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Automatic indoor progress monitoring using BIM and computer vision

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Abstract: Nowadays, the existing manual method for recording actual progress of the construction site has some drawbacks, such as great reliance on the experience of professional engineers, work-intensive, time consuming and error prone. A method integrating computer vision and BIM(Building Information Modeling) is presented for indoor automatic progress monitoring. The developed method can accurately calculate the engineering quantity of target component in the time-lapse images. Firstly, sample images of on-site target are collected for training the classifier. After the construction images are identified by edge detection and classifier, a voting algorithm based on mathematical geometry and vector operation will divide the target contour. Then, according to the camera calibration principle, the image pixel coordinates are conversed into the real world Coordinate and the real coordinates would be corrected with the help of the geometric information in BIM model. Finally, the actual engineering quantity is calculated.

Key words: indoor progress monitoring, BIM, computer vision, object identification

1. INTRODUCTION

Progress control is one of the three control objectives of construction management. Accurate and timely actual progress statistic is the key to better progress control. Current method of collecting as-built progress data require manual data collection, making progress monitoring a work-intensive, time-consuming, and error prone process. In order to make up for the shortcomings of traditional statistical methods, some scholars have put forward a variety of intelligent progress statistical methods, which are mainly based on RFID(Radio Frequency Identification), 3D laser scanning technology and computer vision technology. Yoon et al. [1] proposed a method applying RFID to engineering progress control. This method requires the pre-implantation of RFID tags for each component. The field receivers can transmit the information in the tag in real time so that managers can obtain component installation through the network everywhere. Kim et al. [2] proposed a fully automated registration process to align the 3D point-cloud data with 3D CAD model. By calculating the number and the percentage of the points in the 3D CAD model for each floor, Kim's method could automatically determine the progress of the project. However, RFID-based progress monitoring technology requires the implantation of tags in every component. Enormous components in the construction site make the tags hard to manage. Furthermore, it costs a long time for the 3D laser scanners to generate the point cloud model, which is not suitable for large construction project. In addition, both RFID technology and the integration of point cloud and BIM stay on determining the completing condition of components, without calculating actual engineering quantity of components during construction process. With the rapid development of image acquisition equipment and the rapid evolvement of image processing algorithms, the actual progress monitoring method based on computer vision has the advantages of low cost, high accuracy and easy to use. Golparvar-Fard and Sridharan [3] used time-lapse photography to capture the on-site images and compare the actual progress of the components in the image with the 4D BIM model. Meanwhile, different colors were used for different construction progress. Progress is shown in on-site image using AR(Augmented Reality) technology. On the basis of previous studies, Golparvar-Fard and F. Pe [4] utilized different depth of color to express the duration of the delay, such as light red for a week delay of the components, dark red for more than three weeks' delay. Although the studies mentioned above integrated image processing and BIM, judging the actual progress still depended on manual experience entirely. In order to realize automation monitoring of project progress, Kim et al. [5] got images of a bridge from a fixed camera and 4D BIM model in the same view, respectively. Then the shelters were removed by HSV and binary processing, and compared processed image with mask image. Finally, this research succeeded in the automated monitoring of construction progress. Nevertheless, previous method for progress monitoring stayed on the component level, and had shortcomings in recognizing the process of a certain component during construction progress. Hence, in 2014, Dimitrov et al. [6] trained a classifier that could identify the surface material of component within an image. This effort achieved the automation progress control in construction process level. Considering that most of the research focus on the overall outdoor schedule control and the indoor construction environment is more complex than the outdoor, such as varied lighting conditions, Kropp et al. [7] proposed an automatic monitoring method for indoor dry wall construction process. The method is divided into three processes: panel installation, plastering and painting. Then, different feature recognition algorithms were used to successfully achieve the accurate identification of three processes. In 2015, Kropp and Koch [8] developed a platform that encompasses multiple identification algorithms based on previous studies that can call the corresponding identification processes and algorithms for different indoor identification targets.

