A Preliminary Study on Disaster Waste Detection and Volume Estimation Based on 3D Spatial Information

Conference Paper · June 2017

DOI: 10.1061/9780784480823.051

A Preliminary Study on Disaster Waste Detection and Volume Estimation based on 3D Spatial Information

Hyung Taeck Yoo[1], Hyunwoo Lee[2], Seokho Chi[3*], Bon-Gang Hwang[4], Jinwoo Kim[5]

[1]Graduate Student, Dept. of Civil and Environment Engineering, Seoul National University, 1 Gwanak-Ro, Gwanak-Gu, Seoul, Korea 08826. E-mail: iamtek@snu.ac.kr
[2]Graduate Student, Dept. of Computer Science and Engineering, Seoul National University, 1 Gwanak-Ro, Gwanak-Gu, Seoul, Korea 08826. E-mail: hwlee2014@mmlab.snu.ac.kr
[3]Associate Professor, Dept. of Civil and Environment Engineering, Seoul National University, 1 Gwanak-Ro, Gwanak-Gu, Seoul, Korea 08826. E-mail: shchi@snu.ac.kr (Corresponding author)
[4]Associate Professor, Dept. of Building, School of Design and Environment, National University of Singapore, 4 Architecture Drive, Singapore 117566. E-mail: bdghbg@nus.edu.sg
[5]Graduate Student, Dept. of Civil and Environment Engineering, Seoul National University, 1 Gwanak-Ro, Gwanak-Gu, Seoul, Korea 08826. E-mail: jinwoo92@snu.ac.kr
Corresponding Author

ABSTRACT

Climate-related disasters have increased in terms of occurrence and intensity over the past decades. After the events occurred, the “cleaning up” stage of a significant amount of waste is a prerequisite step for search-and-rescue and damage recovery missions, which requires extensive efforts in terms of time and cost. For effective and efficient disaster waste management, accurate information on the amount and location of the waste should be delivered in a very timely manner. Most existing studies have developed statistical models to predict the amount of the waste using the waste records generated during the past disaster. Although the models were widely used for disaster recovery, they exhibited some limitations. They cannot be applied for the countries that do not have historical data of disaster waste. Thus, this paper proposes a 3D information-based quantification and localization method of disaster waste, using unmanned aerial vehicle (UAV). The proposed method consists of five main processes: Image acquisition, Point cloud generation, Waste dump detection, Volume estimation, and Data visualization. To validate the feasibility of the proposed approach, experiments were performed on waste disposal sites in Seoul (Korea) to measure the volume of solid waste dumps through dense point cloud analysis. In particular, two algorithms were applied in order to extract a group of points representing a waste dump based on the clustering method and calculate the volume of the selected waste dump. An UAV was used to capture 3D images of the site and the images were transformed into point clouds, eventually generating more than 863 million points from the 111 images. The results confirmed the error rate of 7.04% in the volume measurement, promising the potential for wider implementation of the method developed to conduct disaster waste management more effectively.

Keywords: Disaster Waste, Debris, Spatial Information, Point Clouds, 3D Object Detection, UAV

INTRODUCITON

Climate-related disasters have increased in terms of frequency and intensity over the past decades. The aftermath of such events posed monumental challenges to local and federal authorities. These challenges arise when making decisions on locating and rescuing survivors, recovering areas affected by the disaster and providing economical support to the people affected. The management of post-disaster waste is also included among these issues (SJ Jung et el., 2016). The disaster waste can be defined as a solid and liquid waste which comes from a disaster, including debris (e.g., concrete, rebar, roof), vegetation (e.g., trees, limbs), inundated motor vehicles, and hazardous chemicals (Melih Celik et al., 2014).

Disaster waste has significant impacts on the area, both directly and indirectly after the disaster. Depending on its nature and severity, the location of survivors on site and the initiation of recovery work can be delayed or blocked by the waste accumulated on the road. Not only that, the presence of the disaster waste, especially hazardous chemicals, can contaminate the environment and the drinking water system posing epidemics. Thus, improper management of disaster waste can exacerbate these problems.

