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Comparison of Data Reduction Algorithms for Image-Based Point Cloud Derived Digital Terrain Models

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Abstract**—**Digital Terrain Model (DTM) is a digital numerical representation of the Earth's surface. DTMs have been applied to a diverse field of tasks, such as urban planning, military, glacier mapping, disaster management. In the expression of the Earth' surface as a mathematical model, an infinite number of point measurements are needed. Because of the impossibility of this case, the points at regular intervals are measured to characterize the Earth's surface and DTM of the Earth is generated. Hitherto, the classical measurement techniques and photogrammetry method have widespread use in the construction of DTM. At present, RADAR, LiDAR, and stereo satellite images are also used for the construction of DTM. In recent years, especially because of its superiorities, Airborne Light Detection and Ranging (LiDAR) has an increased use in DTM applications. A 3D point cloud is created with LiDAR technology by obtaining numerous point data. However recently, by the development in image mapping methods, the use of unmanned aerial vehicles (UAV) for photogrammetric data acquisition has increased DTM generation from image-based point cloud. The accuracy of the DTM depends on various factors such as data collection method, the distribution of elevation points, the point density, properties of the surface and interpolation methods. In this study, the random data reduction method is compared for DTMs generated from image based point cloud data. The original image based point cloud data set (100%) is reduced to a series of subsets by using random algorithm, representing the 75, 50, 25 and 5% of the original image based point cloud data set. Over the ANS campus of Afyon Kocatepe University as the test area, DTM constructed from the original image based point cloud data set is compared with DTMs interpolated from reduced data sets by Kriging interpolation method. The results show that the random data reduction method can be used to reduce the image based point cloud datasets to 50% density level while still maintaining the quality of DTM.

Keywords**—**DTM, unmanned aerial vehicle, UAV, random, Kriging.

I. INTRODUCTION

A DTM is a representation of the bare earth surface in 3D space that contains elevations of topography. DTMs have been used in all geoscience tasks: civil planning, mine engineering, military purposes, landscape design, urban planning, environmental protection, forest characterization, hydrology, visibility analysis, surface modelling, topographic change, volume computation, geomorphological extraction, satellite imagery interpretation, cartographic presentation, and geographical analysis [1]. DTMs can be generated with LiDAR, Photogrammetry, surveying, or digitization of topographic maps [2]. LiDAR becomes a prior data acquisition technique for high-resolution and high-accuracy DTMs over large areas [3]-[7]. For constructing DTMs while preserving high frequencies of the relief, the airborne LiDAR has become a well-established source used in enhancing spatial knowledge of the topography.

UAV has appeared as a low-cost alternative to the traditional photogrammetric system for a data acquisition. It is also very effective for obtaining image based point cloud production. UAV is an alternative data source for point cloud [8]. Some UAV based studies can be found in [9]-[13]

The accuracy of DTMs relies on several factors: (i) accuracy, the density, and the spatial distribution of elevation points, (ii) interpolation methods, (iii) terrain surface characteristics [14]-[16]. There has been a great number of literature about these factors: accuracy of data acquisition [17], [18]; data density [2], [19]-[22]; the interpolation process [23], [24]; terrain features [25], [26].

II. STUDY AREA

The study area is located at Afyon Kocatepe University in Turkey (Fig. 1). UAV (DJI Phantom 4 pro) with an overlap 80% from a fly height of 120 m 274 vertical aerial photographs were taken. The ground sampling distance (GSD) of the photographs is 3.27 cm. The captured photos were evaluated in Pix4D software and a 3D point cloud was created.

III. MATERIAL AND METHODS

The primary objective of process is producing 3D point cloud by overlapping aerial image data [27]. The point cloud generation from images is called as Structure from Motion (SfM). 274 aerial photos were evaluated in Pix4D software. After data processing, 42776508 points were obtained with a density of 86.76 points/m^2 (Fig. 2).

The Cloth Simulation Filtering (CSF) algorithm is used for the producing of DTM from point cloud [28]. In this study, we used the CSF algorithm for filtering UAV based point clouds. After the filtering process, 34874515 points were detected as ground point data set (Fig. 3). Afterward, data reduction processes were done with CloudCompare© software to the

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ground point data set.

