BIM-based Indoor Positioning Technology Using a Monocular Camera

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Abstract

In recent years, increasing attention has been paid to indoor positioning. This paper presents a BIM-based Indoor positioning technology using a monocular camera. This technology utilizes a monocular camera to obtain on-site image. An improved corner detection algorithm is used to identify the corners of the ground tile in the on-site image. Combining the geometric information from BIM, this paper completes the conversion of image pixel coordinates to the actual coordinates of the indoor ground. Based on the location information of camera in BIM model, this paper achieves the precise positioning of actual indoor target in BIM model.

Keywords

Indoor positioning; BIM; Image recognition; Computer Vision

1 Introduction

The research and application of real-time acquisition of 3-D position information of people and objects has become the hotspot in recent years. Real-time positioning technology is of enormous benefit in people's lives, promoting the progress of transportation and surveying[1]. Also, it plays a significant role in the AEC industry. The 3-D position information of construction personnel and machinery has wide application prospect in construction management, including schedule management, quality management, safety management and operation analysis[2].The Manuscript should not exceed 8 pages in length, including text, figures, tables, and references. Electronic file should not exceed 5 megabytes.

Previously, some scholars have developed several positioning and tracking methods for positioning personnel or machinery on the construction site. Yang et al identified people and specific machinery and realized action tracking by using trained classifier. Combining image recognition and pattern recognition, this method showed good performance in object recognition and tracking in on-site construction[3]. However, this method could not acquire the position information of object. Fang et al acquired real-time position information of target through 3-D point cloud technology[4]. This method used UAV equipped with high-definition camera to obtain image information from different angles in the air and developed a point cloud model. Then, the real-time position information of the target was obtained by matching the real-time image with the feature point. Although this method achieved the position tracking of on-site construction vehicle, it still had defects such as inapplicability to track interior objects of building, inaccurate position information, and sensitivity to complex environments. Compared to outdoor environment, the interior of building is more complicated. After literature review, a conclusion could be developed that the identification ability of computer vision complement with massive information (geometry, material, coordinates) in BIM model. In order to realize real-time positioning of indoor target, this paper presents a BIM-based real-time calibration and positioning method using monocular camera.

2 Literature Review

GPS (Global Positioning System) positioning, the most popular positioning technology nowadays, calculates 3-D position information of GPS receiving devices by using not only signal transmission between different satellites and GPS receiving devices, but also geometric relations. On the one hand, GPS has various advantages like wide range application, low cost, mature technology. On the other hand, GPS has some shortcomings. For example, civilian GPS has low accuracy of 10m[5]. The signals of GPS are susceptible to building disturbances. The accuracy of GPS could not meet with the requirement of indoor positioning. Aaron Costin at el combined BIM and RFID technology, in which RFID tags are pre-implanted into the target device and on-site RFID reader, as well as BIM reader, is used for reading position information. This realizes the positioning, tracking and visualization of target device[6]. UWB (Ultra Wide-Band) is another technology for indoor high-accuracy positioning. UWB needs to set base station with known coordinates. It uses receiving device to read the tag carried by target object and then calculates the relative position. The accuracy of this technology could be up to centimeters. Even though both RFID-based and UWB based positioning technology perform well in indoor positioning, they still strongly depend on pre-planted tags in target. In addition, UWB has defects like short signal coverage radius of only about 10 meters and expensive cost of $140 per square meter[7]. Aiming to solve above problems and realize indoor positioning without pre-implanted tags, Huang el al utilized a device equipped with two cameras to acquire image information. After conversion from RGB image to HSV space, they set threshold to generate binary image and identified the plate in the image. According to the principles of binocular calibration and stereo imaging, the authors calculated the 3-D coordinates of feature points in the plate edge[8]. This method could realize random target positioning without pre-implanted tags on the basis of binocular calibration and image identification. But it also greatly depended on the success matching of feature points. While complex indoor environment easily resulted in difficulties of extracting and matching the target feature points.

3 Methodology

In order to avoid the influence of collision and realize indoor positioning of target without pre-implanted tags, this paper presents a new BIM-based real-time calibration and positioning method using monocular camera.