When it comes to the effort to clean up disaster waste, its amount is said to be one of the most important affairs; disasters can create a large volume of waste. In some cases, the amount of waste equivalent to many years can be generated by a single disaster, so that it overwhelms existing solid waste management facilities in the affected area. For example, the debris generated by Hurricane Katrina in 2005 in the U.S. was estimated to be more than 100 million cubic yards (CY). The great earthquake in Japan in 2001 was notorious for generating about 20 million tons of waste. This year, 1.3 million tons of waste was created by an earthquake in Kumamoto, Japan.

Several efforts have been made to put in place a global disaster waste management system to clean up disaster wastes efficiently and effectively while respecting environmental and budgetary constraints, in order to minimize their impacts on the province affected by disasters.

According to guidelines published by international organizations, including the United Nations Environmental Programme (UNEP), the disaster waste management system consists of four phases; Collection, Sorting, Transportation, and Treatment. The guideline suggested that information both on the amount and the location of disaster waste is necessary. The information is essential for the government to develop a mitigation plan for the distribution of human resources and machinery for efficient and effective work in the field of disaster waste disposal. However, there was no mention of exact methodologies for acquiring data on the amount and location of the disaster waste (UN OCHA et al, 2013).

Some countries that have experienced huge disasters and have suffered from disaster waste disposal work as the U. S. and Japan have developed and use their own statistical model to collect waste amount and location information (Hirayama, N. et al., 2008). In addition, several studies have suggested an improved version of disaster waste amount prediction model. In the U. S., a model called HAZUS-MH, developed by the Federal Emergency Management Agency (FEMA), is widely used to estimate potential losses from several disasters such as earthquakes, hurricanes and floods. Its exact method is based on the statistical theory. The results of prediction are displayed on the map combined with GIS system. In Japan, many studies have proposed equations for predicting disaster waste amount both by disaster-related information (e.g., intensity, frequency) and characteristics of the affected area (e.g., vegetation, density of populations).

However, such statistical models for estimating disaster waste have two limitations; one is the need of historical data on disaster waste generated and the other is the absence of estimated value of disaster waste at the site. The countries that do not have or have insufficient data on waste generated by the past disaster cannot develop their own prediction equations. In addition, these models calculate historical data on the amount of disaster waste rather than the data collected in the real area affected by the disaster.

The primary goal of this research is to propose a new method to measure the amount of disaster waste and its locations automatically, which does not require historical data on disaster waste. Specifically, this research aims to utilize an unmanned aerial vehicle (UAV) which is also called drone and investigate the UAV image post-processing as a method to identify the volume and the location of disaster generated waste. This paper presents the feasibility of the proposed idea: user interaction based on waste dump extraction and volume measurement algorithms. For the purpose of validation, an experiment was conducted on a solid waste storage facility located in Seoul, Korea. Through the experiment we confirmed the promising potential of the proposed method and its contributions.

RESEARCH PROCESS

The key steps including user interaction to build a UAV-based disaster waste estimation model have been described in Figure 1. First, the process of data acquisition was carried out. The type of data collected is called orthophotograph which would be used for the generation of point cloud in the next step. Orthophotography is an aerial photograph corrected geometrically so that the scale is uniform. It is ideally used for geographic information systems (GIS) for accurate 2D/3D mapping. A UAV equipped with a digital camera was used to collect orthophotography of the selected area. This UAV automatically scanned the assigned area and took orthoimages periodically. The overlap ratio rule, over 70%, that is commonly used, was applied to help an accurate point cloud generation.

