Accuracy of 3-D Model Based on Point Cloud: A New Technology for Construction Progress Evaluation

Supanan Rattanapongwanich, Korb Srinavin, Wuttipong Kusonkhum, Narong Leungbootnak, and Phatsaphan Charnwasununth

***Abstract*—Construction industry is considered an important industry in Thailand. The construction project consists of many processes that have to be monitored. The construction progress monitoring and evaluating is one of the most important procedures among others. This research aims to propose the way to monitor the construction project progress using photogrammetry technology. Progress evaluation can be effectively and quickly verified and be able to provide stakeholders with an easy understanding of the project situation. The research used photos of the object with a box-shape to construct a 3-D model. The geometry of the object was measured manually by its width, height and length then compared to the values obtained from the 3-D model. An error of the model was evaluated in terms of Length, Area and Volume. The result of the study showed that error of the developed model in Length, Area and Volume are less than ±1%. This paper proved that 3-D construction model base on point cloud from construction site image can be used to evaluate construction progress with enough accuracy.**

***Index Terms*—Construction progress monitoring, point cloud simulation, project schedule, photogrammetry technology.**

I. Introduction

Construction industry is an important industry in Thailand. The construction sector will expand average of 8-12% per year and the tendency of construction volume in neighboring countries is also increase [1]. That show the construction industry has a growing need for more automated of measuring progress in construction. The construction project consists of many processes that have to be monitored especially about progress measurement [2], [3]. For traditional progress monitoring, the project manager spends lots of time to measure and evaluate the construction progress and recording of activities on-site [4]–[7]. That may affect to cost and schedule management [8]. In recent years, many researches focus on automated construction progress monitoring [9]. This research aims to propose the way to monitor the construction project progress using photogrammetry technology to build 3D model based on point cloud. The photogrammetry technology using varied source to collect information of objects in the construction site.

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II. Available Technologies

Data capturing technology include Image-based technologies, Laser Scanning (LS), Radio Frequency Identification (RFID), Ultra-Wideband (UWB), Global Positioning System (GPS) and Wireless Sensor Networks (WSN) have been developed and used in many industries including construction industry [10]. Photogrammetry is image-based technology that registering site images and generating model from the images to building a 3D point cloud model that used in fields such as topographic mapping, architecture, engineering, manufacturing, quality control and geology [11]. Laser scanning. The data that received consists of a point cloud in 3D coordinate system. Every point cloud is specified with x, y and z coordinates. Even laser scanner offers high accuracy, but it has high cost of maintenance and require user skill [12]. Radio Frequency Identification (RFID) technology have been used for inspection of on-site data [13]. The inspector can receive information by tag scanning for identified and tracked on construction sites [14]. Even this process facilitates to collect information, but it requires to install and maintenance of RFID tags for a long time and its implementation is difficult in daily changing environment of construction site. Ultra-Wideband (UWB) is radio technology for target sensor data collection, precision locating and tracking that can record the 3-D location of each tag on a computer and display the location and movement of each tag on a screen [15]. Global Positioning System (GPS) is a satellite-based radio navigation system. It is a global navigation satellite system (GNSS) that provides geolocation and time information to a GPS receiver anywhere that there is an unobstructed line of sight to four or more GPS satellites and can use as a location tracking tool in construction industry [16]. Wireless Sensor Networks (WSN) is autonomous sensors with a communications infrastructure to remote environmental and physical monitoring such as temperature, humidity, sound, pressure, speed, direction, size, pollution levels and etc. [17]. In another way Bosché found using laser scanning combine photogrammetry has a higher accuracy of data in the construction site. The method is to capture as-built in the construction site with digital images and videos. The method which captures within image-based system is cheaper and easier than laser scanner method and also represent in point cloud [14], [15].

III. Photogrammetry

Photogrammetry is the art, science, and technology of obtaining reliable information about physical objects and the environment through the process of recording, measuring and interpreting photographic images. Photogrammetry is a three-dimensional measurement technique that uses central projection imaging. Shape and position of an object are determined by reconstructing bundles of rays in which, for each camera, each image, together with the corresponding perspective center, defines the spatial direction of the ray to the corresponding object point. The primary purpose of a photogrammetric measurement is the three-dimensional reconstruction of an object in digital form (coordinates and geometric elements) or graphical form (images, drawing, and maps). There are two types of Photogrammetry is Aerial Photogrammetry and Terrestrial (Close Range) Photogrammetry [11]. Aerial photogrammetry used in topographical mapping, begins with digital photographs or video taken from a camera on an airplane. The plane can fly in a winding path to get complete coverage take overlapping photographs or video of the entire area. Close-range or terrestrial photogrammetry uses photographs taken at close to cameras. Close-range photographs can be used to create 3D models but they are not commonly used for the topographical mapping. This type is useful for the 3D modeling of many objects or areas such as buildings, automobile accident scenes [18].

