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Mobile-based Dimension Measurement for Precast Concrete Panels Using Deep Learning and Image Processing

Dinh Quang Duy[1]*, Ganesh Kolappan Geetha[2], Sung-Han Sim [3]

[1] *Department of Global Smart City, Faculty of Engineering, Sungkyunkwan University, Republic of Korea, E-mail address: dinhquangduy@g.skku.edu*
2 Department of Mechanical Engineering, Indian Institute of Technology (IIT Bhilai), India, E-mail address: ganeshkg@iitbhilai.ac.edu
3 School of Civil, Architectural Engineering and Landscape Architecture, Faculty of Engineering, Sungkyunkwan University, Republic of Korea, E-mail address: ssim@skku.edu

Abstract: Presently, prefabricated concrete panels are extensively employed in diverse construction projects across the globe due to their exceptional quality. To maintain the overall quality of these construction projects, it is crucial to ensure that the dimensions of precast concrete panels align with their designated design specifications. Therefore, it is essential to develop a methodology capable of quickly and accurately measuring the dimensions of precast concrete panels. Currently, there are many advanced technologies used to examine the dimensions of prefabricated concrete panels such as terrestrial laser scanning, which is prone to time consuming and cost inefficiencies. To address these limitations, this study suggests a computer vision-based approach that utilizes April Tag markers and images taken from a mobile phone to measure and evaluate the dimensions and quality of precast concrete panels. The proposed algorithm operates as follows: Initially, the RGB image coordinates are converted to the world coordinate systems using April tag markers. Following, the masks of the precast concrete components are extracted using the state-of-the-art Segment Anything Model (SAM). Finally, an algorithm based on image processing technique is developed to estimate the dimensional properties of precast concrete panels. The effectiveness of the proposed method is validated through preliminary experiments conducted in the field-scale precast slabs, and the result is evaluated by comparing to the manual measurement result.

Key words: Precast concrete panel, Smart phone, April tag, Segment Anything model, Dimensional measurement.

1. INTRODUCTION

In recent decades, there has been extensive utilization of precast concrete (PC) components in the construction industry. Compared to other concrete components, PC components offer lower costs, streamlined construction processes, more efficient assembly of components, and environmentally friendly benefits [1][2]. It has been shown in earlier research [3, 4] that using (PC) panels instead of in-situ concrete casting panels can result in labor cost savings of 43% and construction time savings of 70%. Despite all these advantages, improper quality control of PC panels may result in unforeseen delays in construction and system malfunctions, which would have a detrimental effect on the construction process. For example, serious dimensional mismatches in PC components would inevitably result in building delays and higher expenditures for repair or replacement [5]. Therefore, it is essential to make sure that the dimensions of PC panels align with their design information in the early stages.

Recently, due to its capacity to obtain precise and effective geometric data, 3D laser scanners have become more and more popular in recent years [6]. Hence, researchers have paid much attention to geometric inspection techniques for prefabricated elements especially using point cloud collected from laser scanners [8, 9] because of its ability to easily scan large structures and measure distances to different parts of the structure with millimeter-level accuracy. Because of these technical advantages, several researchers have investigated the possibility of dimensional measurements using laser scanning. For example, Li *et al*. proposed a method to measure the dimensions of PC using Point Cloud Data and Range Images [10]. Yoon et al. [11] successfully developed a laser scanning technique to determine the ideal location of precast bridge deck slabs. Kim et al. conducted comprehensive research on PC panels, formworks, and rebars, employing terrestrial laser scanning for dimensional and surface quality assessment [12, 13, 14, 15]. Shu et al proposed a method to inspect dimensions and quality of PC using Point cloud data and deep learning [16]. Although laser-scans based dimensional quality assessment of PC elements has demonstrated numerous advantages in terms of accuracy and effectiveness, the widespread adoption of laser scanners may be met with skepticism due to the time required to collect and process data and its higher cost compared to other tools.

