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A Cloud-Based System for Supporting Quick Location of Precast Concrete Formwork Using Computer Vision and BIM

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Abstract

In precast concrete production sites for elevated roads, adjustable formwork systems are often used to accommodate the precast components of varying shapes and sizes. Therefore, it is needed to locate and adjust the formwork frequently when the elevated road adopts continuously varying cross-sections. However, the traditional way requires significant labor costs and heavy equipment, and is prone to miscalculation. To solve the problem, this paper proposes a quick location system for formwork adjustment based on a smartphone and the latest technologies including computer vision, BIM, and cloud computing. In this research, firstly, the background and existing research were investigated; then, the engineering requirements for quick location of formwork were analyzed and the system architecture was designed; next, the visual measurement and adjustment calculation modules at the back-end were implemented based on computer vision and BIM technology, and the user interface and lightweight BIM interface modules at the front-end were implemented based on HTML, jQuery, Node.js and BIMFACE; finally, the research was summarized and prospected. With the system, surveyors can compute the adjustment amount of the support at the production site with just a smartphone, which can effectively reduce measurement time and improve efficiency. In conclusion, this research provides an effective approach for supporting the quick location of concrete formwork in the production of precast components.

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Keywords: cloud computing, computer vision, lightweight BIM, smartphone, formwork adjustment.

1. Introduction

Elevated roads are an important means of transport and are still being built in countries such as China, for which the main methods of construction include cast-in-place and assembled construction. The cast-in-place method has a long construction period, involves pollution, and can cause inconvenience such as road closures, whereas the precast construction method is more efficient, safe, and environmentally friendly, with components usually produced in plants in a standardized manner, resulting in high-quality performance, rapid production with lower costs [1, 2].

The precast concrete components that are used in elevated roads vary in plan shape and section size due to usage requirements and economic considerations. Therefore, the use of adjustable formwork is required during the production of the components. Since these formworks require multiple point measurements to determine their attitude during the adjustment process, the corresponding workload is quite onerous for the staffs. It is expected that similar workloads will increase significantly with the construction of assembled bridges and the widespread use of precast concrete [3]. The traditional method for the process is that two surveyors holding a total station and a prism, respectively, work together on-site to complete the coordinated measurement of specific points and manually calculate the adjustment amount. This method is costly, cumbersome, error-prone, and inefficient. Therefore, there is a great need for a method that can quickly calculate the adjustment amount of formwork.

Hence, this paper proposes a cloud-based system for supporting the quick location of precast concrete formwork, which allows the surveyor to obtain the adjustment amount using only one smartphone. Firstly, the architecture and functionality of the system were designed according to the actual needs. Then, a computer vision-based measurement method and a BIM-based adjustment calculation method were proposed. Based on this, a collaborative cloud-based system was developed using a cloud server and a lightweight BIM platform, and it allows the surveyor to upload data and select marker points in the lightweight BIM, and invoke the core algorithm in the server to calculate the adjustment amounts and present them on the smartphone. Finally, the system is discussed and summarized.

2. Literature review

Computer vision technology is capable of extracting information from images or videos to understand or quantitatively analyze the corresponding physical world [4] and is currently being increasingly used in the field of engineering measurement. For example, Feng [5] et al. used a visual measurement system instead of a traditional contact displacement sensor to achieve real-time, multi-point measurement of structural displacement response. Tang [6] et al. reconstructed a three-dimensional deformation surface of a concrete column based on multi-vision and realized dynamic real-time measurement of its deformation accordingly. Yang [7] et al. combined computer vision with fully convolutional networks to achieve measurements of crack topology, length, maximum width, and average width metrics. Siebert [8] et al. collected and reconstructed the earthwork site using a camera attached to an unmanned aircraft, whereby the measurement of earthwork geometry information was achieved. Marčiš [9] measured concrete slab deformations at close range and analyzed displacement variations between multiple points on the components through an indoor drone camera mount.

The concept of BIM was first introduced by Eastman in 1975 [10] and has been widely used in the construction industry, effectively enhancing the level of informatization in this industry. However, many BIM models take up a large amount of space, are slow to transfer, and have high equipment requirements [11]. In 2011, the release of WebGL promoted the development of lightweight BIM [12], and in 2015, Autodesk launched its Forge platform to help users achieve lightweight conversion of BIM models. China's Glodon launched the BIMFACE platform two years later. Currently, research and applications related to lightweight BIM are increasing, mainly in the fields of building simulation, operation, and management [11, 13-15].