Camera calibration is a process for solving parameters of camera imaging model. Here, imaging model represents the correspondence between a point in a spatial object and corresponding point in the image. When calibrating, it is necessary to obtain the real world coordinates corresponding to several pixel points in advance and the true distance between these points. BIM is not only a digital representation of the physical and functional characteristics of facilities, but also a shared knowledge resource[9]. Besides a 3-D visual architectural geometric model, BIM is an information model including semantic information such as construction project progress, cost. BIM could provide geometric information, i.e. accurate distance between specific points in the camera calibration phase. When camera calibration is finished, BIM could also provide position information to accurate indoor positioning. Based on reasons above, the methodology of positioning technology proposed in this paper is shown in Fig.1.

3.1 Camera Calibration

The function of the camera calibration is to find the correspondence between the pixel coordinates of the points in the image and the real coordinates of the corresponding points in the real scene. The correspondence could be expressed in matrix form as follows:

$$\begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = sMW \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} = sM[R \quad T] \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} \qquad (1)$$

where, x and y represent lateral and vertical coordinates of the point in the image respectively. X, Y and Z represent the real coordinates of the corresponding points in the real scene. M is a 3*3 matrix, standing for the intrinsic matrix of the camera. W is a 3*4 matrix, standing for the extrinsic matrix of the camera. R, a 3*3 matrix, represents the rotation matrix. T, a 3*1 vector, represents the translation vector. And s is a ratio with random scale.

From Eq. (1), the process of camera calibration is actually a calculation process of solving the intrinsic and extrinsic matrixes of camera. It is worth mentioning that the intrinsic matrix makes up of camera’s inherent parameters such as focal distance, which would not change with the external influence of image shooting angle, and degree of definition. If the intrinsic matrix of camera is known, the calculation will convert from finding correspondence between pixel coordinate and real coordinates to solving the extrinsic matrix of the camera. The extrinsic matrix of camera represents the relationship between the coordinates of camera itself and world coordinate system. It includes the rotation matrix R and translation vector T. The rotation matrix stands for the angle relation between camera coordinate system and world coordinate system. And translation vector represents the spatial distant relationship between camera and target point.

Nowadays, monocular camera calibration mostly uses the calibration method proposed by Zhengyou Zhang in 1988[10]. This calibration method uses a chessboard with known fixed-size grids as the calibration target. By recognizing the corners of the chessboard’s grids at multiple angles, the camera calculates the intrinsic matrix of camera and the extrinsic matrix of camera in each image. During calibration, it is important to input the number of corners and the size of grids, as well as strictly define the arrangement of the plane corners. Zhang’s method has the advantages of high calculation efficiency and high calibration accuracy. Yet when it comes to the calibration requirements in this paper, the size of chessboard is too small as compared to the whole indoor

Error! No topic specified.

Figure 1. Methodology

space to be used as standard calibration reference. With the observation that here is obvious corner feature in the joints intersect of ceramic tiles, this paper improves the calibration method based on theoretical basis of Zhang's calibration method and utilizes the characteristic corner of indoor ceramic tiles to realize calibration without a calibration plate.

3.2 Corner Recognition

As referred, the basis of camera calibration is the correct identification of corner in the target object. The existing corner recognition algorithm, based on Zhang's calibration method, only performs well when recognizing the corner of the black and white chessboard, which shows in Fig.2. As for the indoor condition, the algorithm could not identify the general indoor corner. In order to solve those problems, this paper has developed a more general algorithm for indoor ceramic tile corner recognition. The process of this algorithm shows in Fig.3.