Currently, smartphones are being used to observe and evaluate the dimensions of concrete constructions as well as identify defects like surface cracks [7]. Utilizing images is the preferred method for detecting irregularities in concrete elements due to its ability to collect data rapidly without direct contact. Consequently, the processing of images demands a relatively modest amount of time. Furthermore, due to their widespread availability and the low cost of smartphones and mobile data wireless transmission, mobile phones have been effectively applied in a wide range of civil engineering industrial applications. Therefore, considering the advantages of smartphones, this study aims to implement the mobile phone to handle the drawbacks of laser scanning in terms of measuring the dimensions of PC.

Specifically, this study introduces a pioneering methodology utilizing smartphone imagery for precise PC dimension measurement by integrating SAM with an innovative image processing technique. Figure 1(a) depicts the schematic of the overall hardware configuration for the proposed dimensional assessment method. Figure 1(b) displays the essential steps for the proposed dimensional assessment, comprising data acquisition, coordinate transformation, extraction of binary images, and dimension estimation. This method not only facilitates rapid extraction of dimensions of PC panels but also eliminates the need for specialized equipment, thereby making it accessible.

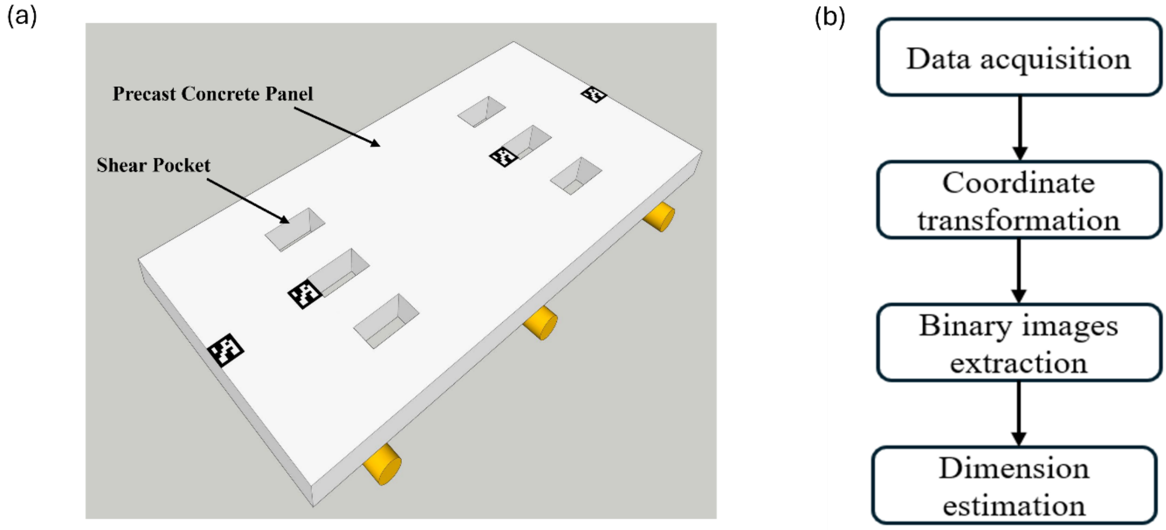

Figure 1: The proposed precast concrete dimensional method. (a) A schematic representing the general configuration of the system. (b) Dimensional measurement procedures.

2. RESEARCH BACKGROUND

2.1 Fiducial Marker

The fiducial markers are popular used in the computer vision field for robust object localization and pose estimation. There are many researchers nowadays utilizing markers because of their superb ability. For example, Kayhani et al [18] introduced a tag-based visual-inertial localization method aimed at estimating the global position of the UAV by employing an on-manifold extended Kalman filter.