However, all the studies above failed to consider the progress monitoring to the specific engineering quantity level, i.e the as-built area of tiles or plaster layer. Therefore, this paper proposes an indoor process control method based on computer vision and BIM, which can accurately calculate the daily completion of engineering quantity。

2. METHODOLOGY

Computer vision, also known as machine vision, is a technology that obtains images of the object using image sensors instead of the human eyes, converts the image into a digital image, and uses computer to simulate the human criteria to understand and identify the image for the purpose of analyzing image and giving corresponding judgement. At present, computer vision has been widely used in many fields of the construction industry, i.e. hazardous area identification for safety management, concrete crack detection for quality management. In progress monitoring as mentioned, scholars have done a lot of researches to refine the automatic monitoring of actual construction progress to the construction process level [3, 4, 6, 7, 8]. However, previous researches of progress monitoring entirely focused on pure computer vision technology, without using BIM during research works. Additionally, in the construction management, project managers prefer to acquire daily progress data in the form of actual completion engineering quantity. Therefore, this paper proposed a new automatic progress monitoring method of indoor engineering quantity integrating computer vision and BIM. The proposed method includes the following three parts:

(1) Train the classifier to complete the initial identification of the target component in given images;

(2) Combine the recognition results of classifier and edge detection algorithm to find the component contour;

(3) Accurately calculate engineering quantity within component contour using the camera calibration principle and BIM technology.

The research process of this method is as follows：

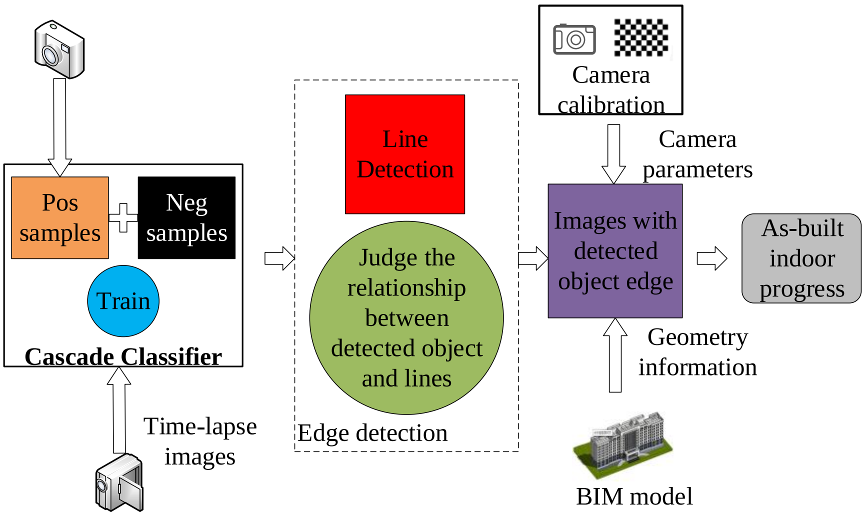

Fig. 1. Research process

3. OBJECT CONTOUR DETECTION

In this paper, the automatic progress monitoring method is designed to calculate the actual completion engineering quantity. Thus, one of the key points of the research is the accurate division of the contours of the target components in given images. Many scholars have studied image-based target recognition, most of whom focused on the improvement or innovation of feature extraction method and classification algorithm. Their research goal is to improve the recognition accuracy. And the recognition results are the bool judgment for deciding "positive" and "negative", which could not accurately detect the contours of targets. Hence, this paper combines the edge detection algorithm based on the conventional target recognition algorithm. Meanwhile, the proposed method detects the target contour accurately and eliminates the influence of the error recognition by the geometric and vector operation.