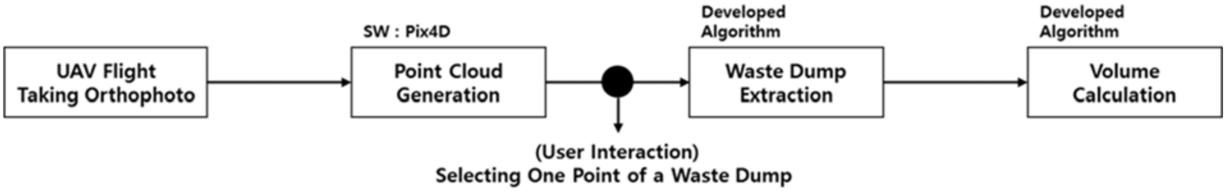


Figure 1. Research Process

The second step is the point cloud generation process. For this phase, several commercial software or toolkits are available. Table 1 shows the software widely used to create point cloud from multiple images. In this research, Pix4D was selected because it provides an accurate point cloud from images taken by drone, point cloud generated by Pix4D is accurate to 5-20cm due to the ground control points (GCPs) function, and it contains modules to measure lengths, areas, volumes of the selected object (Steve Harwin and Arko Lucieer, 2012).

Table 1. Available Options for Generation Point Cloud.

Name	*Platform*	*Open Source*	*Creator*
VisualSFM	OS X, Linux, Windows	No	Changchang Wu
ReCap 360	Web	No	Autodesk
123D Catch	iOS, Android, Windows	No	Autodesk
PhotoScan Standard	OS X, Linux, Windows	No	Agisoft
Pix4D	Windows	No	Pix4D Team
Python Photogrammetry Toolbox	Linux, Windows	Yes	Arc-Team

The last step is to extract the waste dump from the point cloud and calculate their volume. Python-based algorithms have been developed for these phases. Regarding to the extraction of a waste dump between several points, the developed algorithm uses the coordinate value (x, y, z, and RGB) of one point selected by user's mouse click as input data. The algorithm then computes both the distance and the color variation between the input point and its neighboring points; the k neighbor points closest to the input data are considered as the points belonging to the same cluster and the points whose physical distance and the color distance are greater than the designed threshold are eliminated. The computer repeats this calculation until there is no new point added to the cluster. The detailed process of the waste dump extraction algorithm is described in Figure 2(a).

After extracting the points considered as representing the same waste dump, its volume is calculated. First, the points belonging to the extracted cluster are separated into n sections. These sections are derived on the basis of the z coordinates of the points. Then, the volumes of each section are computed using 'Piecewise Quadrature Method'. The volume calculation algorithm process is described in Figure 2(b).

