Visualization of the Progress Management of Earthwork Volume at Construction Jobsite

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Abstract –

In recent years, the use of intelligent construction equipment with sensors attached to construction heavy equipment used in civil engineering earth work has become commonplace. Sensors provide a variety of information on construction equipment, and this information is used to control the cutting edge of construction equipment called machine control and machine guidance. On the other hand, it is also possible to use the information obtained from the sensors in a wide range of applications to manage the construction progress at civil engineering sites. In this study, a network-based cloud system for soil volume progress management in the actual construction site was verified.

Keywords –

Intelligent Construction Equipment; Network system; As-built data; Construction Progress Management

1 Introduction

In civil engineering earth work sites, it is common to control the progress of construction in terms of soil quantity, volume. This is because construction volume is usually contracted by each material volume, and therefore the site manager daily wants to know the volume as soon as possible during construction. However, it is difficult to realize a means of accurately measuring the daily progress volume, for example, in the case of an excavation site, the construction volume is generally estimated from the average load capacity of the dump trucks used to haul the excavated soil and the number of hauls of dump trucks to be taken out of the construction site. In other words, there is no general method for accurately ascertaining the construction volume. Then, the purpose of this study is to obtain the daily progress volume by using the bucket cutting edge history information calculated based on the information from sensors attached to heavy equipment, and to make the progress of the construction work visible so that the site manager can easily understand the situation on the site.

2 System Configuration

The system used in this study was the X-53x Excavator machine guidance system of Topcon Corporation [1]. The system consists of the following, and the configuration of the system is shown in Figure 1.

(a)Tilt sensor 4pcs.
(b)Display
(c)Controller
(d)GNSS, Global Network Satellite System, antenna 2pcs.
(e)Communication routers to connect to the server
(f)Cloud Server of Data collection and management system, Sitelink3D [2]

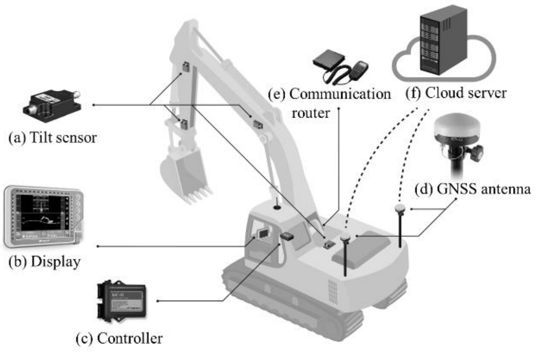


Figure 1. The configuration of the system

3 Construction Site

The construction site of this study was a civil engineering project to excavate and remove sediment from the dam's lake bottom during the winter in order to increase the dam's water storage capacity, this was ordered by Nagano Prefecture and the contractor was Kinoshita Construction Co. Ltd. and the excavation work took 51 days. The planed excavation volume was 53,000 m^3 and the area was 24,000 m^2, and work was carried out by the three-layer bench-cut method. In terms of soil quality, it was mainly sandy soil that was easy to excavate, although some boulders appeared during the last phase of the work. A picture of the construction site is shown in Figure 2.

Figure 2. Construction site photo

4 System principle

The Excavator machine guidance system uses the angle information detected by angle sensors attached to the Boom, Arm, Bucket and Body of the Excavator and the coordinate information detected by the two Global Navigation Satellite System (GNSS) antennas, respectively, to measure in real time the coordinates of the Bucket cutting edge of the Excavator, generally the coordinates at the center, Pc(Xc,Yc,Zc) or the coordinates at right and left ends points Pr(Xr,Yr,Zr) and Pl(Xl,Yl,Zl) of the bucket. The coordinates measurement points are shown in Figure 3. The system displays the difference in height between the measured data and the design data in the z-coordinate (elevation) by comparing it with the three-dimensional design data entered into the system beforehand. The Excavator operator can see the difference between the cutting edge and the design surface, and the system is used for guidance in construction. The display image is shown in Figure 4.