3.1. Object identification

Image-based target identification has always been a hotspot in the field of computer vision. For different objects, multiple features could be used for identification, such as geometry feature, color or texture feature. Most of the indoor components of the construction site mainly have following features: regular planar shape, straight line edges, similar outlooks and distinguishing difficulties. Meanwhile, the colors of engineering components are similar with the condition that dim indoor light. Furthermore, different components will be composed of different materials and material surface textures vary from each other. Therefore, this paper identifies target components by using component textures as a feature to train a classifier. Due to a wide range of indoor building components, this paper shows the realization process using indoor floor tiles as an example.

The target recognition based on texture feature includes two parts: (1) the collection of target's positive samples; (2) the extraction of sample texture feature and the training of classifier. Previously, many scholars have established image databases for texture recognition. For example, Dana et al. [9] created the CUReT(Columbia-Utrecht Reflectance and Texture) database, which includes 61 materials under 205 viewing angles and lighting conditions. Some scholars created the KTH-TIPS(Textures under varying Illumination, Pose and Scale) and KTH-TIPS2 databases by adding the material types and physical samples to CUReT respectively [10,11]. However, all images in these databases were not collected from construction site. Dimitrov et.al [12] developed a building material image database containing 20 common building materials. While these images were shot in the case of ideal outdoor lighting conditions and they were not suitable for training the required classifier in this paper because of changeable indoor light conditions. Hence, images of indoor tile surface are collected from many construction site and a new image database is established. Each type of tiles in the database is collected under three lighting conditions and each of lighting conditions contains three different shooting angles, as shown in Figure 2:

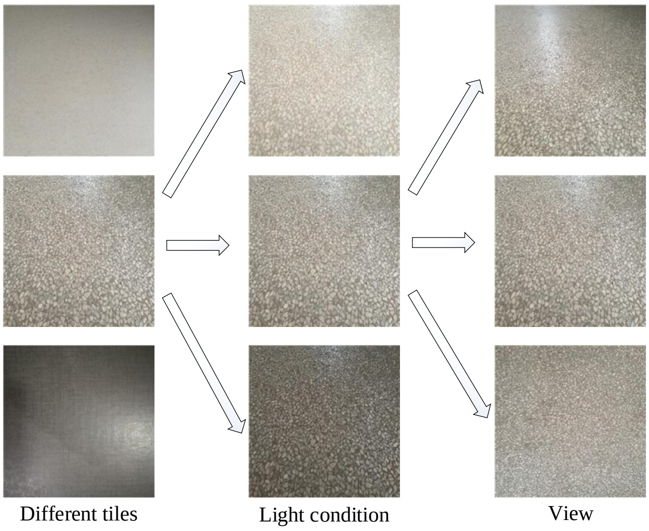

Fig. 2. Training images database

After completing the image data acquisition, this paper extracts texture feature of samples using LBP feature descriptor with rotational and scale invariance. Then, the positive and negative samples are normalized to 64 * 64 pitch and adaboost cascade classifier algorithm is used to train classifier. After getting high robustness, the multi-scale detection algorithm is used to identify the time-lapse images of the construction site. The recognition results are shown in Fig. 3 (b).

3.2. Contour detection

It can be seen that the classifier detects some regions with target characteristics where four rectangles correctly fall on the tile and a rectangle erroneously presented in the cement area. In addition, these rectangles do not accurately delineate the boundaries of tiles and concrete floors. For large-scale indoor components such as tiles, the edge contouring of the target components cannot be achieved by image recognition algorithm alone. Fig. 3 (a) shows that the shapes of the indoor components are mostly regular and there are obvious linear boundaries between different components. Therefore, this paper proposes an image object contouring method which integrated the edge detection algorithm and the image recognition algorithm. When line detection applied to Figure 3 (a), the tile edge contours are accurately delineated, as shown in Fig. 3 (c). At this time, the computer still cannot judge the position relationship between the target component and the edge contour. In order to solve this problem, this paper developed a voting algorithm based on geometric mathematics and vector operation to help computers judge the target orientation correctly. The algorithm can be summarized as follows:

Step 1: Use the calculation point which is the mid-point of rectangular are identified by classifier, and draw the vertical line to each straight line formed by every line segment. If the foot is within the line segment, the vertical distance to the line should be calculated, the nearest line of the foot should be found and then the process gets into the second step. If there is no foot within the line segment, the process gets into the third step;

Step 2: Create a vector A, which is from the beginning to the end of line segment, and the vector B, which is from the starting point of the line to calculation point. If $A \times B > 0$, the point is on the right side of the line, and valRight = valRight + 1. If $A \times B < 0$, the point is on the left side of the line, and valLift = valLift + 1. Then, the process gets into the fourth step;

Step 3 Create the vector A, which is from beginning to end of the first straight line, and the vector B, which is from beginning of the first straight line point to the calculation point. If $A \times B > 0$, the point is on the right side of the line, and valRight = valRight + 1; If $A \times B < 0$, the point is on the left side of the line, and valLift = valLift + 1. Then the process gets into the fourth step;

Step.4 If valRight> valLift, the target component is considered to be on the right side of the line, and vice versa on the left.

The combination of the voting algorithm, classifier and edge detection algorithm not only accurately delineates the contours of the target components, but also solves the technical problems caused by the excessive pursuit of the high robustness classifier. The final test results are shown in Fig. 3 (d):

(a) Indoor Construction (b) Tile classification

(c) Line detection (d) Vote result

Fig. 3. Object contour detection

4. QUANTITIES CALCULATION

After delineating the contour of target components according to the algorithm on the previous section, the engineering quantity can't be calculated directly from images. There are two reasons: (1) The camera imaging principle makes the image coordinate system not equal to the real world coordinate system, which accounts for the impossibility of calculating engineering quantity by using area within contour in given image; and (2) target component could not be fully displayed because of image shooting angle. In order to solve those problems, this paper proposes a method for calculating coordinates integrating camera calibration and BIM, and then calculating the actual engineering quantity.

4.1. Camera calibration

Camera calibration is a process of solving the camera imaging model parameters. The imaging model represents the mapping between a point in the space and the corresponding point in the image. This mapping can be expressed in matrix form as follows:

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

Where x、y represent the lateral and vertical coordinates in given image;

X, Y, Z represent the real coordinates in real scene respectively;

M represents the intrinsic paramaters， which is a 3×3 matrix;

W represents the extrinsic paramaters， which is a 3×4 matrix;

R and T are rotation vector and transformation vector respectively. R is a 3×3 matrix and T is a 3×1 matrix;

And s is random scale.

After obtaining the image pixel coordinates and real world coordinates corresponding matrix according to the camera calibration principle, the real world coordinates of every line segment, shown in Figure 3 (c), could be calculated. It should be noted that the real world coordinates are currently based on the lower left corner of the calibration plate. For the convenience of follow-up processing, the real world coordinate system is moved to the position below camera. Then, we have obtained the real coordinates of several key points of the target contour. However, the accuracy of the coordinate value calculated by the camera calibration method is related to the number of grid plates, the number of calibration images and the sharpness of the image. It indicates that error is inevitable. In order to further improve the calculation accuracy of engineering quantity, this paper introduces BIM technology and using BIM to provide information to eliminate the coordinate calculation error.

4.2 Coordinate revise using BIM

BIM is a digital representation of the physical and functional characteristics of facilities. It is a shared knowledge resource [13]. It is not only a 3D visual architectural geometric model, but also an information model containing semantic information includes building project, cost etc. Through BIM model, we can easily access any information about the building. For this research, BIM has the storage of geometric information of target component, especially the tile side length and the room deep etc. Camera is placed in a corner of the room and the relative coordinates of projection on the ground and the corner of the tile (x0, y0). The tile side from BIM is n. Then the coordinates of line segment's ends is (x, y), and the coordinates is (x, y) after eliminating errors:

If $\frac{x+x_0}{n}-(x+x_0)\%n>0.5$, $\mathrm{X}=n[(x+x_0)\%n+1]$

Else, $\mathrm{X}=n[(x+x_0)\%n]$

If $\frac{y+y_0}{n}-(y+y_0)\%n>0.5$, $\mathrm{Y}=n[(y+y_0)\%n+1]$

Else, $\mathrm{Y}=n[(y+y_0)\%n]$

Notes：% mines divide exactly

At present, we have obtained the exact real world coordinates of the key points of the tile edge. And the engineering quantity can be obtained directly by solving the area within the red line area, which is shown in Fig. 4.