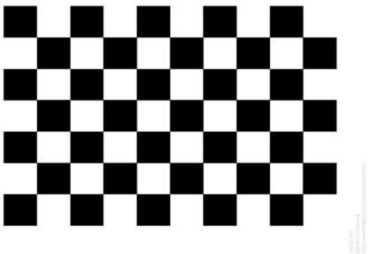

Figure 2. Chessboard

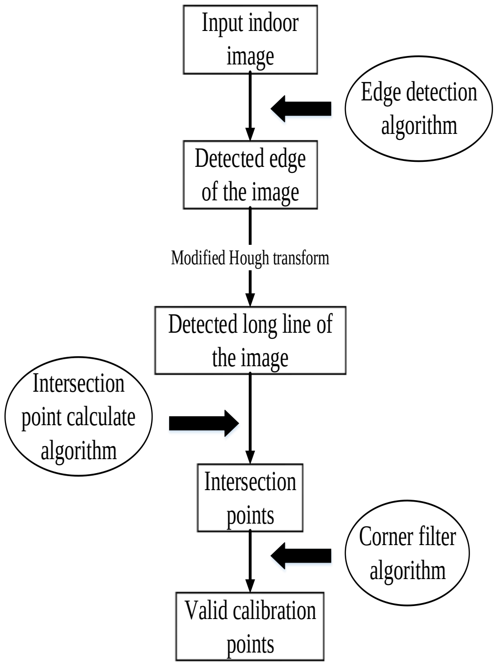

Figure 3. Calibration point extraction process

As Fig.4 (a), indoor ceramic tiles have obvious line feature in joints. For this property, this paper first uses the line detection algorithm to extract all the long straight lines in the image. And corner mostly exists in the intersection of two straight lines, shown in fig. 4(b). Therefore, the algorithm of calculating the intersection of two straight lines would be used in all the extracted straight lines from last steps. Inevitably, on-site construction images are influenced by factors like lights and sundries. This tends to produce disturbed straight lines and extra corners when extracting correct and useful ceramic tile corners. Moreover, because of the problems from shooting angles, it could not be guaranteed that the correctly recognized corners of ceramic tiles belong to the same piece of ceramic tile. Also, it is hard to arrange the order of the corners in the same way as a chessboard. During actual calibration, the real vertical coordinate, Z, of the calibrated point is usually set to 0. With Eq. (1), it just needs 4 calibrated points for finding the exact solution of extrinsic matrix. Thus, this paper used screening algorithm for searching for four corners in the same ceramic tiles. Then, these four corners are used as the final calibrated points, illustrated as Fig. 4(c).

Figure 4(a). Original indoor image

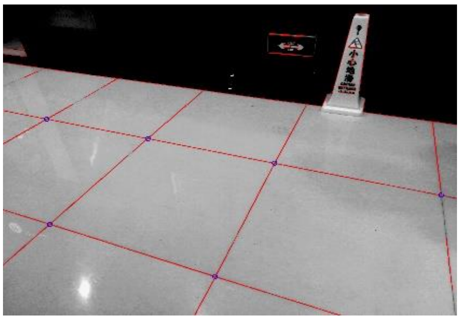

Figure 4(b). Detected lines and intersection points

Figure 4(c). Valid calibration corners

3.3 BIM Information Extraction

An important part of realizing camera calibration is assigning a predefined real coordinate to the calibration point of target. In Zhang's calibration method, predefined real coordinates are determined manually by pre-input according to the known size of chessboard. Based on the correct extraction of four corners in the same ceramic tile, this paper refers to the geometric information from BIM model directly without manually inputting coordinates.

BIM model contains the geometry and position information for all components of the building. Through automatic reading of the geometric information of the corresponding tile in BIM model, the technology proposed by this paper could achieve a fast automatic monocular camera calibration. When calibration is completed, the 3-D real coordinates of positioning target in the image will be determined by the solved coordinate transformation matrix. Strikingly, the 3-D coordinates, solved at this time, refer to the coordinates system established by four calibration points. For the sake of obtaining the actual coordinates of the target relative to the whole building, it's a key to read the camera's position information that predefined in the BIM model. After simple coordinates transformation, the target will be accurately positioning in the end.

4 Case Study

The proposed indoor positioning technology is verified in an academic building. This academic building has 6 floors and hundreds of sub-space including conference rooms, labs, classrooms, office rooms and so on. Then, an image shooting device is fixed on a lab in the 4th floor. And the intrinsic matrix of camera has been acquired by general camera calibration method.

Fig.5(a) shows the random image shooting by the fixed camera. Now, the blued stool is used as the positioning target for the verification of feasibility of the developed method. First of all, after the detection using the straight line detection algorithm, there are two problems. One is that the number of straight lines in the joints of ceramic tiles is too small. Another one is that a large number of disturbing invalid lines present in the rest of the image. With studying the original image, three reasons are found for these phenomena: (1) since the light is too strong in the left side of the image and makes serious reflection in the left side of the ground, there are a lot of small pieces of straight lines after initial detection; (2) the target itself has the linear characteristic; and (3) due to poor construction quality and long-term use, the width of ceramic tiles' joints are not uniform and sometimes the joints are too small to show the colors in the image. This results in difficulty of forming the straight line feature in lab's ceramic tiles. Fig.5(b) presents the intersection of straight line determined on the basic of straight line detection. From this, it is easy to know that invalid corners are occurred in disturbing straight lines. As expected, the four valid corners are still selected after doing the corner screening algorithm, shown in Fig.5(c). That indicates the algorithm for recognizing valid calibration points has the ability to resist indoor light changes and object interference.