IV. Proposed Method

A. Lens Calibration

There are two main techniques to calibrate camera [19], 1) photogrammetric calibration, which required basic knowledge of the physical objects such as its dimensions, coordinates and directions, in addition to the 2D information from the captured image. 2) Self-calibration. This paper used the photogrammetric calibration with digital chessboard capturing (Fig. 1) by a camera with specifications in Table I and import the images captured chessboard into software to calibrate until the process is finished and shown the calibration report in Table II. The images captured chessboard after lens calibration process that shown blue and red marks on the source images to represent the detected corners of the checkerboard pattern (Fig. 1).

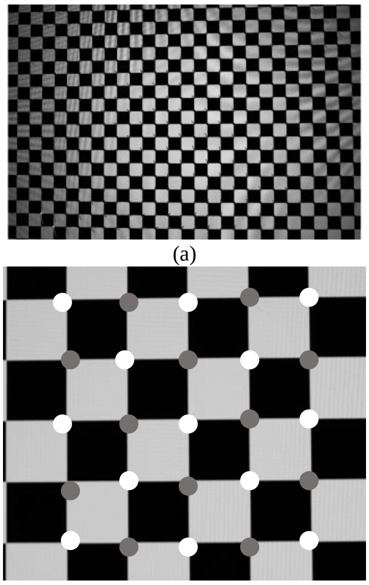
TABLE I: Camera Specifications

Type	Specification
Model name	FUJIFILM X-E2
Sensor	(APS-C) X-Trans CMOS II
Lens	XF18-55mmF2.8-4 R LM OIS
Effective pixels	16.7 million pixels
Wireless Transmitter	Standard, IEEE 802.11b / g / n (standard wireless protocol) Access mode Infrastructure
Photo format	JPEG (Exif Ver 2.3), RAW (RAF format), RAW+JPEG (Design rule for Camera File system compliant / DPOF-compatible)

The camera calibration data is used to identify and correct the distortions introduced into the image due to the curvature of the lens, the focal length, and the perspective effects. The report of lens calibration such as parameter, value and standard error are shown in Table II.

TABLE II: Lens Calibration Report

Parameter	Value	Std Error
Image width	4896	-
Image height	3264	-
Focal length (x)	3821.71	3.0027
Focal length (y)	3822.92	3.02428
Principal point (x)	2470.23	0.636189
Principal point (y)	1661.45	0.725868
Skew	0	0
Radial K1	-0.0498229	0.00122872
Radial K2	0.0657656	0.00534378
Radial K3	-0.0289497	0.00697121
Radial K4	0	0
Tangential P1	0	0
Tangential P2	0	0



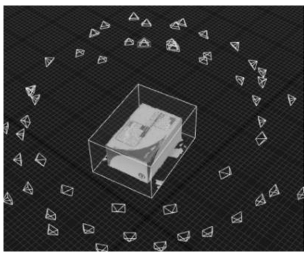
(a)

(b)

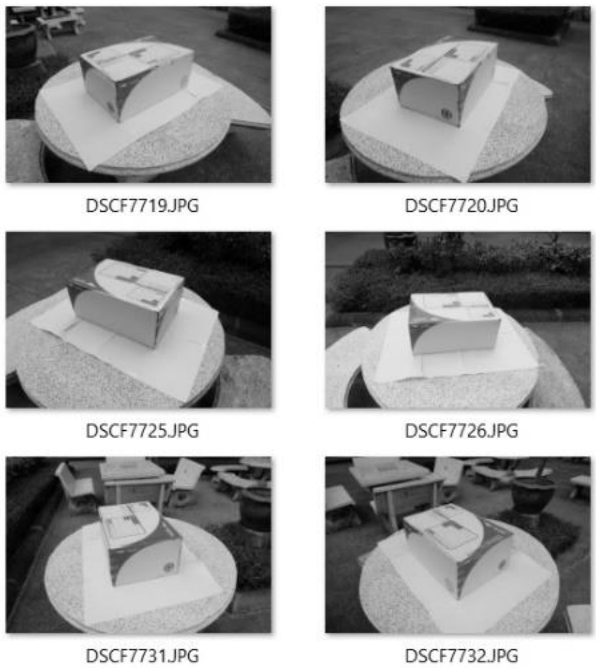
Fig. 1. (a) Images captured chessboard for lens calibration. (b) Gray and white marks on the source images represent the detected corners of the checkerboard pattern.

B. Image Capture

The images have captured in different positions on two circular paths, which different angle around the object with both angles are not exceeding 30 degrees (Fig. 2). Then check the working images from all for use to 3D generation.



(a)



(b)

Fig. 2. (a) Position of the cameras around the object.
(b) Image of sample object collected by camera.