Westman and Kaess [19] developed a framework designed for the pose estimation of underwater robots, utilizing the April Tag system. These applications benefit from their advantageous features, including fast detection speed, a straightforward marker generation process, the availability of marker detection algorithms, and a simple system setup. Moreover, the tracking system design can be simplified as only one camera is needed to track various markers. Moreover, the tracking system design can be simplified as only one camera is needed to track various markers. Among various fiducial markers, the April Tag marker stands out among various fiducial markers due to its advantages of requiring lower computational power and offering higher detection accuracy.

2.2 Segment Anything Model

In contemporary times, pre-trained models have assumed a pivotal role in science, technology, and engineering. Meta AI Research recently introduced a novel image segmentation network named Segment Anything (SA), which has garnered attention for its innovative approach [17]. The Segment Anything Model (SAM) has been trained with over one billion masks on 11 million images [17]. The vast volume of data available can greatly propel SAM forward in terms of performance and accuracy compared to existing models. SAM's development revolves around three main components: task, model, and data, which are interconnected, requiring a comprehensive solution to address them. Among these, segmentation is a prominent task, defined broadly enough to provide a robust pre-training objective and cater to a wide array of applications. Note that, thanks to SAM, the segmentation task can be completely achieved without the need for training. As a result, high-quality masks can be obtained quickly and cost-effectively.

3. METHODOLOGY

This section explains the framework as shown in Fig.1(b). The first step of implementation is data acquisition, wherein several images are captured from the surface of the precast concrete (PC). The algorithm will then start looking for the known size April Tag markers. If the marker is found, the camera transforms images of 3D projections into 2D images. Consequently, SAM is implemented to extract binary information and finally measure dimension of PC panels in the last step.

3.1 Data acquisition

To obtain the highest level of inspection accuracy, it is crucial to first determine the proper location for the markers to be installed on the surface of PC panels. For improved processing in the following stages, the photos taken with smartphones need to have sufficient distinct information, such as markers, shear pockets, and the width and length of the PC panels. Once stratify those parameters, the location, and features such as corners and centers of markers. Figure 2 shows the detected marker with its family name.

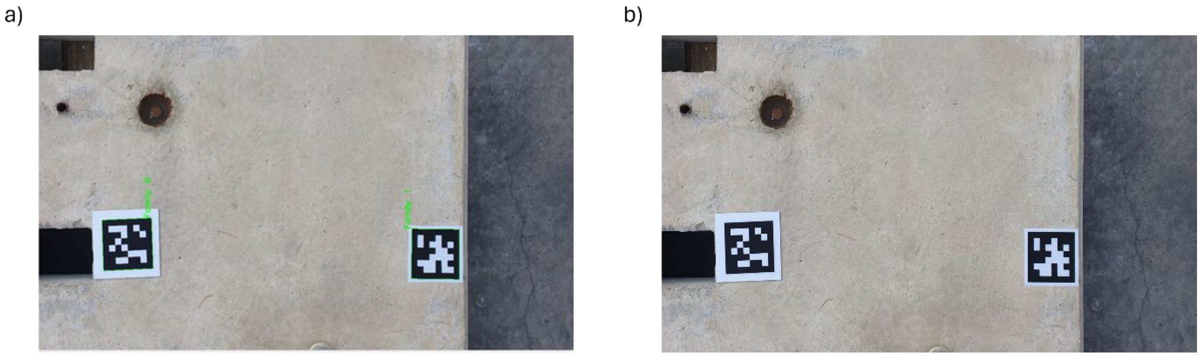

Figure 2: The detected markers. (a) detected markers. (b) the original markers

3.2 Coordinate transformation

The RGB camera coordinates of the markers must be transformed into the world coordinate system to ascertain the dimensions of PC components, a process that remains independent of the camera positions. To accomplish this objective, homogeneous transformation is utilized to project 3D points in space onto 2D points [20]. When cameras take pictures of the world and show the images on an image plane, this projection takes place. The following equation represents the expression in homogeneous coordinates.

