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Evaluation of UAV LiDAR Survey for Detecting Soft Ground Settlement at Construction Site in Coastal Area of Korea

Jae-Cheol Lee,[1] Hee-Jin Oh,[2] Dong-Ha Lee,[1*] and Seog-Hoon Hwang[3**]

[1]Department of Integrated Energy and Infra System, Kangwon National University,
1 Kangwondaehak-gil, Chuncheon-si, Gangwon-do 24341, Republic of Korea
[2]Infra Technical Team, HL D&I Halla Corp.,
289 Olympic-ro, Seoul-si 05510, Republic of Korea
[3]CEO, NEOTIZ Corp., 1 Kangwondaehak-gil, Chuncheon-si, Gangwon-do 24341, Republic of Korea

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Rapid and efficient 3D spatial-information-collecting technology has recently become necessary in construction work. In particular, the use of light detection and ranging (LiDAR) techniques to collect and model 3D location information using a laser scanner connected to an unmanned aerial vehicle (UAV) or aircraft is growing. When civil engineering work is performed on soft ground, it results in engineering issues such as long-term settlement and localized structural damage. However, research on LiDAR survey of soft ground is limited. Therefore, a construction site in a coastal area, a container terminal (Stages 2–6) in Busan New Port, was selected as the target of this study to validate the efficacy of using UAV LiDAR survey to assess the settlement of soft ground. The performance of the UAV LiDAR survey for soft ground settlement calculation was evaluated by comparing and analyzing the settlement calculation performance using a digital elevation model (DEM) grid time-series analysis with the performance of settlement measurement using a measuring instrument. As a result of this study, the method of calculating settlement using UAV LiDAR and DEM applied in this study is judged to satisfy the field survey regulations for calculating soft ground settlement.

1. Introduction

Recently, new technologies such as artificial intelligence and the Internet of Things have been extensively employed to achieve optimal outcomes at construction sites by considering various factors such as economic feasibility, efficiency, and accuracy. New high-precision, rapid, and efficient 3D spatial-information-collecting technologies are required in the field of surveying. In particular, the use of laser scanners, which can efficiently and quickly capture a large quantity of data on a wide range of observation objects, is expanding; one typical method is light detection and ranging (LiDAR) survey.

*Corresponding author: e-mail: geodesy@kangwon.ac.kr
**Corresponding author: e-mail: hwangsh86@gmail.com
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LiDAR refers to a survey technique that extracts information about the ground surface by calculating the coordinates of a location by scanning a laser pulse on the ground and observing the arrival time of the reflected pulse using a laser scanner mounted on an aircraft or unmanned aerial vehicle (UAV).(1) Once the data acquired using LiDAR are processed, they can be used to create a digital elevation model (DEM) or a digital surface model (DSM). A DEM consists of grid data constructed from the coordinate data of the reflection points of the laser pulses and spatial position data randomly extracted from these points, whereas a DSM is a DEM with added information about terrain cover, such as trees and artifacts. Compared with other methods, DEMs and DSMs using LiDAR are superior in terms of time, cost, and accuracy, and are frequently utilized in disaster prevention programs to map, for example, coastal areas, forest areas, and floods.(2,3)

The recent research on using LiDAR survey data at domestic construction sites has included studies on earthwork volume calculation,(4,5) stability evaluation of earthwork slopes in civil engineering works,(6) and building 3D highway data.(7) Among investigations of the utilization of UAV and laser scanners at overseas construction sites, a study using UAV to effectively monitor the subsidence of waste landfills(8) was conducted to help waste landfill managers overcome potential problems. In addition, there were studies on the applicability of UAV LiDAR to coastal environment mapping to solve the problem of the poor resolution of the existing image mapping method,(9) a technique and method for landslide monitoring using UAV survey results,(10) and presenting indicators and methods for accurately detecting landslides and evaluating monitoring capabilities.(11)

However, because South Korea (henceforth Korea) is bordered by the sea on three sides, construction work for site preparation through the reclamation of coastal areas is increasing to promote land utilization and balanced development across the provinces. Because many such construction projects are conducted on soft ground, the existing studies on LiDAR survey on soft ground, which can pose engineering issues such as long-term settlement and localized structural damage, are insufficient.