Fig. 1 The study area

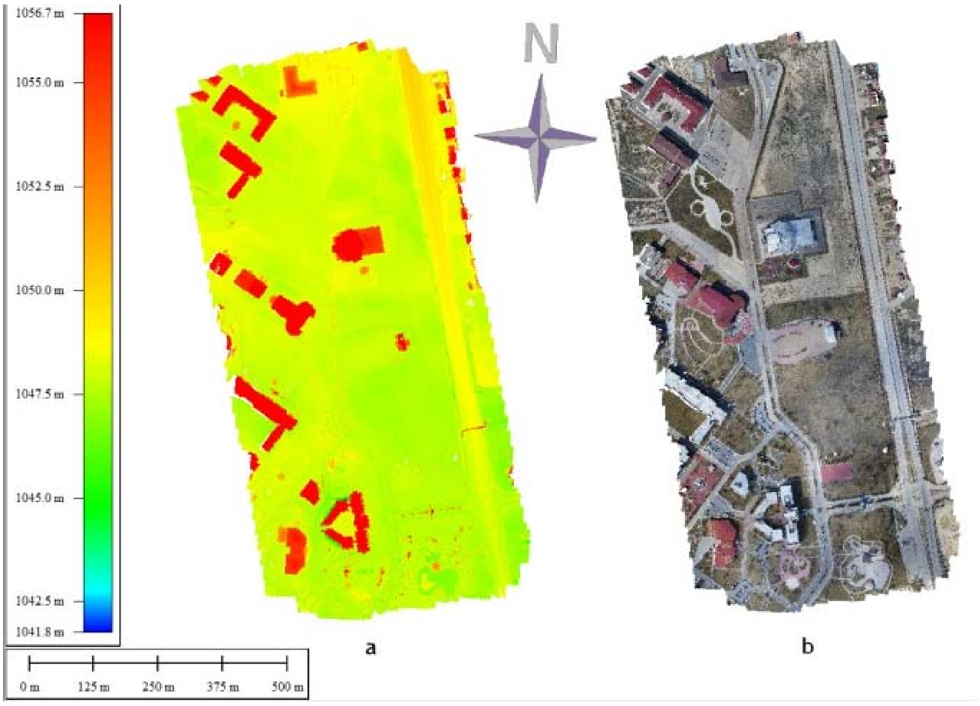

Fig. 2 Image based point cloud: (a) Colorized by elevation point cloud, (b) True color point cloud

For evaluating the data reduction algorithms on DTM accuracy and to explore the data reduction extent for adequate DTM accuracy; the data density is sequentially reduced. The ground points data set (100%) is reduced to a series of subsets by using random data reduction algorithms: 75%, 50%, 25%, and 5% of the ground point data set. This data reduction process is similar to the previous studies of [29], [30]. Subsequent to the data reduction, the ground point data set and the reduced data sets are used to produce a series of DTMs. DTMs are constructed via KRIGING method [2].

The assessment of DTM accuracy is made according to elevation differences between the reference DTM and the test DTMs using (1):

$$\Delta Z = Z_{(100\%)} - Z_{(i\%)} \tag{1}$$

ΔZ is the height difference between reference ($Z_{(100\%)}$) and test ($Z_{(i\%)}$) DTMs, and i refers to the data density (i = 75, 50, 25 and 5) [2].

For the analysis of elevation differences, minimum and maximum values of ΔZ are determined and the overall performance of DTMs is evaluated through ME, MAE, and RMSE accuracy measures:

$$ME = \frac{1}{n}\sum_{k=1}^{n}\Delta Z \tag{2}$$

$$MAE = \frac{1}{n}\sum_{k=1}^{n}\left|\Delta Z\right| \tag{3}$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{k=1}^{n}(\Delta Z)^2} \tag{4}$$

n is the number of the points used for the validation of accuracy, k refers to the residual sequence. Underestimation or overestimation the true value of the interpolation method is measured by ME. MAE is calculating the average deviation of DTM from the true value. RMSE is calculated to determine the overall accuracy of DTM surface [2].

IV. ANALYSIS

Reference DTMs of the study area to be used for comparison is constructed from the original (100%) UAV based point cloud dataset using KRIGING by Surfer© 13. The interpolation parameters (for the reference DTMs) are optimized through cross-validation technique [2].

The reduced data sets, based on random algorithms, are used to construct the test DTMs with KRIGING method, at each data density level (75%, 50%, 25% and 5%). The test DTMs (DTMi%; i = 75, 50, 25 and 5) are subtracted from the corresponding reference DTMs (DTM100%) for elevation differences. The graphical representations have been used for the comparative evaluation by residual map for each test DTM (Fig. 4).

V. RESULTS AND CONCLUSIONS

The elevation residual maps (Fig. 4) indicate that the deviation of the test DTMs from the reference DTM is getting greater due to the decrease of data density, for random data reduction algorithms. The statistics of elevation residuals based on random algorithms at selected data density levels are presented in Table I.

MEs is recorded at the centimeter level at 5% data density for random data reduction algorithm (-0.010 m). MEs are sub-centimeter at 25%, 50% and 75% data, showing that interpolation biases were negligible.

Fig. 3 Point cloud filtered by CSF (Ground point)

TABLE I
THE STATISTICS OF THE ELEVATION RESIDUALS (UNITS IN M)

	RANDOM			
	75%	50%	25%	5%
Min	-0.531	-0.450	-3.933	-4.028
Max	0.429	0.657	0.630	0.840
ME	0.001	-0.004	-0.003	-0.010
MAE	0.015	0.026	0.038	0.064
RMSE	0.033	0.052	0.086	0.128

Throughout the decreasing data densities, the test DTMs have increasing MAEs ranged from 0.015 m to 0.064 m showing significant increases for random data reduction algorithms as data densities decreased from 75% to 5%.

RMSEs ranged from 0.033 m. to 0.128 m showing significant increases as data densities decreased from 75% to 5%. As expected, the lowest RMSEs are obtained at 75% data density level.