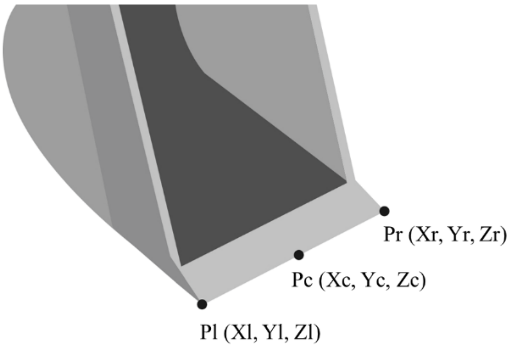


Figure 3. The coordinate measurement points of bucket cutting edge

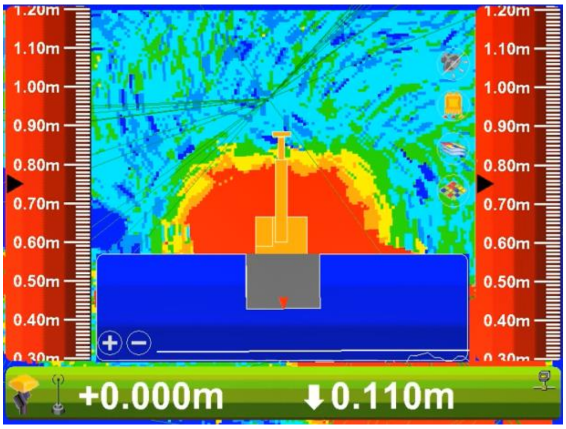


Figure 4. Display image

By using the cloud data collection and management system, Sitelink3D system, in this study, the coordinate data of the bucket cutting edge are transmitted through the mobile phone line in real time and stored on the server. The bucket cutting edge data stored on the server is automatically processed on the server and can be output as gridded mesh data. This data enables us to grasp the 3D shape of the construction site. It is also possible to calculate the daily construction volume, the excavation volume, by calculating the daily differences in the 3D geometry processed on the server. The Sitelink3D system can output grid mesh data and construction volumes as daily reports, allowing the site manager to visually grasp the day's construction results on a daily basis.

5 System Accuracy Verification

The purpose of this study was to verify the accuracy of the system in order to numerically verify the output construction volume. In terms of hardware accuracy, the errors of each sensor contribute to the system accuracy. In this study, the RTK, Real Time Kinematic, method was adopted as a method of GNSS, coordinate measurement. RTK is one of the most accurate surveying methods for surveying moving objects in real time, with a 2-3 cm error in coordinating detection. In this study, a multi-GNSS type antenna was used to improve the stability of the detection of GNSS satellites, which can detect Japan's Quasi-Zenith Satellite System (QZSS), satellite. On the other hand, since the angle detection error of the angle sensor cannot be directly converted to the coordinate measurement error, the accuracy of the machine guidance system is generally discussed in terms of the total system error including the GNSS coordinate measurement error. It was confirmed that the system was calibrated prior to the start of construction, and that the coordinate measurement error was within ±5 cm as specified in the Accuracy Verification Test Procedure of the Ministry of Land, Infrastructure and Transport [3].

Next, I describe the error of gridding to represent the 3D shape of the construction site. The grid data consist of the Z-coordinates extracted when gridded with X and Y coordinates of a certain interval on the plane through which the line of the bucket cutting edge passes. Figure 5 shows an image of the grid data.

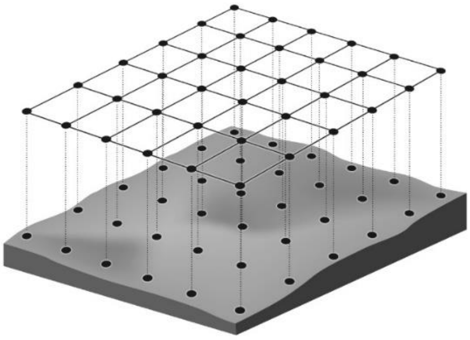


Figure 5. Image of Grid data

In this study, grids were created at 20 cm intervals in the X and Y directions. The grid data are different from the actual 3D shape because it is a polygon shape. The line of the bucket cutting edge is a straight line, so there is no error in the gridding process. On the other hand, it can be understood geometrically that the error in the direction of bucket rotation is small if the bucket moves in a flat plane, but the error is large if the bucket moves steeply. Here, I discuss the error when only the bucket is in rotational motion as a typical movement. The bucket used has a length of 1.5 m, so the rotational motion draws the shape of an arc of 1.5 m radius. On the other hand, the grid is represented by the z-coordinate, which is the arc divided by 20 cm. Figure 6 illustrates the difference.

