3D Laser Scanner in a Structural Framework

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As interest in smart construction technology increases, various smart construction technologies are being used for sustainable construction management. Among these technologies, 3D laser scanning technology receives data such as the speed, time, direction, and distance of light or laser beams reflected from the target object, allowing the representation of the object's shape in a 3D-coordinate-based point cloud. Currently, a variety of equipment is used in 3D laser scanning, with the time-of-flight (TOF) method and phase-shift method commonly employed for laser scanning to detect the wavelength. This technology stands out for phenomena analysis and monitoring, with various applications being studied for construction engineering and management in construction industry.

Keywords: 3D laser scanning technology ; point cloud data ; smart construction technology

1. Introduction

With the recent activation of Fourth Industrial Revolution technologies, the construction industry is also very interested in various applicable smart construction technologies [1]. Representative smart construction technologies applicable to the construction field include Building Information Modeling (BIM), Internet of Things (IoT), 3D laser scanning technology, drone surveying technology, Augmented Reality (AR), Virtual Reality (VR), etc. [2]. By applying these smart construction technologies to construction work and management, various application methods such as energy saving and labor saving, as well as solving problems occurring in the construction industry, are being researched [3]. This research will ultimately lead to sustainable construction management. This is because the efficient use of construction resources and the creation and management of the environment on an ecological basis result in sustainable construction management and can achieve sustainability in the construction industry [4].

Among the smart construction technologies, 3D laser scanning technology is excellent at capturing real-world phenomena and is being utilized to analyze and monitor various existing conditions. Therefore, research is being conducted on how to measure and analyze the state of construction works using this 3D laser scanning technology [5]. This technology allows the collection of the current state of objects in the form of point cloud data (PCD) [6]. Recently, research on 3D laser scanning technology is being performed to monitor and analyze the current state of an object in various fields, including the construction industry, such as crop yield measurement in agriculture [7], railway environmental modeling [8], bridge monitoring [9], forest modeling and monitoring [10], cultural heritage monitoring, etc. [11].

The 3D model created from PCD obtained using devices like 3D laser scanners, LiDAR equipment, and 2D data conversion devices has been studied in conjunction with BIM as Scan to BIM [12]. The limitation of the PCD, unless integrated with other technologies, is that it is limited to analyzing existing conditions. Recent research has focused on utilizing PCD in the construction field by overlapping it with BIM to assess work progress through similarity measurements [13] and by employing algorithms to convert point clouds into shapes, thus using surface-based recognition metrics to monitor work progress compared to BIM [14]. Various studies are ongoing on BIM in conjunction with PCD for sustainable construction management.

The accurate and up-to-date measurements of work progress on a construction site are essential to sustainable project management functions such as scheduling and cost management but are currently performed using traditional building surveying techniques and visual inspection [15]. Traditional techniques for work progress management that manually collect and manage construction progress data contain inaccurate and missing information during the construction phase [16]. Traditional work progress measurements rely heavily on manual tasks and have been criticized by construction practitioners for their repeatability, inefficiency, and potential for error [17]. Automatic techniques for progress measurement studied until recently can be divided into two categories: the first is imaging techniques such as 3D laser scanning [17][18][19][20][21][22][23], 3D ranging cameras [17][23][24][25], and 2D-based modeling [26][27][28][29][30][31], and the second is geospatial techniques such as wireless fidelity (Wi-fi) [32], Global Positioning System (GPS) [33], barcodes [34][35], Radio-Frequency Identification (RFID) [36][37][38], and ultra-wideband (UWB) [39]. In particular, the three-dimensional model, which is known as PCD, obtained through 3D laser scanning technology, takes a form that is very similar to reality. PCD can be used in a variety of ways because it contains various types of information such as the location, color, and intensity of the object. Therefore, when analysis of the current status of an object is required, such as progress measurement, it is considered appropriate to apply 3D laser scanning technology to compare 3D information.

2. Data Collection Methods for Construction Progress Measurement

In construction projects, progress measurement is utilized as a metric to track the progress of construction [40]. To achieve accurate progress measurement, it is essential to first have a precise understanding of the construction project's progress [41]. However, due to factors such as the increasing scale of construction projects and the concurrent progress of various facilities, obtaining reasonable and accurate information for progress rate measurement has limitations [13]. Research related to the automatic acquisition of information on construction progress on construction sites can be categorized into imaging techniques [17][18][19][20][21][22][23][24][25][26][27][28][29][30][31] and geospatial techniques [32][33][34][35][36][37][38][39]. The types and characteristics of these technologies are presented in **Table 1**.

Table 1. Data collection methods for progress measurement.