$$x = PX$$

where x is an image point represented by a homogeneous 3-vector and X is a world point. The camera matrix P possesses 11 degrees of freedom, equivalent to the number of degrees of freedom of a 3×4 matrix defined with an arbitrary scale factor. These degrees of freedom, or parameters, can be categorized into two groups: 5 internal and 6 external parameters. The 5 internal camera parameters are typically represented by a matrix K:

$$K = \begin{pmatrix} \alpha_x & s & x_0 \\ 0 & \alpha_y & y_0 \\ 0 & 0 & 1 \end{pmatrix}$$

Here α_x and α_y represent the focal lengths of the camera in terms of pixel dimensions in the x and y directions respectively, (x0, y0) is the principal point on the image plane and s is a skew parameter. The 6 external parameters describe the relationship between the camera orientation and a world coordinate system, comprising 3 rotations (represented by a 3×3 matrix R) and 3 translations (represented by a 3-vector t). Thus, the camera matrix P can be represented as:

$$P = K[R|t]$$

The homogeneous coordinates are used in the algorithm when at least 4 points are detected, specifically the corners obtained from markers in this study.

3.3 Binary image extraction

In this stage, the images after coordinate transformation are conducted to extract the binary images using SAM. The output of this stage is the digital images where each pixel can have either black or white values. Note that these images have the same size and coordinates as the transformed images. SAM can actively produce high quality object masks from input prompts such as points, and it can be used to generate masks for every object on the image [17]. For convenience, in this study, a scrollbar is created to control the locations of points (stars) on SAM. Therefore, the binary information of PC components such as shear pockets and edges are achieved. A sample from SAM is shown in figure 3.

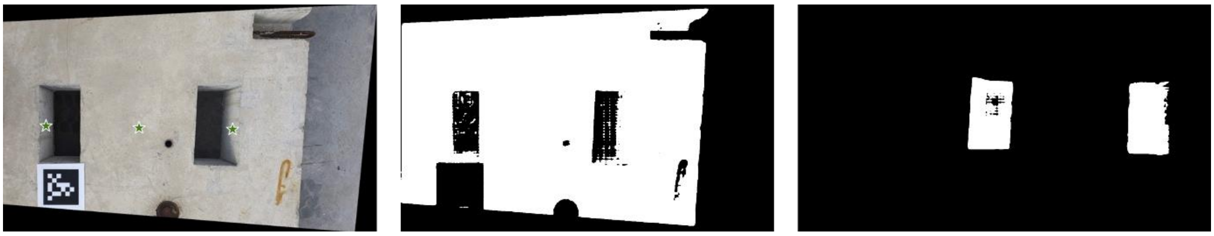

Figure 3: An example results from SAM.

3.4 Dimension Estimation

In the last step, the result of images from the previous steps is utilized to compute two factors (1) the dimensions (length and width) of PC panel, (2) the dimensions of the shear pockets. A novel image-based algorithm is created to automatically generate dimensions of PC components. The panel's length can be determined by adding up the distances between markers placed alongside the surface of the PC, while the width refers to sum of the distances from two edges to the center of a marker. In the case of the shear pocket, the geometric shapes are extracted from the binary images generated by SAM and transformed images. The dimensions of the shear pocket are determined based on the dimensions of these rectangular shapes. Figure 4 shows the results of dimension extraction.

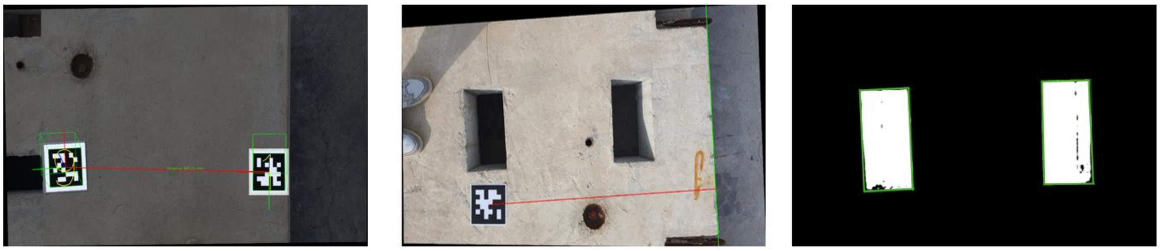

Figure 4: The dimensional results of PC components.