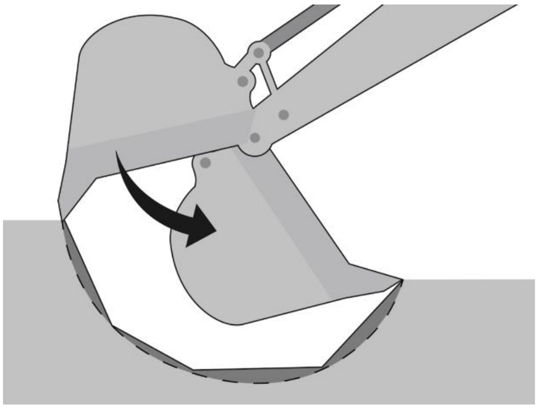


Figure 6. Image of gridding errors

The calculated volume error is the difference between the total area of the arc area and the area to be clipped by the grid data. For a turning radius of 1.5 m, this difference is calculated to be about 2%. The error of the volume by gridding process is assumed to be a typical value of 2%.

On the other hand, if we assume that the volume error is at most 5 cm larger than the error in the z-direction after the calibration adjustment, the volume error will contribute to that error in the depth direction. The volume of soil excavated at this site is 53,000m^3 and the area is 24,000m^2, and the average depth of excavation is 2.2m. The contribution of the system's error of 5 cm in the z-direction to the volume was calculated to be 0.05m / 2.2m = approx. 2%. Based on the above, we can estimate that the error in the overall volume calculation results due to gridding and system errors in this study is up to about 4%.

6 Obtained Data

The data obtained from the daily construction history of the Bucket cutting edge are grid data processed by 20 cm on the server. On the other hand, before the start of construction, the 3D point cloud data of the entire construction site is acquired by the UAV laser surveying, and the TIN, Triangulated Irregular Network, data, which represents the 3D shape of the construction area converted from the point cloud data, are acquired. The pre-construction TIN data are uploaded to the cloud server, and since this study is an excavation site, the current construction site shape can always be virtually formed on the server by updating the 3D shape data when the elevation of the bucket cutting edge of excavator passes lower than the pre-construction TIN shape.

7 Soil Weight Measurement System

In this study, in addition to the machine guidance

Excavator, a soil weighting system was introduced at the same time. The LOADEX100[4] of Topcon Corporation, which directly measures the weight of the soil held by the bucket by using hydraulic data obtained from the hydraulic sensor of the Excavator. This measurement data are sent to Akasakatec Inc's cloud-based soil management system, VasMap[5], which manages the weight of the soil per truck and the daily transport of the soil. The purpose of introducing LOADEX100 is to be able to accurately measure the amount of soil held by the bucket, which was not known before, and to be able to manage the exact weight of each dump truck loaded with soil. The acquired data are recorded digitally on a cloud server, allowing to know directly the daily hauling weight. In the past, the only way for dump trucks to avoid violating the Road Traffic Law by overloading was to load less than the truck's load capacity by considering the margin, but this system will allow for maximum efficiency in loading. As a result, the cost is reduced by enabling more efficient vehicle dispatch compared to the conventional method, contributing to increased productivity. In this study, the soil weight calculated from LOADEX100 was measured daily; however, since construction history data are measured in volume, the daily moisture content of the soil was measured and the soil weight was converted to volume as a reference for progress of volume measurement.

8 Data Reference

Three methods were used as references for the data to be obtained in this study. One is the periodic surveying with UAV laser scanner by a surveyor every two weeks and, in which the final shape is measured by a ground-based laser scanner. The survey results were used to evaluate the 3D grid data. Another one was to evaluate the volume calculated from the aforementioned weight measurements system, and the last one is volume calculations based on the conventional method by dump truck operation times.

9 Visualization

9.1 As-built Shape

The 3D as-built shape obtained from the grid data is shown in Figure 7. This figure shows the overall shape of the construction site, which allows the site manager to grasp the 3D shape of the site using information obtained from the cloud without actually going to the site. In addition, by comparing with the design data, it is possible to easily identify the un-constructed areas and the volume of un-constructed work.

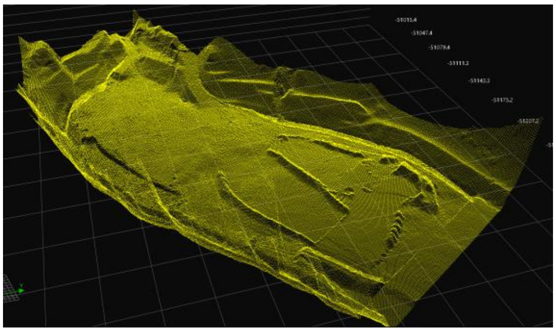
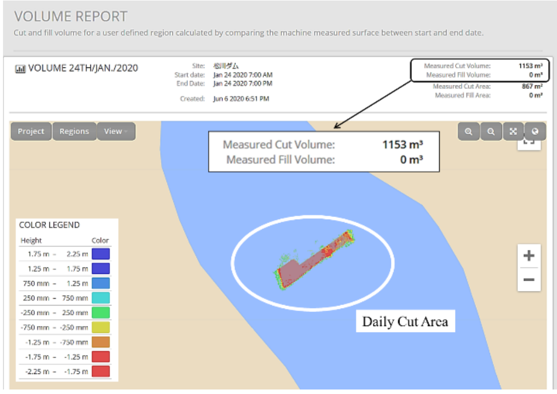