In terms of overall accuracy, there is no considerable decrease for the test DTMs constructed from high data densities (75% and 50%) (Fig. 4). Therefore, it becomes certain that the test DTMs based on 75% and 50% point densities are adequate.

As a result of the application, DTM was generated from point clouds of different intensity according to a random data reduction algorithm. In the DTMs produced at 25% and 5% density, the maximum and minimum impact of the contradictions occurred. This is due to the stage of obtaining and filtering the point cloud.

The UAV based point cloud is one of the most capable, effective, and reliable tools for collecting high-accuracy and high-density 3D terrain data leading to mapping products. UAV based data can be used for DTM generation by photogrammetric techniques. The limitations of the use of image-based point clouds depend on the quality of the photo. However, high-density data lead to imposing challenges with respect to data storage, processing and manipulation. Big data volumes require data reduction without losing relevant geometric details while constructing DTMs. The data should be reduced by keeping critical data. In order to represent the terrain with the reduced data, future researches using different data reduction algorithms are essential for determining adequate data reduction algorithm and the threshold data density for DTM generation.

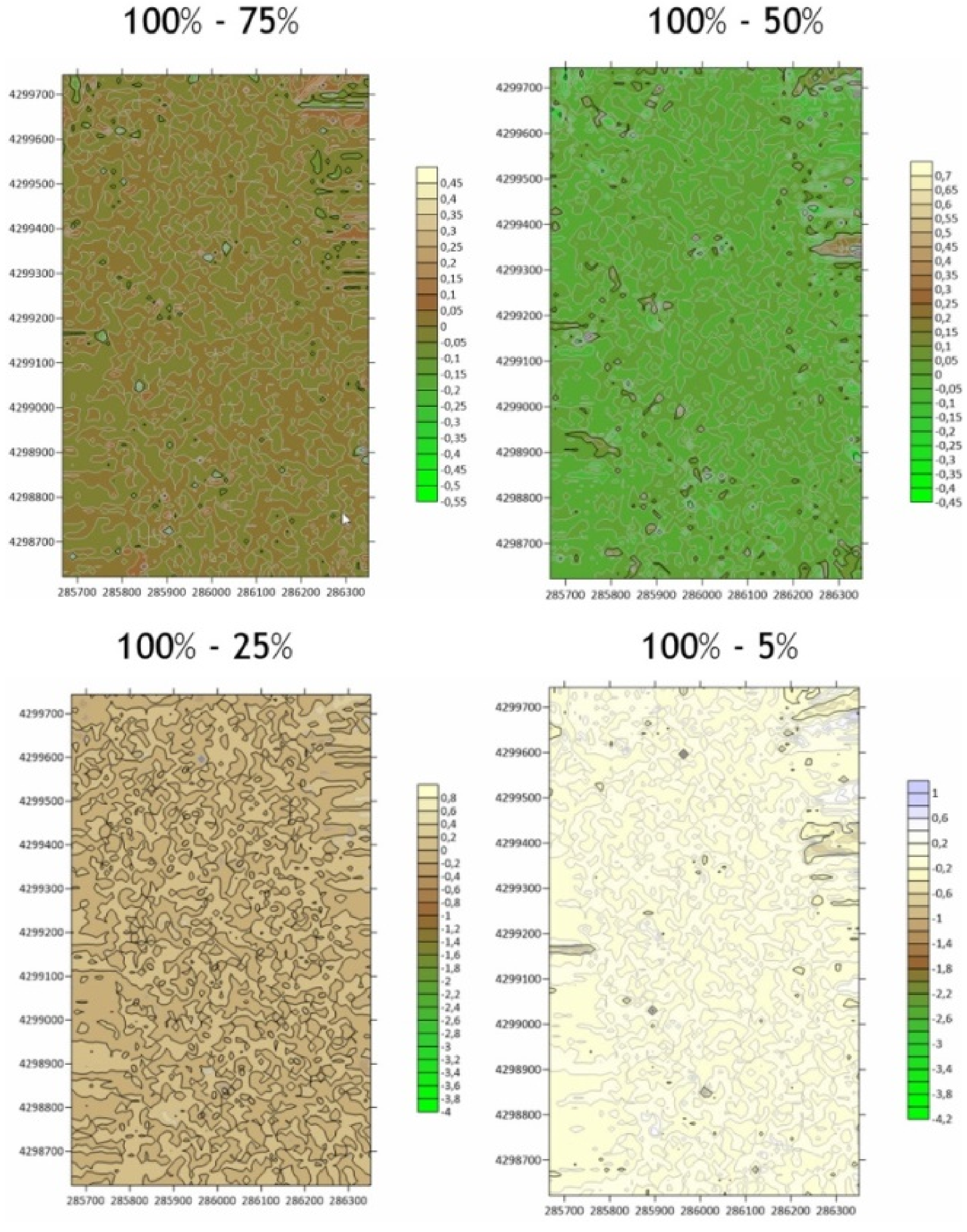

Fig. 4 Residual maps of test DTMs for the study area

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