Cloud computing enables users to perform complex computations from low-provisioned mobile devices by shifting the computational work to remote resource providers [16]. Early on, it was mainly used in e-commerce and social media, but with the popularity of smartphones and the development of mobile internet, its market size has grown and deepened into various industries, including construction. For example, Polter [17] et al. developed the BIM-grid framework to support dynamic collaborative management in civil engineering projects by integrating private web and public cloud resources. Chen [18] et al. implemented collaborative mobile-cloud computing to assess the condition of civil infrastructure.

According to the literature review, many researches have applied latest information technologies including visual measurement, cloud computing, and lightweight BIM to the construction industry, providing valuable references for solving similar problems. However, up to now, no research has been found to integrate these technologies to solve the problem of quick location of formworks.

3. System design and development

3.1 Research objective and system requirements analysis

Based on the analysis of the engineering requirements and the limitations of existing researches, this research aims to propose and implement a system that enables surveyors to quickly measure the 3D coordinates of marked points across formwork, calculate the adjustment amounts, and present them on production sites with just one smartphone.

To achieve this objective, the system comprises three main requirements: firstly, a module capable of accurately measuring the relative 3D coordinates of marker points through computer vision; secondly, a module that calculates the adjustment amount of formwork based on the BIM model and visual measurement module; and thirdly, a user interface system that facilitates quick uploading of information and visualization of adjustment amounts by the user.

3.2 System architecture design

In this research, the B/S architecture was chosen to design the system to ensure better serviceability and cross-platform workability. The system architecture is shown in Fig. 1. In the representation layer, the necessary information including images is uploaded by the surveyor through interaction with the smartphone. In the business layer, the relevant data uploaded by the representation layer through the network is received and processed, based on which the visual measurement module and the adjustment calculation module in the back-end server are invoked to quickly obtain the relative position of the formwork and automatically calculate the adjustment amount accordingly. In the data layer, information is received from the representation and business layers, and the adjustment amount is transmitted back to the representation layer for visualization by the surveyor on the smartphone.

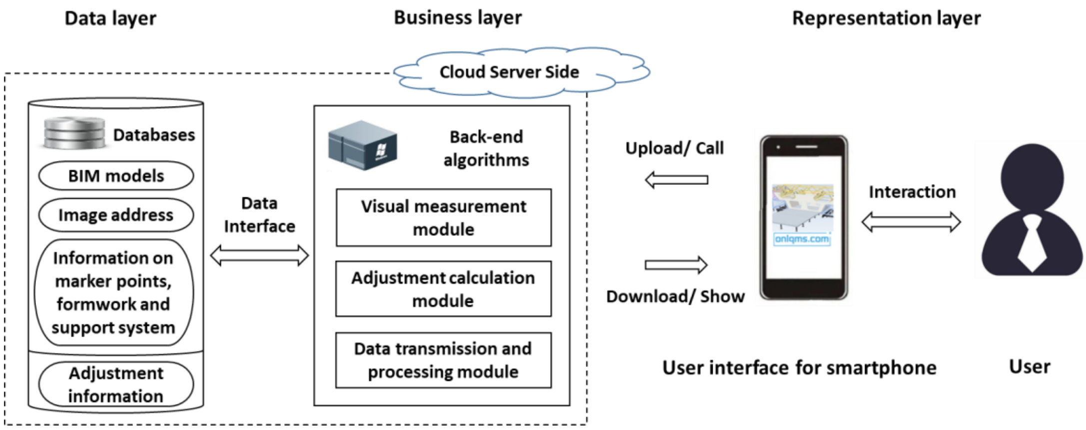


Fig. 1. System Architecture

3.3 Back-end algorithms of the system

3.3.1 Visual measurement module

The process inside the visual measurement module consists of 3 main stages, including preparation, 3D reconstruction, and conversion stages, and its flow is shown in Fig. 2.

