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RAPID 3D OBJECT RECOGNITION FOR AUTOMATIC PROJECT PROGRESS MONITORING USING A STEREO VISION SYSTEM

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ABSTRACT

Progress monitoring, a critical tool for successful construction projects, provides information on the present state of construction, which can then be compared with the original plan. The comparison can be used in decision-making to control variations in project performance. However, current methods for acquiring and updating information on the progress of a project using digital cameras and laser-based systems are inadequate for monitoring project progress effectively due to their high computational processing, cost, and time requirements. A recently developed stereo vision system has the potential to provide information about construction project progress more efficiently, rapidly, and cheaply. In this paper, the framework for a rapid 3D object recognition technique and some preliminary experimental results are described. The results of the experiment show possibilities for applying the technique to automatic project progress monitoring and control systems.

KEYWORDS

3D object recognition, image processing, stereo vision system, progress monitoring

1. INTRODUCTION

Successful project management requires monitoring project progress and comparing it with the originally planned schedule by identifying possible deviations between the actual and the expected project status [1, 2]. The first requirement for effective progress monitoring is the collection of large amounts of spatial data in a rapid and accurate manner.

However, although the progress monitoring process, which includes measuring and managing project information during the construction phase, is an important task for construction management, the construction industry currently relies heavily on manual methods. Site managers still spend a significant amount of time measuring, recording, analyzing, and comparing progress against the project schedule [3, 4, 5]. This information is difficult to use for controlling project progress in a timely manner, and is inadequate for effective construction progress monitoring [6, 7, 8].

In recent years, advanced approaches to progress monitoring have been studied to replace traditional methods of collecting and managing spatial data. Images from digital cameras or video cameras are generally used to monitor project progress [9, 10, 11]. Image-based approaches have the advantage of low costs and a simple acquisition process. They can serve as a good communication tool for recording the actual status of the project visually [2]. Methods for progress monitoring based on images can be classified into two types, one using 2D spatial data from digital image, and the other using 3D spatial data obtained from two or more digital images.

The method employing 2D information recognizes the status of the site using digital image from the construction site. The digital image is often used to detect status changes by updating current information at regular intervals and making comparisons [3, 7, 11, 12, 13]. These approaches have their merits, since they recognize the condition of a construction site easily and rapidly, but they have limited accuracy when acquiring location information about objects of interest.

The 3D method generates 3D spatial data based on two or more images and applies it to progress monitoring. Using photogrammetry, a 3D spatial data acquisition method based on multiple digital images, the obtained 3D spatial data is mostly applied to progress monitoring by comparison with 3D CAD data in the project database [2, 9, 14, 15]. Photogrammetry provides 3D spatial data at a low cost; however, it has drawbacks in that it requires a complicated process and a considerable amount of time to analyze the multiple digital images [16].

For real-time progress monitoring, real-time data acquisition is also necessary. Recent research has investigated automatic 3D spatial data acquisition technology such as laser scanning system [6, 17, 18]. Although laser scanning technology acquires 3D spatial data in real-time, it takes considerable time to process the data and the equipment costs are still high. Therefore, it is difficult to apply real-time progress monitoring using laser-based technology in the construction industry.

A recently developed stereo vision system provides 3D spatial data through a fully automated pre-calibration process based on acquired images, and thus does not require an additional calibration process. The stereo vision system is considered to have the potential to overcome the previous limitations of image- and laser-based approaches. It is also expected to effectively acquire 3D spatial data for progress monitoring.

The aim of this research has been to suggest a method for 3D object recognition based on a stereo vision system, and to define its potential uses in progress monitoring. For this purpose, a framework for progress monitoring using a stereo vision system is proposed. Methods for extracting specific features for comparison with pre-planned 3D CAD data are developed and presented. Experiments are then conducted to test the applicability of the proposed method, and preliminary results are presented.

2. FRAMEWORK FOR 3D OBJECT RECOGNITION FOR PROGRESS MONITORING

In this section, the framework of the overall automatic progress assessment process using a stereo vision system is described (see Figure 1).

Stereo vision system is composed of two or more sensors and can provide 3D spatial data and images from the same perspective. 3D spatial data can be acquired from a stereo vision system using the correspondence between images generated from the left and right sensors. Each value that does not correspond with both images can be considered noise, making it hard to generate 3D spatial data, so it is therefore difficult to recognize objects utilizing 3D spatial data alone.