Therefore, in this study, we aim to evaluate the performance of UAV LiDAR survey for settlement measurement of soft ground at the construction site of a container terminal (Stages 2–6) in Busan New Port, located in a coastal area of Korea.

2. Methods

In order to evaluate the accuracy of the calculation of soft ground settlement by UAV LiDAR survey, the following observations were performed and data were acquired. The LiDAR scanning was carried out on May 26, June 9, June 23, and July 16, 2021 using Velodyne's 3D LiDAR scanner VLP-16. The research site has soft ground created by dredge reclamation, and there are no interfering structures or obstacles within the flight path. The flight was conducted considering the distance from the ground control point.

In the data matching process, the position and posture correction of the UAV and the LiDAR data must be matched. For this purpose, the global navigation satellite system (GNSS) and inertial navigation system (INS) data are utilized. 3D point cloud data are obtained by preprocessing, which is a filtering operation to extract data suitable for the purpose by removing unnecessary data. The 3D spatial information that has undergone data processing is point cloud data, and its use is inconvenient for calculating the amount of settlement. Therefore, a DEM was created by applying an appropriate interpolation method and appropriate grid size for nearby point cloud data. When creating such a digital elevation model, the optimal interpolation method and optimal grid size that maximizes the use of point cloud data were determined to create the final DEM.

A comprehensive evaluation of the UAV LiDAR survey accuracy was performed through comparative analysis of the values measured using 10-point settlement measuring instruments in the study area and the settlement values calculated using the final DEM.

2.1 Study area

A soft-ground site located in a coastal area, the construction site of a container terminal (Stages 2–6) at Busan New Port, was chosen as the study area to evaluate the performance of UAV LiDAR survey.

As shown in Fig. 1, the optimal interpolation method was applied and the grid size was estimated to create a DEM using the performance of one of the measuring instruments (J-SK) at the study site on May 26, 2021. Furthermore, the UAV LiDAR performance of estimating soft ground settlement was evaluated using a 10-point time-series measuring instrument (K-SK). Table 1 shows the locations and heights of the 12 settlement measuring instruments.

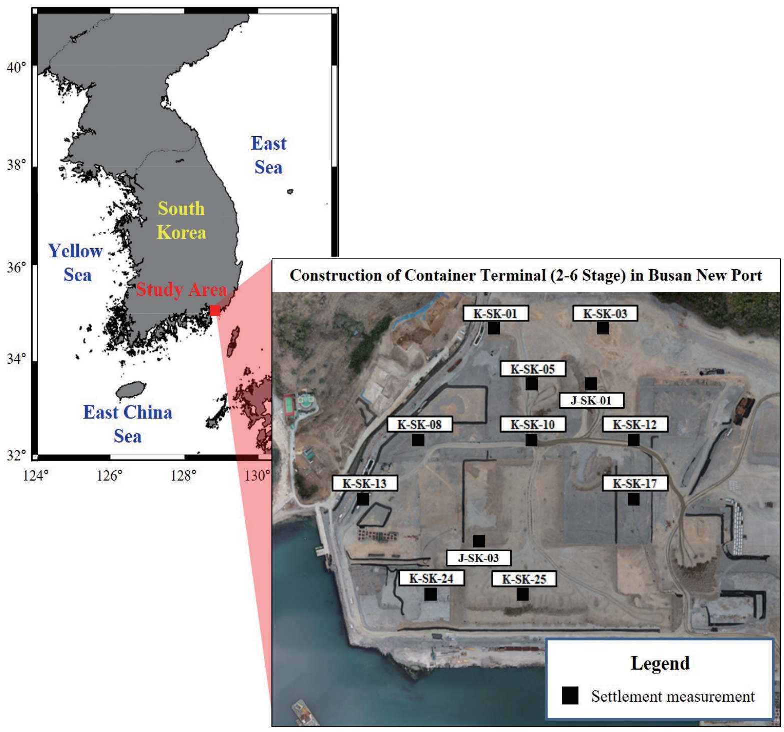

Fig. 1. (Color online) Study area.