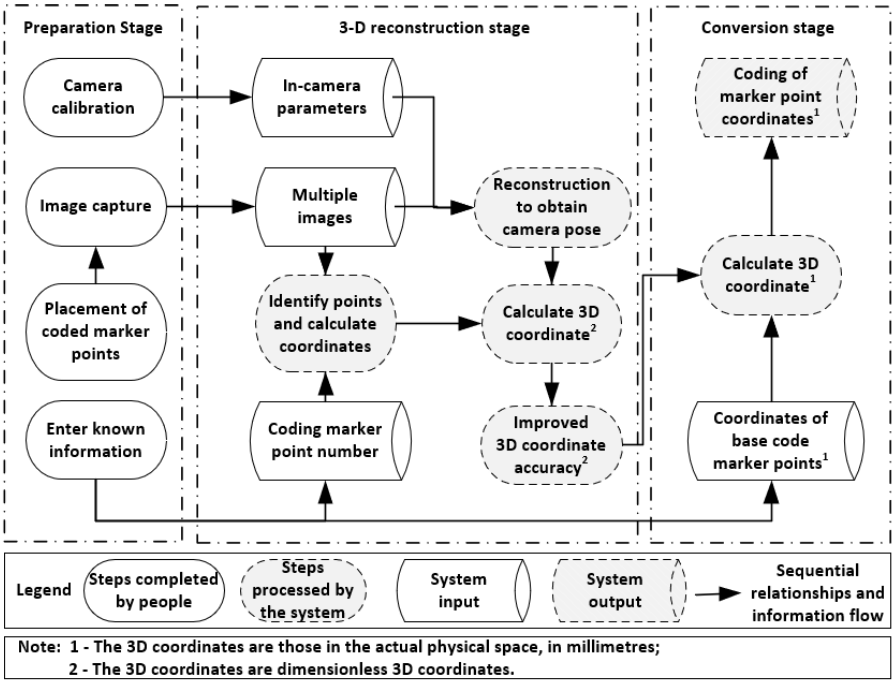


Fig. 2. The flow of the visual measurement module

In the preparation stage, the camera parameters are calibrated in advance and ring-coded marker points (hereinafter referred to as marker points) are arranged in the field, then multiple photographs are taken and uploaded. In the 3D reconstruction stage, the coordinates of the marker points in each image are calculated in pixels by using the modules from the open-source computer vision library OpenCV, and then the modules from Open MVG are used to reconstruct the images in three dimensions and to obtain the position and pose of the camera used for photography. Next, the 3D coordinates of the marker points are calculated based on the image coordinates of the marker points and the camera parameters of each image, based on which the software SBA is invoked to implement the beam method leveling algorithm and output the 3D coordinates of the marker points with smaller errors. In the conversion stage, the conversion matrix is derived from the benchmark plates containing multiple marker points with known actual coordinates, and the actual 3D coordinates between the marker points are derived accordingly. The marker points and benchmark plate used in the construction are shown in Fig. 3.

Fig. 3. Marker points (left) and benchmark plate (right)

3.3.2 Adjustment calculation module

In traditional measurement, the 3D coordinates of the marker points are read manually and the adjustments are calculated manually accordingly. In this research, the process is fully automated through BIM and visual measurement technology. In the previous section, the visual measurement module has calculated the relative 3D coordinates between the marker points, while existing projects usually have accurate BIM models containing a wealth of geometric and attribute information. Therefore, users can interact with the smartphone to identify the measurement points in the lightweight BIM to achieve a digital twin of the marker points, thus determining the relative position of the marker points on the formwork, and in turn, being able to find the relative position between the formwork to be measured and the formwork that has been adjusted into position.

The adjustable precast pedestal for production of concrete components consists of formworks and a support system, the main adjustment process of which is shown in Fig. 4.