One of the characteristics of the stereo vision system is that each point of the 3D spatial data has its own RGB color value. Thus, in this research, objects of interest are recognized using the RGB color value, then extracted as 3D spatial data. To recognize the object of interest based on image processing techniques, the RGB color values and the image pixel values (R, G, B, X, Y) are extracted to generate 2D images from 3D spatial data containing the values of the 3D coordinates (x, y, z), the color (R, G, B) and the pixel location (X, Y).

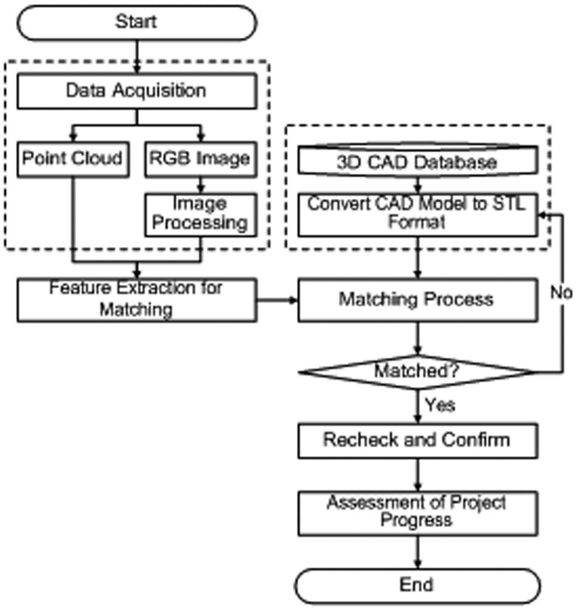


Figure 1. Framework for Progress Monitoring

Content-based image retrieval and image improvement techniques are then applied to generate images that allow the exact features of the object to be easily and accurately identified. After extracting the feature through image processing techniques, the 3D spatial data corresponding to the object can be acquired.

The final step is matching and comparing the obtained data with as-planned data, such a 3D CAD model converted into STL file. The comparison can then be utilized for monitoring, assessing, and controlling the progress of the project. Furthermore, the obtained 3D spatial data can be applied to create as-built drawings that can be utilized in various ways for advanced, automated construction management.

The detailed process of data acquisition, image improvement, and matching with as-planned data is described in the following section.

3. THE DETAILED METHOD OF 3D OBJECT RECOGNITION USING 3D SPATIAL DATA

The characteristics of the 3D spatial data obtained from the stereo vision system are introduced in Section 3.1. Detailed methods for extracting the features of an object of interest using 3D spatial data (consisting of 3D coordinates (x, y, z), RGB color (R, G, B) and pixel location (X, Y) are illustrated in Section 3.2. The final step, described in Section 3.3, is to compare the obtained data with as-planned data to monitor progress using matching and assessment techniques. Auto CAD and Matlab^{TM} were used for data processing and graphical representation.

3.1. 3D Spatial Data Acquisition – Experimental Setup

The three-sensor baseline stereo camera Bumblebee XB3 provides high-resolution 3D images with excellent stereo processing support. The data from the stereo vision system is composed of 8 elements: three values for the 3D coordinates (x, y, z), three color values (R, G, B), and two image pixel values for the pre-calibrated image (X, Y). Images can be obtained by combining the RGB color value and two image pixel values. This method delivers 3D spatial data by coordinating the three values from the coordinates from the same perspective as the image.

3.2. 3D Spatial Data Extraction using Acquired Image Data

3.2.1. Feature Extraction using Content-based Image Retrieval

Content-based image retrieval is based on several typical visual characteristics such as color, texture, and shape. In identifying the object, shape and color properties are generally used [19]. Although research has been conducted on recognizing objects using the shape information from 3D spatial data [20], this type of system is still restricted in its ability to recognize the object completely.

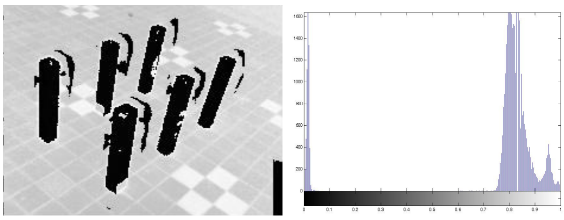
Color-based approaches enable recognition of an object more rapidly and easily [19]. Among the various color spaces, Hue, composed of the HSV color space, is less sensitive to illumination changes and camera direction and is one of the color spaces widely used in image processing [19, 21]. Considering that most construction activities are performed in outdoor environments and are exposed to adverse weather conditions, the differentiation of objects of interest using hue values allows for more robust object recognition.