Table 1
Settlement measurement instrument locations and heights.

No.	Measuring point	Transverse Mercator coordinates		Orthometric height (m)			
		X	*Y*	05.26	06.09	06.23	07.16
1	J-SK-01	274761.0010	178849.2670	8.819	—	—	—
2	J-SK-03	274551.0019	179149.2670	5.069	—	—	—
3	K-SK-01	274586.1306	178749.2670	9.880	9.874	9.856	9.854
4	K-SK-03	274786.1306	178749.2670	9.356	9.353	9.346	9.346
5	K-SK-05	274651.0019	178849.2670	9.924	9.844	9.771	9.695
6	K-SK-08	274451.0019	178949.2670	8.632	8.540	8.462	8.396
7	K-SK-10	274651.0019	178949.2670	8.762	8.683	8.598	8.523
8	K-SK-12	274851.0019	178949.2670	8.010	7.977	7.945	7.901
9	K-SK-13	274351.0019	179049.2670	8.716	8.689	8.657	8.994
10	K-SK-17	274851.0019	179049.2670	7.416	7.376	7.335	7.265
11	K-SK-24	274476.9003	179229.3229	6.845	6.795	6.757	6.707
12	K-SK-25	274639.8040	179213.6826	6.686	6.613	6.556	9.315

2.2 Data organization and preprocessing

The UAV LiDAR data were acquired in the planning and design stage on May 26, June 9, June 23, and July 16, 2021, at the construction site of the container terminal (Stages 2–6) in Busan New Port. On each date, the weather, GNSS deployment environment, distance from the ground control point, and aircraft speed and direction taking into account the wind were recorded.

A flowchart of the data preprocessing steps to produce 3D aerial LiDAR points for the terrain using data obtained during the flight and from the ground GNSS reference station is shown in Fig. 2. After observation, the data decoded by the data processing computer included UAV LiDAR and GNSS/INS data. Thus, the raw data points were produced using terrestrial GNSS reference station data of known points, sensor separation distance, and system calibration information. The data calculated in this manner were converted into a single point cloud with a consistent coordinate system, using a process known as matching.(12) There are multiple possible matching methods, but in this study, the iterative closest point method was applied, which has been frequently used to match 3D laser scanning data.(13,14)

2.3 Time series analysis of DEM

The optimal interpolation was evaluated using the data of the May 26, 2021 UAV LiDAR survey after the preprocessing step was completed. Interpolation was used to estimate and represent the altitude of points without information from the points with information to express the terrain as a continuous function. Interpolation of DEMs can yield estimates of the elevation of points at which sample elevations have not been observed. The Kriging interpolation, triangulated irregular network (TIN), and natural neighbor interpolation (NNI) methods, which are the most commonly used in DEMs, were employed to create the DEM in this study.(15)