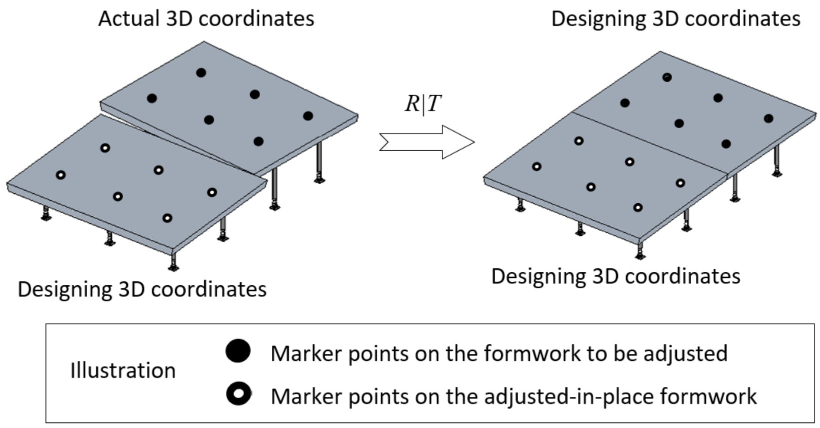


Fig. 4. Formwork adjustment process

When calculating the adjustment of the support system members, it is assumed that the formwork is rigid and free from manufacturing errors, so that the marker points on the formwork to be adjusted can be moved from the actual 3D coordinates to the design 3D coordinates by adjusting the members of the support system, i.e., extending or shortening the cylinder, the screw, and the column, thus adjusting the formwork to be adjusted from the actual position to the design position.

The transformation matrix (rotation matrix R and translation vector T) of the marker points on the formwork to be adjusted from actual 3D coordinates to design 3D coordinates satisfies:

$$X_d = RX_r + T \tag{1}$$

whereX_d is the design 3D coordinate of the marker point on the formwork to be adjusted, and X_r is the actual 3D coordinate of the marker point on the formwork to be adjusted.

In the calculations, since the actual 3D coordinates and the design 3D coordinates of the marker points on the formwork to be adjusted are known, the transformation matrix can be derived from Equation (1), the matrix represents the effect of adjustment of the support system on the actual 3D coordinates of the marker points on the formwork and can be divided into six components, namely translation in the direction of the three axes and rotation in the direction of the three axes:

$$\begin{cases} R = R_z R_y R_x \\ T = T_x + T_y + T_z \end{cases} \tag{2}$$

whereR_z represents the rotation matrix in the direction of$x$, y and$z$, respectively, and T_x, T_y and T_z represent the translation matrix in the direction of x, y and z, respectively.

In fact, since the extension or shortening of each support in the formwork is in the same direction as the axis direction, the relationship between the partial adjustment and the rotation and translation matrix of each axis direction for each cylinder, screw or column is:

$$\begin{cases} R_i = d_i \times a_{ri} \\ T_i = a_{ti} \end{cases} \tag{3}$$

where i indicates the direction of the coordinate axis and can be taken as x, y or z; a_{ri} indicates the partial adjustment amount required for the cylinder, screw, or column to produce R_i in the direction of the $i$coordinate axis; a_{ti} represents the partial adjustment required by the cylinder, screw or column to produce in the direction of the i axis; d_i represents the distance between the axis of the cylinder, screw or column itself and the center of rotation in the direction of the i axis. According to Equation (3), all the partial adjustments of each cylinder, screw, and column can be found, and the sum of them is the adjustment amount.

3.3.3 Experimental equipment and programming

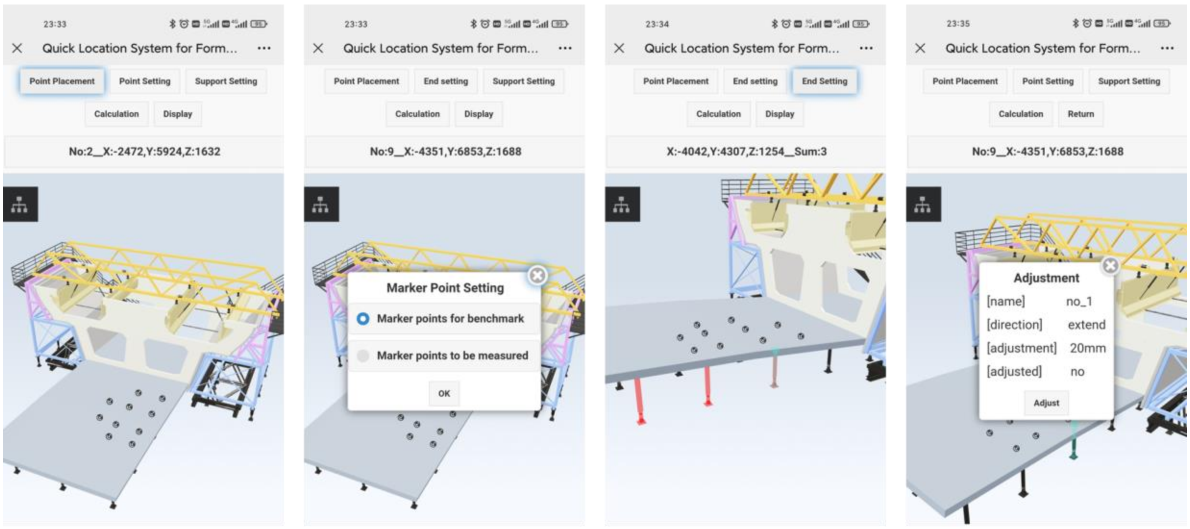
As it is cumbersome and unsafe to bring a laptop to the production site, and the smartphone cannot run measurement programs quickly and independently, a server needs to be set up to run the measurement programs. This research used the Ali-Cloud platform as the cloud server-side, renting an ECS.g5 server with an 8-core 32GB CPU and RAM, Windows Server 2019 operating system and an 80 GB enhanced SSD cloud drive for less than USD 150/ year. The back-end algorithms were established and the modules for visual measurement and adjustment calculation were developed by using C++, where reliable opensource software code, including Open MVG 1.4, Open CV 4.0.0, and SBA 1.6, was used.