Figure 7. A sample of 3D as-built shape

9.2 Cut Volume

An example of a volume report output from the cloud data collection and management system Sitelink3D is shown in Figure 8.



VOLUME REPORT

Cut and fill volume for a user defined region calculated by comparing the machine measured surface between start and end date.

VOLUME 24TH/JAN./2020

Site: 松川ダム
Start date: Jan 24 2020 7:00 AM
End Date: Jan 24 2020 7:00 PM
Created: Jun 6 2020 6:51 PM

Measured Cut Volume: 1153 m³
Measured Fill Volume: 0 m³
Measured Cut Area: 867 m²
Measured Fill Area: 0 m²

Measured Cut Volume: 1153 m³
Measured Fill Volume: 0 m³

COLOR LEGEND

Height	Color
1.75 m - 2.25 m	🟦
1.25 m - 1.75 m	🟦
750 mm - 1.25 m	🟦
250 mm - 750 mm	🟦
-250 mm - 250 mm	🟩
-750 mm - -250 mm	🟨
-1.25 m - -750 mm	🟧
-1.75 m - -1.25 m	🟥
-2.25 m - -1.75 m	🟥

Figure 8. A sample of volume report output

In this report, the cutting depth of excavation in the area is shown in color as a daily report. In addition, the volume of cut volume for the day is displayed in quantity. By simply looking at this report, the site manager can get an idea of the cutting area and cut volume for the day.

The cumulative data obtained from this cut volume report is shown in Figure 9. The graph in the figure shows the cut volume based on bucket cutting edge history and laser 3D surveying, a soil volume measurement system, and the conventional method based on the number of dump truck hauls as a reference, all at the same time. This graph shows that the cumulative total based on the bucket cutting edge history data is not much different from the three references mentioned above. Finally, for the actual construction volume of 55,000 m^3 calculated from the laser survey, on the other hand, the calculated volume obtained from the bucket cutting edge history was 55,640 m^3, which is an actual difference of about 1.2%.

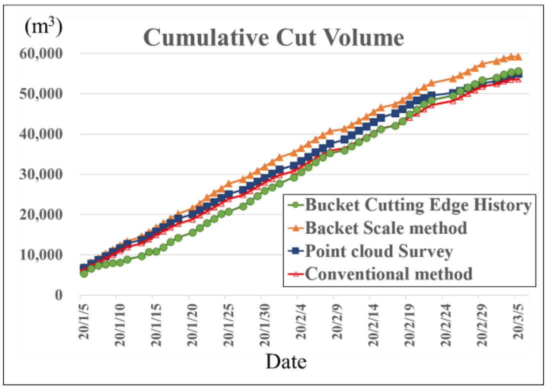


Figure 9. The cumulative cut volume data

10 Consideration

By conducting this study, we found the following. The accuracy of calculated volume of obtained from the historical data of the bucket cutting edge is approximately 1.2% of the total quantity of construction on site, this is consistent with the assumed system error mentioned above. However, if we focus on the daily construction volume, the volume cannot be accurately calculated when the history of the bucket cutting edge does not represent the construction shape due to the appearance of megaliths during the construction process, or when the excavated soil is temporarily placed in the field. Therefore, we feel that it is necessary to evaluate it in terms of numbers over a certain period of time. It has also been reported that accurate volume cannot be calculated even when the bucket edge is pierced into the ground at an acute angle without excavation due to accidental mishandling [6].

11 Conclusion

The historical data of the bucket cutting edge of the machine guidance excavator was used to visualize its construction progress. The volume quantities obtained from the historical data were accurate enough to track the daily construction progress. As a result, daily surveying work, for example, which was originally done as an additional work, can be greatly reduced by using the construction history data. From a productivity standpoint, not only does it reduce the workload of field agents at civil engineering sites, but it can also be used as a tool to more accurately assess the situation.

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