Category	Type	Characteristic	Refs.
Imaging techniques	**3D laser scanning**	• Automated collection, high accuracy, data timeliness • High cost, operations specialist	[17][18][19][20][21][22][23]
	3D ranging camera	• Portable, relatively cheap, wide texture information • Short-range applications, limited site information	[17][23][24][25]
	Image-based modeling	• Low cost, compactible, high resolution, texture information • Sensitivity to data acquisition according to site environment	[26][27][28][29][30][31]
Geospatial techniques	**Wi-fi**	• Convenience, portable, easy deployment • Increased installation and disassembly cost	[32]
	GPS	• Wide positioning range, strong adaptability • Low precision, limited to outdoor	[33]
	Barcode	• Low cost, compactible • Time-consuming, sensitive data	[34][35]
	RFID	• Wide practicability, adaptability • Time-consuming, error-prone	[36][37][38]
	UWB	• Reliable signal, long reef range, provide 3D positioning • High cost, daily-necessity-embedded	[39]

Imaging techniques include 3D laser scanning, 3D ranging cameras, and image-based modeling. Among these techniques, 3D laser scanning utilizes measurement techniques based on LiDAR or LaDAR to construct laser points received in a three-dimensional coordinate system in the form of a point cloud. This technique allows for the automatic collection of data that closely resemble reality, contributing to high accuracy and improved timeliness of data. However, it has disadvantages, including the need for experts to operate 3D laser scanners and the relatively high cost of hardware [17][18][19][20][21][22][23]. There are also 3D ranging cameras, which have the advantage of being compact and portable but have limited operating distances and limited in-field data that can be obtained [23][24][25]. Additionally, image-based modeling has user-friendly hardware, a relatively low price, and flexible hardware operation, and it allows the collection of a variety of data [26][27][28][29][30][31]. Geospatial technologies include wireless fidelity (Wi-Fi), Global Positioning System (GPS), barcodes, Radio-Frequency Identification (RFID), and ultra-wideband (UWB). Both Wi-Fi and UWB are technologies that use transceivers to collect data. Wi-Fi is cost-efficient in terms of hardware, but with increased installation and disassembly costs because its transmission range is limited [32]. However, although UWB offers long transmission distances and 3D data-collection capabilities, its application requires significant hardware investment [39]. GPS relies on satellite signals to locate specific objects but has limitations when used indoors [33]. Barcodes are widely used for material tracking and management due to their low cost and ease of use [34][35]. RFID uses chips to handle data and has the advantage of easily accessing stored data [36][37][38]. Utilizing these various data collection techniques has made it possible to collect and utilize construction site data with improved reliability, accuracy, and timeliness compared to collecting data manually.

3. Three-Dimensional Laser Scanning Technology and Its Application in Construction

PCD refers to data that can be acquired through 3D laser scanning technology, enabling the construction of a complete 3D model by combining PCD obtained from various scanning locations. This technology receives data such as the speed, time, direction, and distance of light or laser beams reflected from the target object, allowing the representation of the object's shape in a 3D-coordinate-based point cloud [31]. Currently, a variety of equipment is used in 3D laser scanning, with the time-of-flight (TOF) method and phase-shift method commonly employed for laser scanning to detect the wavelength.

The PCD that consist of the point cloud includes several features such as three-dimensional coordinates (XYZ), color (RGB), and intensity information. Depending on the equipment's characteristics, it may contain two or more of these features. Such features allow for robust predictions about the shape of the object based on the points collected by reflections. However, there are limitations in using these physical features for the direct classification of components that constitute the object within the PCD [13].

Several studies [5][42][43][44][45][46][47][48][49] have been conducted on the application of 3D laser scanning technology in the construction field, focusing on sustainability, maintenance, and civil engineering project management. In the study by Cheng and Jin [42], 3D laser scanning technology was applied to the reverse engineering of historical architecture. Their study showed that the historical architecture, which was reconstructed using a digital 3D model from a 3D laser scanner, could record shape, construction style, and structure richly like real architecture. It also supplied basic data for record data and repair protection. Bernet et al. [43] present the results of a study in which the data obtained from 3D laser scanning became a good material to implement an analysis concerning construction and surveying in the maintenance of buildings belonging to the cultural heritage. Moyano et al. [44] compared two scanners used in geodetic measurements for the purpose of BIM in historic buildings. The results of their study revealed that the differences in measurements from two laser scanners (Personal Laser Scanning and Terrestrial Laser Scanning) are not excessively large and admissible for a Scan-to-BIM procedure. Ding, Z. et al. [45] developed a digital framework integrating BIM and reverse engineering (RE) to reduce mistakes and reworks for renovation projects. Their study proposed a digital construction framework for improving information utilization, which integrated BIM, RE, and other advanced tools such as 3D laser scanning technology and prefabricated construction. A review study by Hosamo and Hosamo [46] presented a comprehensive and state-of-the-art review of digital twins using laser scanners in bridge maintenance and engineering. The study by Park and Kim [47] aimed to verify the feasibility of earthwork digitalization technology by applying 3D laser scanning technology to actual sites. The usefulness of its use in construction management was verified by numerically measuring changes in earthwork volume at actual earthwork sites. In a review study by Singh et al. [48], even though the lack of infrastructure in underground mines for data transfer, geodetic networking, and processing capacity remain limiting factors, the 3D laser scanning technology is becoming an integral part of mine automation because of its affordability, accuracy, and mobility, which should support its widespread usage in years to come. In a study by Wang J. et al. [49], the application of 3D laser scanning technology in the field of curtain wall design and installation, including scanning operations, point cloud data collection and processing, 3D BIM model reconstruction, and related BIM model exercises, was addressed. Kim and Kim [5] applied 3D laser scanning technology to check the quality of structural frame construction using a case study, in which it was possible to check the spacing, verticality, and thickness of wall rebars, and to check the dimensions of concrete walls, and the horizontality and thickness of concrete slabs during frame construction.

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