.2 Distance Estimating Experiments

We did two experiments to calculate 3D distances and the results are depicted in Tables 1 and 2. In first experiment, we used 5 LED spots (similar to Fig.4) and measured the distances to each spot from a lower distance range (Table 1). The average error was around 4~6%. In second experiment, we used 4 LED spots and checked for the accuracy for a wide distance range. The average error was about 1~3% (Table 2).

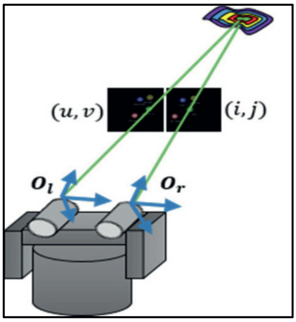

Fig. 9. Calculating 3D coordinates of a corresponding LED spot

Table 1. Estimated 3D distances of 5 points. Real distances are mentioned in *Dist* column in centimeters.

Dist (cm)	P1	P2	P3	P4	P5	Avg	Error(%)
80	76.359	79.686	72.617	74.676	77.845	76.237	4
100	91.879	95.920	91.078	92.503	94.615	93.199	6
120	113.686	114.789	112.715	113.890	113.065	113.629	5
140	132.484	134.443	132.024	129.567	131.881	132.080	5

Table 2. Estimated 3D distances of 4 points. Real distances are mentioned in *Dist* column in centimeters.

Dist (cm)	P1	P2	P3	P4	Avg	Error(%)
300	303.037	293.658	290.358	300.039	296.773	1
330	330.363	346.611	339.973	329.079	336.506	2
370	378.757	375.874	373.683	359.664	378.494	2
400	416.115	417.167	400.495	409.566	410.836	3

5 Conclusions

In this paper, we proposed a new method to calibrate radiation detection devices using homography translation relationships. Bright LED spots on a planar surface are used as radioactive sources and pinhole cameras are used as radiation detection devices. Pan/tilt scan method is used to generate radiation images. A set of calibration pattern images captured from vision cameras are converted into pinhole camera images by applying homography relationships between pinhole and vision cameras. Image processing methods are applied to find center points of LED spots and Epipolar geometry is applied to find the corresponding matching points. 3D coordinates were obtained with high accuracy using triangulation and the error was very low. As future work, we are planning to apply advanced stereo matching methods and image processing techniques and stereo matching methods to process radiation images and to detect n number of radioactive sources on a widely spread plane.

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