CALCULATION OF VOLUME CHANGES WITH 3D POINT CLOUDS OF DIFFERENT PHYSICAL ENVIRONMENTS

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ABSTRACT:

The calculation of the three-dimensional changes on objects is so important in many disciplines. Three-dimensional changes need to be accurately calculated for many areas; such as the deformation analyzes, the changes that occurred after the natural disasters, the volumetric differences before and after the construction projects, and the flood management. Nowadays, one of the most important issues, especially in the construction sector is calculating the amount of excavation and backfilling volumes in the project area that will be made or had made. These computations can sometimes be made for projects such as a general building construction, like roads or tunnels, while others may include water-covered areas such as a dam or filling of seaside. The project site in the study, carried out in a land that includes an area near the seaside and a filling area in the sea from the Ordu city center. The 3D dense point cloud data generated from images by image matching that obtained with the help of UAV (Unmanned aerial vehicle) was used to make calculations related to the area above the sea. For the calculations related to the filling area in the sea, the bathymetry map which was converted to the 3D point cloud was used. Firstly, with the help of the algorithm written in MATLAB, the first 3D point cloud and the second 3D point cloud which belongs to the same study area in different time, were added. Then, with the polygon to be selected on the screen, inquiries of excavation or filling can be made in the entire working area or different area. The excavation and filling volumes was calculated by the proposed algorithm with the 3D point clouds from two different periods, was given promising results.

1. INTRODUCTION

1.1 General Instructions

Nowadays, it is very important to quickly and accurately calculate volumetric changes in many project areas. Generally, during the studies carried out in the related section of the engineering projects (road, construction, mining, etc.), the excavation and filling volumes must be known in order to make the cost calculations. Developments in technology has also led to major changes in the scope and speed of the projects. In geomatics engineering, LiDAR and photogrammetric point clouds being used intensively and parallel to this, the use of image-based point cloud generated by unmanned aerial vehicles has become widespread. In this context, excavation areas have been enlarged in the field studies and the time for making the related calculations has been shortened. Although classical methods cannot keep up with this speed, systematic errors that come cumulatively can have big effects on the results. In the literature, volumetric change calculations are generally made with four different techniques, which are explained in detail in the following sections.

1.2 Calculation of the Volume by Cross Sections

The volume calculation by cross section method is mostly used in construction projects such as roads and tunnels. It is based on the principle of extracting cross sections at predetermined intervals in line with the desired project axis. The areas of the cross sections and distances between them are calculated. By multiplying the sum of the two cross-sectional areas and the distance between them, double of the volume can be calculated.

1.3 Calculation of the Volume with Surface Leveling

Surface leveling is applied in projects that are mostly carried out in uneven areas where altitude changes are low. The area that to be leveled is divided into rectangular geometric shapes such as triangles or squares and the grid points that to be leveled are determined. Levelling is carried out on the determined points by assigning elevation values to these points. The calculations of volume can be made according to the height values of the geometric shapes formed according to a specified reference surface and the corner points.

1.4 Calculation of the Volumes from the Curved Contour Map

The calculation of the volume by using the contour curves is similar to the volume calculation by cross-section method. The cross-sectional areas are used as areas of contour curves, and the distances between cross sections are used as elevation differences between contour curves.

1.5 Volume Calculation with Digital Terrain Models

In volume calculations using digital terrain models, there is a need for a large number of points that can best represent the

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land. The computer calculation is required for processing thousands of points produced by local methods, laser scanning technologies or photogrammetric methods. This method, which requires intensive mathematical calculations with developing technology, is the most preferred technique of volume calculations in computer environment. In order to use this technique, it is necessary to distribute the points measured on the surface of the land in a way to form a smooth network with interpolation methods. The volumetric calculations can be made by using rectangular or triangular areas obtained after the gridding process (Yanalak and Baykal, 2003; Guibas and Stolfi, 1985; Lee and Schachter, 1980). If the surfaces formed as a triangular prism after the gridding, then the volumetric calculations will be carried out by using equation 1, if the surfaces formed as a square or quadrilateral prism, then the volumetric calculations will be carried out by using equation 2.

$$V_{\text{triangle}} = \frac{h1 + h2 + h3}{3} \cdot F \qquad (1)$$

$$V_{\text{quadrangular}} = \frac{h1 + h2 + h3 + h4}{4} \cdot F \qquad (2)$$

The "V" in the equations refers to the volume of each triangular or quadrilateral area resulting from the grids, "h" means the height in the grid corner, and "F" means the grid area. With the current technological advancements, the speed and density of the photogrammetric point cloud data are becoming more and more important in the volumetric calculations.