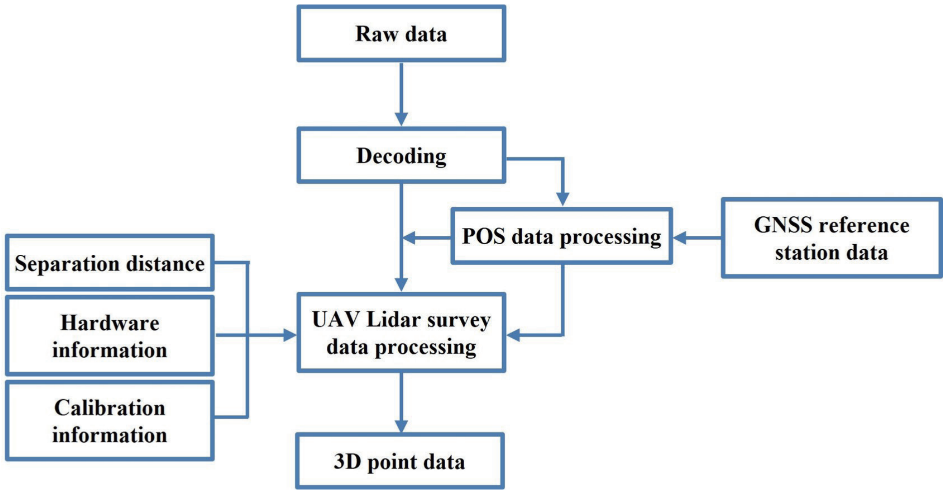

Fig. 2. (Color online) Data preprocessing flow of UAV LiDAR survey.

3. Results

3.1 Optimal interpolation and grid size of DEM

Kriging interpolation, TIN, and NNI were applied to the UAV LiDAR survey data to determine the best interpolation method for DEM construction. The elevation obtained by each DEM and measuring instrument were compared, and it was determined that the Kriging interpolation method produced the closest results with a difference of −0.381 to −0.441 m. These results are shown in Table 2, and the DEM for each method is shown in Fig. 3.

Grid sizes were set to 0.5, 1.0, 1.5, and 2.0 m applying the Kriging interpolation method, and the measurements at a single point were compared. The results are summarized in Table 3. The Kriging interpolation result approached the value obtained with the settlement measuring instrument as the grid size decreased, except for the 2.0 m grid, which showed a smaller difference than that of the 1.5 m grid, indicating higher accuracy. However, these were the values at (274587, 178749), which was close to the measuring instrument coordinates but not the actual grid point coordinates. A grid larger than 2.0 m was deemed unsuitable for the purposes of this study. Furthermore, a grid size of 0.2 m was deemed insufficient because the capacity of the DEM and the time necessary to generate it would both be greater than those of the 0.5 m grid. Therefore, the best grid size was determined to be 0.5–1.0 m, and the 0.5 m grid size was found to be the most appropriate for this study.

3.2 Evaluation of UAV LiDAR survey

The performance of the DEM constructed using the Kriging interpolation method and 0.5 m grid was compared with the performance of the ten settlement measuring instruments deployed at the study site. The results are summarized in Table 4 and Fig. 4.

Table 2
DEM obtained with various interpolation methods and measurement results.

No.	Reference point H (m)	DEM		Height difference $H - Z$ (m)
		Interpolation method	Measurement point Z (m)	
J-SK-01	8.819	Kriging	9.20	−0.381
		TIN	9.38	−0.561
		NNI	9.60	−0.781
J-SK-03	5.069	Kriging	5.51	−0.441
		TIN	5.62	−0.551
		NNI	5.84	−0.771