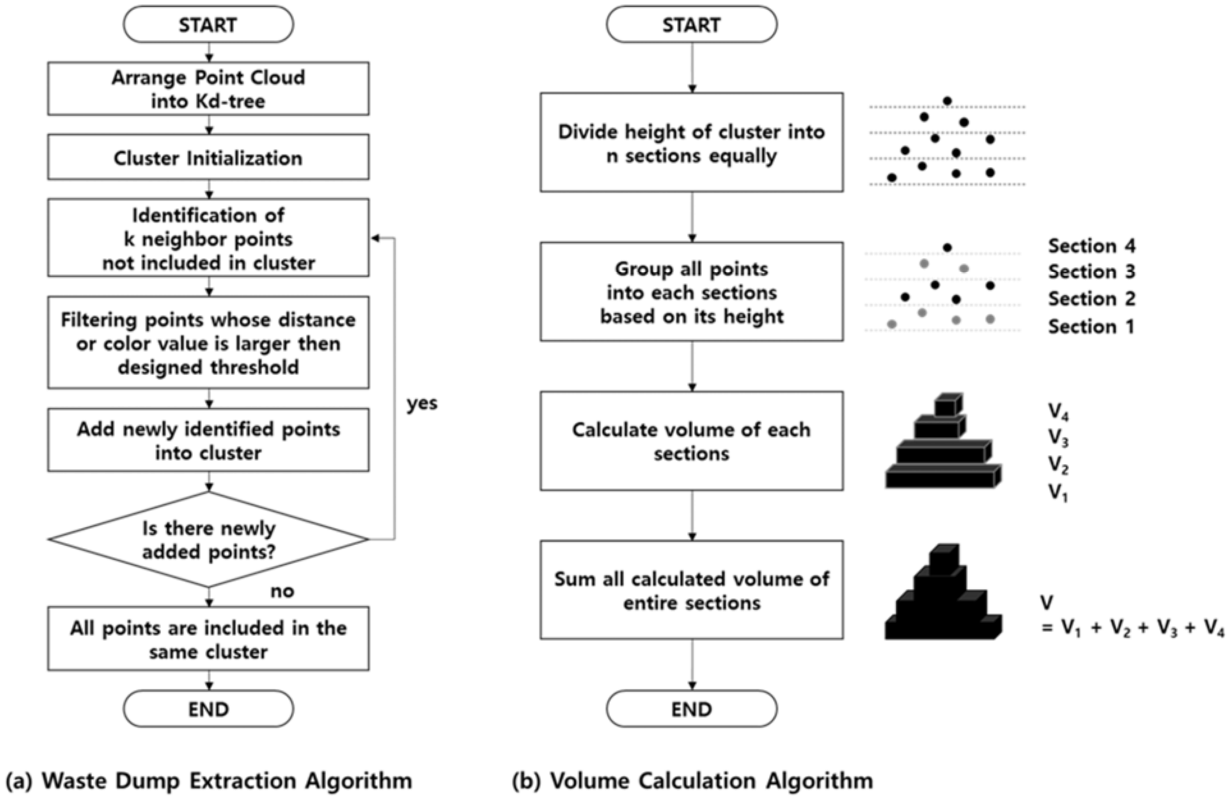


Figure 2. Waste Dump Extraction Algorithm and Volume Calculation Algorithm

CASE STUDY

In order to validate the proposed method, a case study was conducted at a solid waste staging site in Seoul, Korea. A dense point cloud of the waste staging site was acquired using Pix4D and orthoimages taken by a UAV. The reason we chose the waste facility as a test-bed was that the visual characteristics of the waste, such as the color variation or irregular shapes were quite similar with the disaster waste. After point clouds generation, the volume of the waste dump was calculated using the developed algorithms. The detailed description of this case study is as follows:

Used UAV. The Phantom 3 Professional quadcopter is a UAV with a 3-axis camera, which is extremely light and easy to manage. It captures 4K orthoimages of the waste staging site. In addition, this UAV provides pre–planned automated flight so that the drone performs the overlay required to generate a point cloud with high precision.

Flight for Image Acquisition. A mobile application called Map Pilot was used for planning flight route of the UAV. Based on the information on the scanning area's boundary, the percentage of overlap of neighboring images, flight altitude, etc., this application calculates flight route of the drone. During this phase, the research team acquired 111 orthoimages from the waste treatment facility.

Point Cloud Generation. The Pix4D mapper was utilized to perform the image processing using orthoimages taken by drone. It is capable of interpolating a large number of images to build 3D point cloud data. 111 images acquired from drone were processed by sequential built-in functions including noise filtering, lens distortion, and structure from motion (SFM). As a result, the 3D point cloud that consists of 8,362,854 points (491.69 points per m^2 in terms of density) was generated (Figure 3(b)).

Figure 3 (a) Flight Route of the UAV (Map Pilot), (b) Dense Point Cloud

Waste Extraction and Volume Measurement. The generated 3D point clouds were exported as a PLY format. After that we have transformed the PLY file into a PCD format to apply both waste dump extraction and volume calculation algorithms. The user first selected one point of from waste dumps in the point clouds (Figure 4(a)), and the algorithms then clustered a group of points representing the expected waste dump (Figure 4(b)) and eventually estimated its volume. In Figure 4(c), the result of the calculation was 1932.28m^3.