In this study, the digital terrain model method was used to calculate volume. Volumetric calculations were made on the combined photogrammetric 3D point cloud data and the bathymetry data in MATLAB by implementing the proposed algorithm.

2. THE STUDY AREA AND DATA SET

The study was carried out at the central coast of Ordu in an area where sea filled to make place for public facilities. In this study area, the RGB images that obtained by a drone (Multirotor Surveying Robot S) with the Olympus E-PL5 camera (c = 14.1mm) and the bathymetry data in CAD format were used. The images were taken at an average height of 120 m and the ground sampling distance (GSD) was 4.12 cm. The study area is shown in Figure 1.

Figure 1. The study area

The study area (Figure 2) before the filling process was completed and the study area after the filling operation was completed (Figure 3) is shown below.

Figure 2. Condition of the study area in the first period

Figure 3. Condition of the study area in the second period

In addition, the 3D dense point cloud and bathymetry data of the study area combined together and the boundaries of these data is shown in Figure 4.
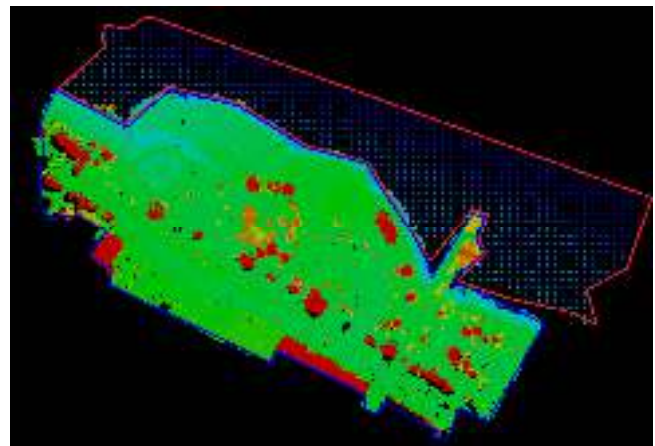

Figure 4. the 3D point cloud (blue color) and bathymetry data (red color) of the study area

As can be seen in Figure 4, the 3D point cloud data of the fill area within the blue boundary is rather dense (400 points /m²), the bathymetry data within the red boundary that was

interpolated to a density of 1 m (1/m²) grid spacing, has less density.

3. METHODOLOGY

In this study, it was aimed to calculate the volumetric changes by evaluating the 3D dense point cloud data and the bathymetry data that generated for the project area. For this purpose, first, the images obtained in two different periods with the help of UAV, are processed with a software which uses image matching techniques (Pix4D, Agisoft PhotoScan etc.) to generate 3D dense point cloud data. In addition, for the filling project to be carried out at the shore, a network structure should be created by interpolating the bathymetry data, which was generated in the CAD environment.

The inclusion of above ground details such as buildings, vegetation, vehicles etc., causes errors in volumetric calculations. In order to calculate the volumetric changes using the generated 3D point cloud data, only ground points should be left in the point cloud data for the first and second periods. At this stage, LAStools software, which uses progressive TIN (Triangulated Irregular Networks) densification algorithm was used for ground extraction before starting the volumetric calculations with 3D point clouds. The triangulation is performed from every three points in the lowest elevation area that determined in 3D point cloud by the progressive TIN densification algorithm. Ground and non-ground points determined according to the elevation angle from the triangle corners and the perpendicular distance measured from the triangle center (Axelsson, 2000).

The first and second period point clouds containing the ground points and the bathymetry point cloud which formed by gridding of the bathymetric data, were made ready to be processed in MATLAB. The volume to be calculated for each quadrature grid was coded using equation 2 in MATLAB. In addition, with the help of the generated software, it is possible to calculate the volumetric changes only in the defined area, which can be selected from the MATLAB interface by a polygon (Figure 5).

Figure 5. The sample polygon that selected for the required area of MATLAB interface

The workflow diagram for the proposed algorithm written in MATLAB is shown in Figure 6.
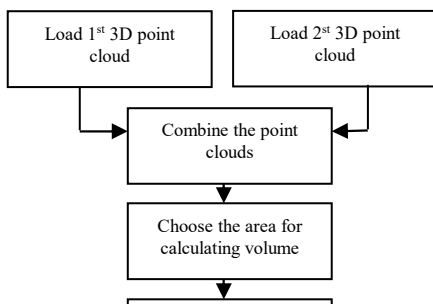

Figure 6. The workflow diagram for proposed algorithm

4. RESULTS AND DISCUSSIONS

As a result, the volumetric changes for the excavation-filling process in different physical environments were determined by the evaluations made in the MATLAB environment. In order to assess the accuracy of the calculations, a synthetic 3D point cloud was generated in MATLAB as a test data.