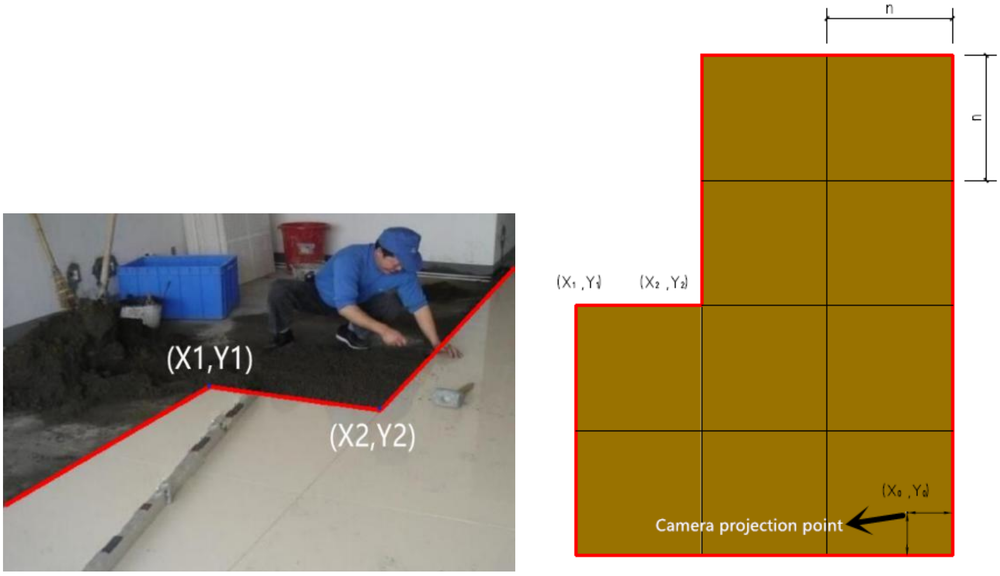

Fig. 4. Key points coordinate transition

5. CONCLUSION

In order to solve the problems such as time-consuming, low efficiency and easy error caused by the current manual progress monitoring on construction site, this paper presents a method of automatic control method for indoor progress monitoring integrating computer vision technology and BIM, which can accurately calculate the real-time completion of engineering quantity on construction site. Firstly, this paper trains image classifier for identifying the indoor target components by using the image samples collected at various construction sites, which can effectively identify the target components in given construction site images. Then, on the basis of pattern identification, this paper combines the linear detection algorithm and the voting algorithm used to judge the relationship between the target and the linear position. Based on the combination, the influence of the false positive on the recognition result could be eliminated. Furthermore, the object contour could be accurately delineated. According to the principle of camera calibration, this paper transforms the key pixel coordinates of the contour into real world coordinates, and then extracts the geometric information of the target components from BIM model, which eliminates the errors generated by the coordinate solution. Finally, the exact engineering quantity is calculated.

In this paper, the proposed method refines the automation process monitoring to the specific level of engineering, which meets the practical requirements of on-site construction process management. Apart from that, combined with the analysis of workers, engineering quantity information collected by this research could be the reference of further analysis of working efficiency. Also, this research could provide data supports to the establishment of scientific labor management.

There are some limitations in the proposed indoor progress monitoring method. For instance, the line detection algorithm may detect lines which is not belong to the contour because of the obstruction of the site sundries. This line detection-based method is just suitable for components with regular shape, for the inregular shape like plaster layer, different contour detection algorithm needs to be developed.

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