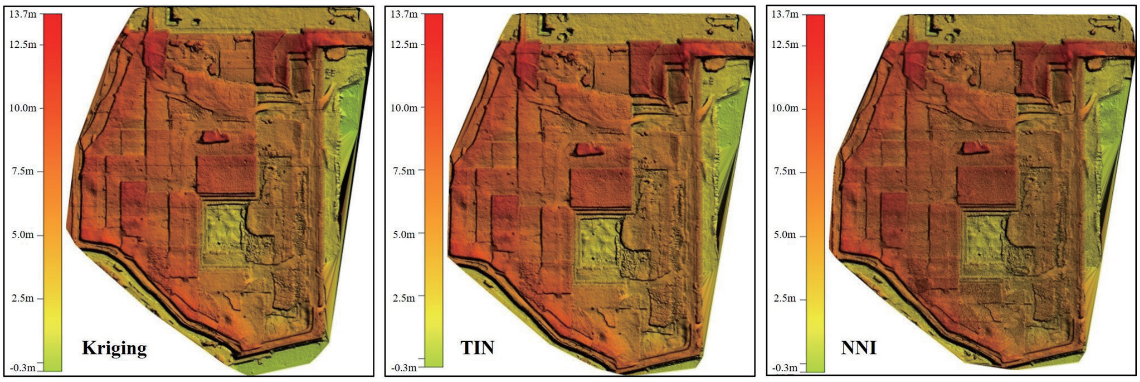

Fig. 3. (Color online) DEM generated by various interpolation methods.

Table 3
DEM obtained with various grid sizes and measurement results.

Point name	Reference point H (m)	DEM (m)		Height difference $H - Z$ (m)
		Grid size (m)	Measurement point Z (m)	
J-SK-01	8.819	0.2	9.13	−0.311
		0.5	9.15	−0.331
		1.0	9.20	−0.381
		1.5	9.32	−0.501
		2.0	9.22	−0.401

The root mean square error (*RMSE*) of the DEM produced using the data from May 26, 2021, was 0.233 m, which is the smallest difference from the actual measured value. The *RMSE* of the DEM produced with data collected on June 23, 2021 was 0.262 m, which was the largest difference from the actual measured value. In contrast, the *RMSE* limit in Article 25 (Inspection and Adjustment Using Reference Points) of the Aerial Laser Survey Work Regulation is specified as 0.25 m. Since the UAV LiDAR results satisfy the regulations or exhibit only a slight difference, the adequacy of its measurement performance for soft ground settlement was verified.

Table 4
UAV LiDAR survey performance.

No.	Measuring point	May 26, 2021	June 9, 2021	June 23, 2021	July 16, 2021
		Height difference, $H - Z$ (m)			
1	K-SK-01	0.340	0.344	0.246	0.284
2	K-SK-03	0.176	0.303	0.396	0.216
3	K-SK-05	0.174	0.324	0.361	0.335
4	K-SK-08	−0.188	0.120	0.122	0.206
5	K-SK-10	0.272	0.153	0.058	0.293
6	K-SK-12	0.250	0.217	0.335	0.291
7	K-SK-13	−0.184	0.209	0.377	0.014
8	K-SK-17	0.276	0.286	0.145	0.375
9	K-SK-24	−0.035	−0.085	0.057	0.137
10	K-SK-25	0.286	0.213	0.206	0.165
Minimum		−0.188	−0.085	0.057	0.014
Maximum		0.340	0.344	0.396	0.375
Average		0.137	0.208	0.230	0.232
RMSE		0.233	0.240	0.262	0.253