4. EXPERIMENTAL RESULTS

The methodology proposed is validated using real-world datasets obtained from a precast concrete specimen. The validation process is performed as follows: 1) the fiducial markers are positioned on the surface of the precast concrete so that one side of the first and last markers overlaps the left and right edges, respectively, while the others will be installed along the length of the precast concrete; 2) 15 sets of images are gathered from various angles alongside the length and width of the PC panels for dimension measurements; 3) those sets of images are subsequently analyzed using the proposed algorithm to extract the measurement results. The specimen with its ground-truth dimensions, obtained manually using typical techniques, are shown in Table 1 in millimeters. For this study, the Samsung Galaxy S10 is utilized to capture images, and April tags with the family name (36h11) are installed on the surface of the precast concrete. The average result from the 15 sets of images obtained through the proposed method indicates an accuracy of 98.3% for the width and 98% for the length of precast concrete. Likewise, the width and length accuracy for shear pockets are 97.7% and 97.5%, respectively. Table 2 is one of the fifteen trial sets that were extracted from the precast concrete panel.

Table 1. Ground-truth dimensions of the precast concrete.

Name	Precast Concrete 1	Shear Pocket 1	Shear Pocket 2	Shear Pocket 3	Shear Pocket 4	Shear Pocket 5	Shear Pocket 6
Width	1970	320	320	320	320	320	320
Length	5000	170	170	170	170	170	170

Table 2. The accuracy of the precast concrete's measurements.

		System Measurement (mm)	Measured Dimension (mm)	Error %
Prefab Panel	Length	4928.3	5000	1.43
	Width	2007.23	1970	1.89
Shear Pocket 1	Length	307.53	320	3.9
	Width	173.86	170	2.27
Shear Pocket 2	Length	313.08	320	2.16
	Width	172.23	170	1.31
Shear Pocket 3	Length	316.07	320	1.23
	Width	174.41	170	2.59
Shear Pocket 4	Length	313.81	320	1.93
	Width	172.43	170	1.43
Shear Pocket 5	Length	318.165	320	0.57
	Width	172.245	170	1.32
Shear Pocket 6	Length	328.35	320	2.61
	Width	184.04	170	8.26

For the length of the precast concrete panel, errors typically fell within 1.7%. This discrepancy arises from the sensitivity of length measurement to camera positioning, which impacts the accuracy of the scaling factor used to determine its physical dimensions. The errors in estimating the width were slightly higher at 2%, while errors in the measurement of shear pocket dimensions were 2.3% for width and 2.5% for length. This can be attributed to the fact that the accuracy is influenced by the information extracted from the Segment Anything model, particularly the positions of the check points, which are the most important parameters determining the quality of the masks.

5. CONCLUSION

This study describes a new method using a mobile phone to measure the precast concrete panels and its components. The images captured by a mobile phone are processed using SAM, April Tag and a novel image processing technique developed in this study to estimate the dimensional properties of the precast concrete panels. Multiple sets of images are processed to show the effectiveness and applicability of the proposed technique. The result confirms that the proposed technique can swiftly, accurately, and reliably measure the length, width, and shear pockets of the precast concrete panels, presenting a promising solution for measuring precast concrete panels and their components. Factors such as camera angles and the quality of binary images extracted based on checkpoint positions from the Segment Anything Model significantly influence the accuracy of the proposed method. Therefore, further research is required to control these parameters and enhance the algorithm's effectiveness. Furthermore, assessing the capability of this method to measure dimensions under varying light conditions will be a consideration for future evaluation of the proposed technique.

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