Figure 5(a). Image with positioning object

Figure 5(b). Line and intersection points detect

Figure 5(c). Valid calibration corners

After the extraction of valid calibration points, the geometric information of ceramic tile is automatic obtained from BIM model. Fig.6 illustrates the geometric information of the ceramic tile. In this case, the size of ceramic tile is 39.5cm*39.5cm. The initial real coordinates (unit in mm) of the four valid points are (0, 0, 0), (0, 395, 0), (395, 0, 0) and (395, 395, 0), respectively. And the corresponding pixel coordinates of them are (415, 1945), (1162, 1375), (1283, 2401) and (1944, 1648).

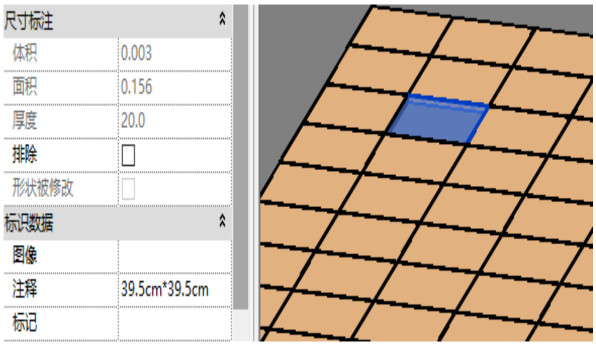

Figure 6. Geometry information of calibration object in BIM

According to the known intrinsic matrix of camera and the coordinates of valid calibration points, authors get the extrinsic matrix by using the function of solving extrinsic matrix. That function is from OpenCV, the open source library in computer vision domain. Then, authors obtain the coordinate transformation matrix of the image pixel and its corresponding real point. Now, in order to positioning the blue stool and find its real 3-D coordinates, a simple algorithm is used to select the positioning point determined by the triangle centroid of three stool feet. The coordinates of the positioning point are (2277, 1137) in the image, shown in Fig. 7. Then, a coordinate system is built with an origin in the lower left corner in Fig. 5(c). Based on this coordinate system, the real 3-D coordinates of the positioning point are (256.3, 590.5, 0), calculated by the matrix transformation algorithm. For the aim of positioning target object in the whole building, the position information of camera is read from BIM model. In this case, the camera is located 75cm above the 4th floor and the lower left corner of the whole building is treated as the origin of coordinate system. Accordingly, the camera coordinates are (4220, 2377.5 11550) and the coordinates of the lower left corner in Fig. 5(c) are (-945, 790, -750) relative to the camera. Finally, the real coordinates of target are (3531.3, 3758, 10800). The comparison between the coordinates of the target and the on-site actual measurement results is shown in Table 1.

Figure 7. Positioning point of the object

Table 1 Comparsion between calculated coordinate and real coordinate

Direction	X	Y	Z
Calculated coordinate （mm）	3531.3	3758	10800
Real coordinate （mm）	3580	3917.5	10800
Accurancy （%）	98.64	95.93	100

From Table 1, the proposed method in this paper has high accuracy. And with the use of BIM, the height information could guarantee 100% accuracy. However, the errors of X and Y directions could be up to 10cm. Through analysis, two reasons are found: (1) the number of valid calibration points chosen for calibration is not enough so that the resulting transformation matrix may not be the optimal solution; and (2) there is a major error in selecting positioning point of target object.

5 Conclusion and Future Work

5.1 Conclusion

After analyzing the shortcomings of various positioning technology like GPS and UWB, this paper proposed a new indoor positioning method combining monocular camera calibration and BIM technology. The main results are as follows:

- Proposed the camera calibration method implemented by using indoor ceramic tiles and geometric information from BIM model without the use of chessboard-like calibration plate;
- Developed a new corner recognition algorithm by combining straight line detection algorithm and line intersection algorithm;
- Developed a corner screening algorithm for the extraction of valid calibration point;
- Established a complete indoor positioning process by using the camera position in BIM and the coordinates transformation relation of camera calibration;
- Realized the positioning of target object in one lab of a 6-floor academic building with 100% accuracy in Z direction, 95% accuracy in X and Y directions.

5.2 Future Work

There are some limitations and shortcomings in the proposed indoor positioning method. For instance, since there are a lot of pixel points around each stool feet in the image, using triangle centroid of three stool feet as positioning point in the case study has a negative influence on the accuracy of positioning point. This brings major error to the selection of target positioning point. Furthermore, the deformation of the stool due to imaging principle also causes difficulties in the selection positioning point.

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