C. Point Cloud Generating.

The images were imported to photogrammetry software and. The image-matching algorithm in software identifies corresponding points. For a given point in one image, the software searches a two-dimensional grid of points in another image and presented the simulated point cloud model in physical shape of the object (Fig. 3).

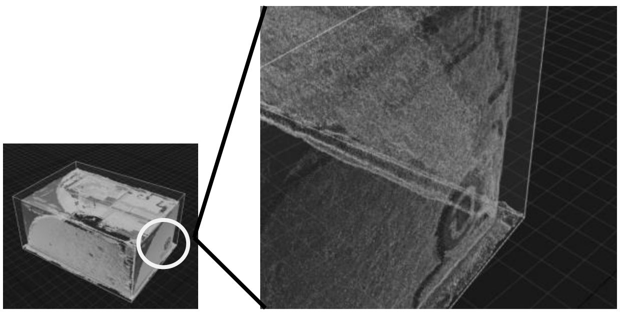
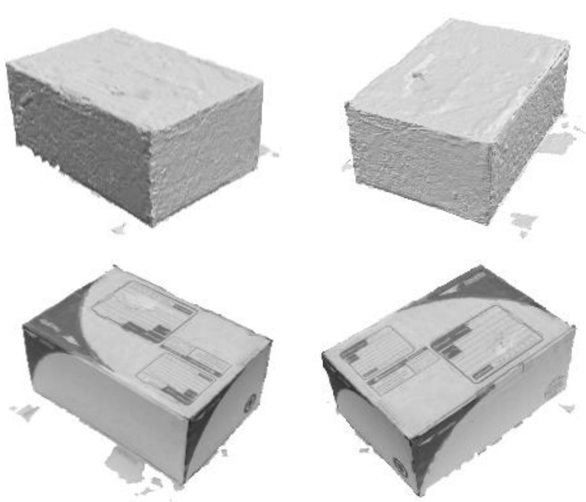


Fig. 3. Point cloud simulation.



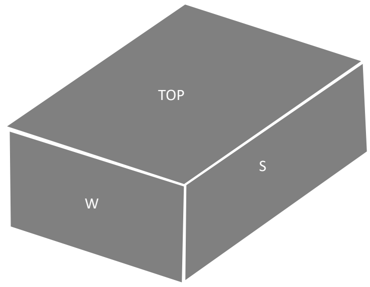


Fig. 4. Reconstruction process of sample object.

D. Modeling Surface Using Point Cloud

The triangulation converts the given set of points into a consistent polygonal model (mesh). This operation partitions the input data and usually generates vertices, edges, and faces (representing the analyzed surface).

E. 3-D Model Construction

This process calculated model for created a 3-D model to build postbox in clear shape (Fig.4). Then geometry of the object was measured manually by its width, height and length and compared to the values obtained from the 3-D model. An error of the model was evaluated in terms of Length, Area and Volume (Table III).

TABLE III: RESULT

	Manual measurement (cm.)	Automated measurement (cm.)	error
Width	30.90	30.83	0.01
Length	45.40	45.43	0.07
Hight	20.00	20.03	0.17
Area (Top)	1,398.32	1,400.61	0.16
Area (A side)	907.85	909.96	0.23
Area (B side)	615.90	617.52	0.26
Volume	27,961.74	28,054.16	0.33

V. RESULT

The result showed the comparison between a real post box that measured with manually equipment (Measuring Tape, ruler) and generated 3-D model that measured with manually software measuring. Define the tradition measurement was correct and fined details of error. The details of the error obtained from the study are shown in Table III. The measured error for the width is -0.16, which means that a width accuracy of 99.84%, for the height its error is 0.01 and accuracy is 99.99%, for the length its error is 0.17 and accuracy is 99.83%, for the top area its error is -0.15 and accuracy is 99.85%, for the area of side A its error is 0.17 and accuracy is 99.83%, for the area of side B its error is 0.00 and accuracy is 100.00% and the accuracy of volume is 99.99%. The result of the study showed that error of the developed model in Length, Area and Volume are less than ±1%.

VI. CONCLUSION

This paper represented the photogrammetry method that can construct 3-D model with completely shape base on point cloud from photos captured and shown the result of comparison geometry measured between the 3-D model and the sample model base on point cloud is shown in term of error of the developed model in Length, Area and Volume are less than ±1% that proved the 3-D construction model base on point cloud from construction site image can be used to evaluate construction progress with enough accuracy that can be effectively and quickly verified and be able to provide stakeholders with easy understanding of the project situation.

CONFICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Rattanapongwanich S. conducted the research; Kusonkhum W. and Charnwasununth P. analyzed the data; Srinavin K. and Leungbootnak N. supervised the research; all author had approved the final version.

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