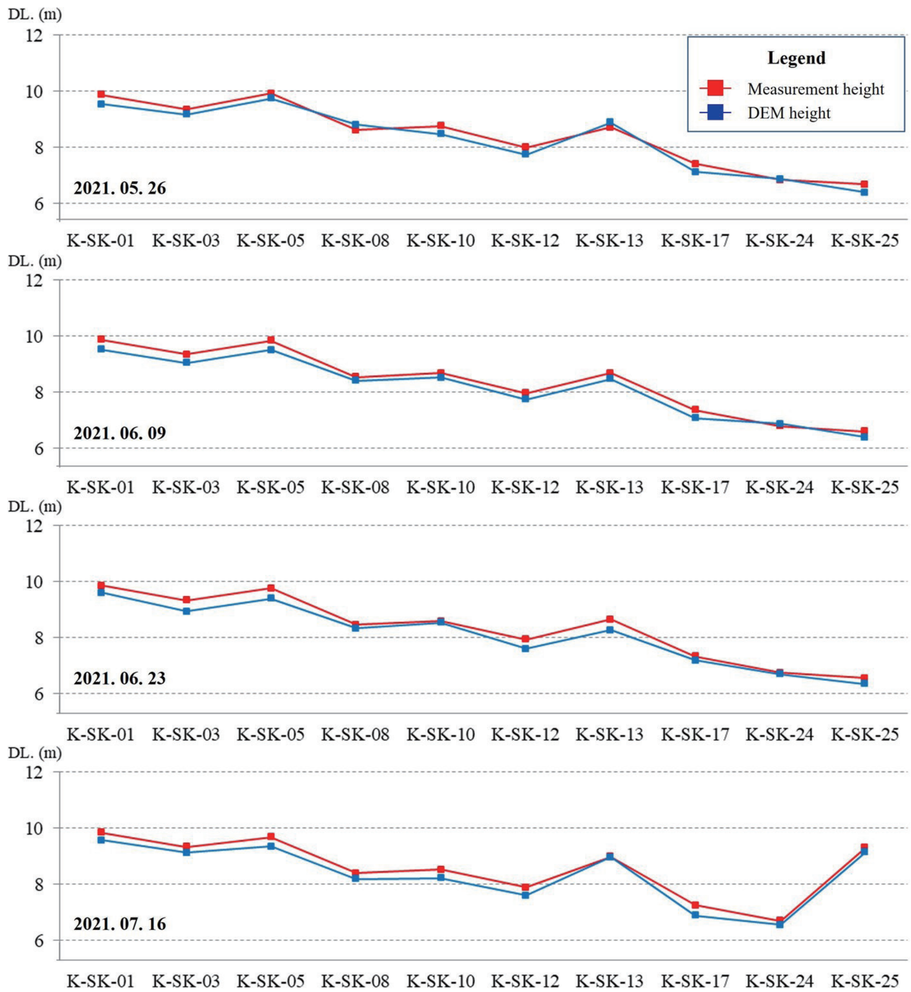

Fig. 4. (Color online) Performances of UAV LiDAR survey.

4. Conclusions

We evaluated the soft ground settlement calculation performance of UAV LiDAR survey. To evaluate the optimal performance of the survey, the optimal interpolation was determined by creating a time-series DEM of the work area, and the optimal grid size for settlement analysis was obtained. By comparing the performances of settlement measuring devices on soft ground and the UAV LiDAR survey, the following conclusions were reached.

1. An observed baseline data point from the UAV LiDAR survey results was compared with the height obtained by the Kriging interpolation, TIN, and NNI methods to determine the optimal interpolation method for DEM construction. The Kriging interpolation method produced the closest result to the measured value, with a difference of −0.381 m.
2. The optimal grid size for settlement calculations was determined by comparing the measurements of one point (J-SK-01) with various grid sizes of 0.5, 1.0, 1.5, and 2.0 m. A grid size of 2.0 m or greater was inadequate for the purposes of this study, while a grid size of less than 0.5 m was deemed inappropriate because of an increase in the required DEM capacity and time needed to construct it. Therefore, the most appropriate grid size was determined to be 0.5–1.0 m, and the 0.5 m grid size was judged to be optimal.
3. A time-series DEM was created by applying the optimal interpolation method (Kriging) and grid size (0.5 m) obtained in this study to the UAV LiDAR survey data, and the results were compared with the performance of ten measuring instruments installed at the study site. As a result, the DEMs created from the observations on May 23 and June 16, 2021 were marginally above the limit of *RMSE*, which is defined as 0.25 m in Article 25 (Inspection and Adjustment Using Reference Points) of the Aerial Laser Survey Work Regulation. However, the DEMs created from the observations on May 26 and June 9, 2021 satisfied the work regulations.

We examined the optimal DEM construction method for soft ground settlement calculation and the performance of UAV LiDAR survey that complied with the Aerial Laser Survey Work Regulation. Because UAV LiDAR survey technology is rapidly evolving, an ongoing study is required to develop a more accurate and cost-effective DEM construction method in the future. Constructing an accurate and affordable DEM is anticipated to enable its application in a variety of industries.

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