3.4 Front-end user interface of the system

To implement the system functionality, it was necessary to select a suitable mobile and develop a front-end user interface for the smartphone. For this research, a Huawei Mate30 smartphone was purchased for USD 750 as a mobile for taking photos, transferring data, and presenting adjustments. It weighs 196 g, has 128 GB of memory, a 40-megapixel main camera, and a maximum photo resolution of 7296 x 5472 pixels. In developing the measurement program, this research developed a user interface system based on HTML5, CSS, and the jQuery Mobile component of the jQuery framework, and wrote a program based on Node.js to transfer data between the mobile and cloud servers, with a Visual Studio Code development environment. The user can create a corresponding project on the smartphone and uploads information such as pictures, camera references, and models required for the measurement procedure to the server by using functions such as Create New Task, Upload Images, Upload BIM Model, and Upload Camera Intrinsic on the smartphone as well.

Then, the user can select the Start Measure function to open the lightweight BIM interface system, which is based on the BIMFACE platform through customization. The main functions include Point Placement, Point Setting, Support Setting, and Display, and its functional interface is shown in the four sub-diagrams a), b), c) and d) in Fig. 5, respectively.

Considering that the screen of the smartphone is too small for the user to directly select the required marker points, JavaScript is used to invoke the API of the BIMFACE platform to highlight the formwork where the marker points are located, while restricting the web page to lock the current view, and at the same time, displaying the 3D coordinates of the marker points at the click in real-time. It makes it easier for the user to accurately place the marker points by moving their fingers. After placing the marker points, the user can click on them one by one and set their properties in the corresponding pop-up window by the Point Setting function. When the user sets support near the formwork through the Support Setting function, the system will automatically read the maximum and minimum coordinates of the enclosing frame of the selected support and calculate the 3D coordinates of the center of the section where the support is connected to the formwork to determine the relative position of the support to the marked points.



a) Point Placement b) Point Setting c) Support Setting d) Display

Fig. 5. Lightweight BIM interface system on the smartphone

The uploaded data are passed to the back-end server in JSON format via the POST method of the HTTP protocol on the web page through the Calculation function, while the data is parsed and stored by Node.js. The algorithm is invoked to conduct the adjustment calculation. Once the calculation is complete, the user can send a request to the back-end via the Display function to obtain the adjustment amounts for each support and present them in the interface, and the supports can be adjusted accordingly.

4. Conclusion

This research proposes a quick location system for formwork adjustment based on the smartphone and the latest technologies including computer vision, BIM, and cloud computing to effectively solve the engineering problems, such as total stations are time-consuming and costly, and cannot adapt to the requirements of measurement tasks. Using the system, multiple points can be measured simultaneously on a production site with just one smartphone, and the amount of adjustment can be viewed visually. The total cost of the system is less than USD 900 and the weight is less than 200 g, which is 10% and 5% of a total station respectively, making the system valuable for engineering applications. With the popularity of cloud computing and the improved performance of smartphone network transmission and photography, this system has the potential to be widely used, and our group will continue to refine the system and validate it in practice in the future.

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