To extract features from an image generated from the corresponding point between the left and right parts of a stereo image, it is necessary to convert the RGB color value into an HSV color value due to the sensitivity of RGB color to light and environmental conditions. Before the conversion process, the obtained image should be processed by a technique called image adjusting that adjusts the image intensity values or color map in order to differentiate the object of interest from other objects. Figure 2 shows an original image (a) and an adjusted image (b).

Next, the hue threshold is used to extract the object of interest from the image based on the converted HSV color space. Figure 3(a) shows the hue of an image in the HSV color space. The object of interest can be differentiated from the image based on a hue distribution. As converted from RGB color space, the distribution histogram ranges from 0 to 1. Therefore, the columns can be separated by a hue threshold below a value of 0.05, which corresponds with the columns, as shown in Figure 3(b).

(a) (b)

Figure 2. (a) Original Image, (b) Adjusted Image



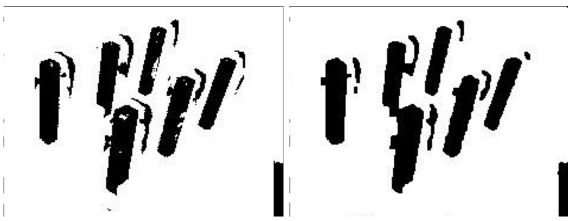
(a) (b)

Figure 3. (a) Hue of the HSV Color Space, (b) Hue Distribution Histogram

3.2.2. Image Improvement

After generating a feature from the image, several steps for image improvement are needed, such as noise cleaning and image dilation [22]. First, to reduce the noise, the image generated from the HSV color space using hue distribution histogram is filtered. This paper, the method used median filtering with a 3x3 window to reduce noise. Figure 4(a) shows the feature-extracted image based on the HSV color space. Figure 4(b) shows the result of filtered image.

A small amount of noise still remains near the columns even after the filtering process. Image dilation, one of the fundamental morphological functions, is then used to eliminate additional noise and clarify the object by adding pixels to the boundaries of the objects. In this experiment, image dilation can make extracted features appear more robust and perfect.



(a) (b)

Figure 4. (a) Feature-Extracted Image from HSV Color Space, (b) Improved Image

3.3. Extraction of 3D Feature Data from Improved Image and CAD Matching

Through the image improvement processes, more complete and perfect features can be extracted from the image obtained. Because identifying the object of interest from the image is based on the 2D image with 3D spatial data, 3D spatial data corresponding with the extracted feature can be obtained. Figure 5 shows the result of the extracted 3D spatial data.

To utilize the acquired 3D spatial data for project progress monitoring, it is necessary to compare the obtained data with as-planned data such as a 3D CAD model. Because 3D CAD, which is a general means of creating as-planned data, has a unique file format (Figure 6(a)), it is essential to first convert the

CAD data to an open-source format such as the STL format before beginning data processing [6]. Afterward, comparison between the as-planned data and the acquired data is possible using a matching and checking process (Figure 6(b)).

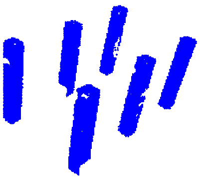
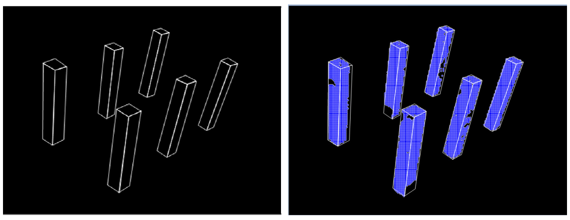


Figure 5. Extracted 3D Spatial Data



(a) (b)

Figure 6. (a) As-planned CAD Model, (b) Matching Obtained Data with As-planned Data

4. CONCLUSIONS

As more complex and dynamic construction projects emerge, the need for advanced project progress monitoring has increased. Because current approaches to progress monitoring are manual, slow, and inefficient, research on automatic project progress monitoring is increasingly required. Rapid 3D object recognition based on acquisition of 3D spatial data at construction sites can be useful for automatic project progress monitoring.

This paper shows an approach to rapid 3D object recognition using 3D spatial data from a stereo vision system for progress monitoring at a construction site. Based on the HSV color space and image improvement techniques, 3D spatial data about the features of objects of interest can be extracted perfectly from the image. Complete 3D spatial data corresponding to the object can then be acquired.

A preliminary experiment allowed the comparison of spatial data obtained using a stereo vision system with 3D CAD data. This experiment showed that the stereo vision system can be used for effective project progress monitoring. Future research will be conducted on automatically matching and comparing the obtained spatial data with as-planned data. Ultimately, the system will be applied to real construction sites and will be linked with information systems such a PMIS (Project Management Information System) to assess project progress automatically.

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