(a) 3D Model of Scanned Site
Pix4D

(b) Extraction Result
Python

(c) Volume Estimation
Python

Figure 4. (a) Selected Waste Dump, (b) Extraction Result, (c) Volume Calculation Result

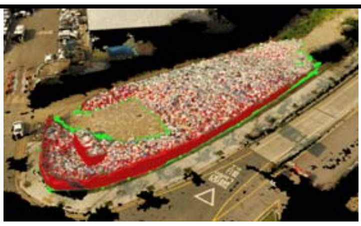
Result Validation. Since the actual volume of the extracted waste was unknown, the built-in volume calculation function of Pix4D was used as the ground truth value to evaluate the volume measurement performance of the proposed method. First for validation of the Pix4D function, we measured the volume of the object whose volume was known: an arm roll box (Figure 5). Compared with the real value of 40m^2, the result of the Pix4D method was 37.04m^2 with an error rate of 7.04%. This result shows the acceptability of the Pix4D result to be used as the ground truth value for the validation of the proposed method (Table 2).

Table 2. Validation of Pix4D's Point Cloud Processing

	True Value	*Measurement Result*	*Error Rate*
 Figure 5. Arm Roll Box	40 m^3	37.04 m^3	7.04 %

The validation of the proposed method was then conducted: comparison between the result by the Pix4D function and the result by the proposed method. The same volume of waste dump was calculated by two approaches. The results showed 7.04% as the error rate (Table 3).

Table 3 Validation of Proposed Method's Point Cloud Processing

	True Value	*Measurement Result*	*Error Rate*
 Figure 6. Selected Waste Dump	2078.63 m^3	1932.28 m^3	7.04 %

CONCLUSION

This research aimed to propose the use of images taken by an unmanned aerial vehicle to estimate the volume and location of disaster waste. In particular, the paper focused on the feasibility of the proposed method using orthoimages taken by the UAV and point clouds processing: algorithms for waste extraction based on clustering and volume calculation. Through the case study of a solid waste staging facility, this method showed an error rate of about 7% showing the potential for a variety of implementations.

The proposed method can be used to identify the amount and location of waste, rubble, and debris generated by the disaster. Not only that, result of the calculation can contribute to decision making on the distribution of vehicles and labors for the transport of disaster waste from the disaster fields to the staging site. While this paper focused on demonstrating its feasibility, further work includes improving its accuracy and applicability in real disaster-affected areas.

ACKNOWLEDGEMENTS

This work was supported by the National Research Foundation of Korea (NRF) Grant (No. 2015R1A5A7037372) funded by the Korean Government (MSIP), Promising-Pioneering Researcher Program through Seoul National University(SNU) in 2015, and the Korean Federation of Science and Technology Societies(KOFST) grant funded by the Korean government (MSIP:Ministry of Science, ICT and Future Planning)

REFERENCES

UN OCHA, MSB, UNEP. (2013). “Disaster Waste Management Guidelines.”

SJ Jung and JY Kim. (2012). "Comparison of Disaster Debris Guidelines and Analysis of Flood Debris Recovery." Journal of Korea Society of Waste Management, 29(5)., 497-503.

Brown, Charlotte, Mark Milke, and Erica Seville. (2011). "Disaster waste management: A review article." Waste management, 31(6), 1085-1098.

Hirayama, N., Kawata, Y., Suzuki, S., and Harada, K. (2009). “Estimation procedure for potential quantity of tsunami debris on tsunami earthquake disasters. Sardinia 2009.” In Twelfth International Waste Management and Landfill Symposium. S. Margherita di Pula, Cagliari, Italy.

R. B. Rusu and S. Cousins. (2011). “3D is here: Point Cloud Library (PCL)” in Proceedings of the IEEE International Conference on Robotics and Automation (ICRA), Shanghai, China.

Booth, W. (2010). “Haiti faces colossal and costly cleanup before it can rebuild.” The Washington Post., Haiti.

Taylor, A. (2008). Sichuan's earthquake, six months later. The Boston Globe.