4.1. Creating a Synthetic Data Set

A synthetic 3D point cloud was created in MATLAB to test the accuracy of the proposed algorithm because the actual values in the project area are not known. The synthetic 3D point cloud was generated by dividing a 50×50 m² test area into 100000 equal parts in the X and Y axes to match the density of the 3D point cloud of the study area. In addition, the height values for the X and Y values corresponding to each grid corner must be defined. For this purpose, random height values were generated using equation (3) to assign height (H) to each point.

$$H_{(i)} = cos\left(y_{(i)}/3\right) \ + \ sin\left(x_{(i)}/4\right) + 15 \qquad (3)$$

In order to generate a test data, a 3D dense point cloud created using the surface equation is shown in Figure 7.
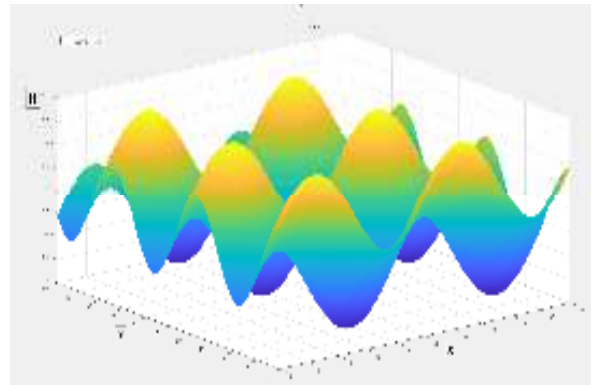

Figure 7. View of the synthetic point cloud

In order to assess the accuracy of the proposed algorithm, volume of the synthetic 3D dense point cloud was calculated as 37377.373 m³ by mathematical program Maxima. Then, volume of the same synthetic data also calculated with MATLAB, 37348.375 m³ was obtained with 3 cm grid spacing and 37363.021 with 1.5 cm grid spacing. It can be seen that by decreasing the grid spacing, calculated volume can be closer to the actual value of itself. The results show that the volumetric

changes determined for two different surfaces in MATLAB were calculated correctly.

4.2. Results from Test Area of Ordu

In order to calculate the volumetric changes with the proposed algorithm, it is necessary to combine the 1st period 3D point cloud and the bathymetry 3D point cloud from Ordu coastal fill (Figure 8).
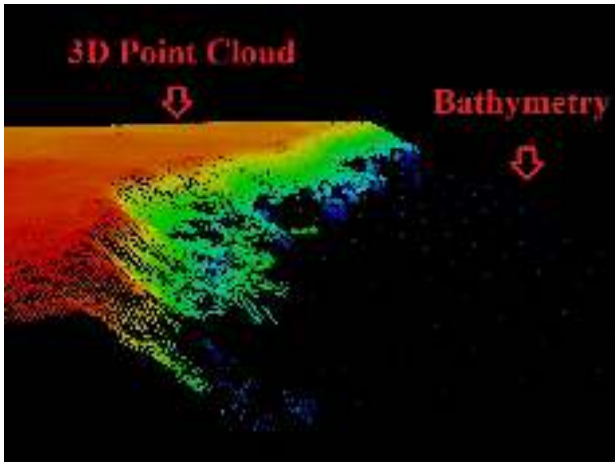

Figure 8. The view of the combined data with first period and bathymetry 3D point cloud

A polygonal region manually selected from the combined 1st period point cloud (photogrammetric and bathymetric) which was created in Matlab and 2nd period point cloud data. A reference plane created from the lowest points within the selected polygon to calculate volumes for each point cloud. Then the actual volumetric change was calculated by the differences between these volumes. According to the calculation made with the software with a 3 cm grid interval, the volumetric change in the Ordu study area was calculated as 14748.14 m³. The calculated volumetric change was 14760.16 m³, when the grid spacing was reduced to 1.5 cm.

5. CONCLUSION

Nowadays, when many commercial software (Pix4D etc.) that can produce 3D dense point cloud from images are examined, it is known that the volumetric changes between two different terrain surfaces represented by millions of points cannot be calculated directly by the software. In this respect, the proposed algorithm can be added as a module to commercial software as well as being free. In this study, the fact that calculated volume for the synthetic 3D point cloud data by the Maxima mathematical program and the volume calculated by the proposed algorithm is very close to each other, shows the accuracy of the calculations. With the proposed algorithm, when calculating the excavation-fill amounts from two different point cloud data belonging to the same area, other parameters related to soil structure (swelling coefficient etc.) should be taken into consideration as well as the grid size. Based on these results, it can be seen that the proposed algorithm will contribute to the high accuracy and fast calculation needs of the excavation and filling calculations which are used extensively in the engineering disciplines.

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