DAMAGE ASSESSMENT AND 3D MODELING BY UAV FLIGHTS AFTER THE 2016 KUMAMOTO, JAPAN EARTHQUAKE

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ABSTRACT

Unmanned Aerial Vehicles (UAVs) are becoming an efficient tool of high-resolution image collection for the places that are difficult to access or observe from the ground. In this study, UAV flights were carried out by the authors over various damage sites due to the 2016 Kumamoto, Japan earthquake, such as surface faulting, overturned tombstones, landslides, collapsed buildings and a bridge. The UAV flights captured high-resolution video footages and photos, and using them, three-dimensional (3D) models were developed based on a SfM (Structure-from-Motion) technique. The developed models could depict the damage situations vividly, and the accuracy was evaluated through comparison with aerial photos and field measurement results.

***Index Terms*—**UAV, SfM, 3D model, the Kumamoto earthquake, damage situation

1. INTRODUCTION

Remote sensing became one of the most important tools of information gathering at an early stage of the occurrence of a disaster, especially when the affected area is vast and difficult to access from the ground [1-3]. The platforms of remote sensing are categorized into satellite, airborne, and ground-based ones. Although satellite remote sensing became quite powerful and popular, airborne platforms have advantages in rapid deployment to target areas for higher-resolution image acquisition. It is noted that a new type airborne platform was revealed recently; that is unmanned aerial vehicle (UAV) or drone.

UAVs have been used in recent decades for several civilian purposes, such as pesticide spraying, inspection of infrastructures such as bridges and towers, reconnaissance of hazardous areas. But the recent appearance of small, inexpensive, mass-production multi-rotor-type UAVs changed the situation [4]. UAVs have been used in damage assessment of structures after natural disasters [5]. Optical images taken from drones enabled us to make detailed damage-level classification of structures.

The use of drones is expanded from professional to personal. But some inconvenient incidents occurred in the capitals of USA and Japan in 2015, and the laws and regulations for drones were issued in several countries [6-8]. Thus drone flights in urban areas and near airports became quite difficult.

The present authors have introduced several UAVs aiming at investigation of their capability in information gathering of affected areas due to natural disasters. Several test flights of UAVs were carried out in the affected areas due to the 2011 Tohoku, Japan earthquake [9]. In this study, UAV flights were conducted by the present authors over various damage sites due to the 2016 Kumamoto, Japan earthquake [10]. Using the captured images, three-dimensional (3D) models of several affected sites were developed based on a Structure-from-Motion (SfM) technique.

2. THE 2016 KUMAMOTO EARTHQUAKE, UAV SURVEYING FLIGHTS, AND SFM TECHNIQUE

A M_w6.2 earthquake hit the Kumamoto prefecture in Kyushu Island, Japan on April 14, 2016 at 21:26 (JST). A considerable amount of structural damages and human casualties had been reported due to this event, including 9 deaths. The epicenter was located in the Hinagu fault with a shallow depth. On April 16, 2016 at 01:25 (JST), about 28 hours after the first event, a bigger earthquake of M_w7.0 occurred in the Futagawa fault, closely located with the Hinagu fault. Thus, the first event was called as the "foreshock" and the second one as the "main-shock".

Extensive impacts due to strong shaking and landslides were associated by the Kumamoto earthquake sequence, such as the collapse of buildings and bridges, and the suspension of road and railway networks. A total of fifty (50) direct deaths were accounted by the earthquake sequence, mostly due to the collapse of wooden houses in Mashiki town and landslides in Minami-Aso village [10].

The present authors have conducted several field surveys of the affected areas. In our fourth field surveys on August 9 and 10, 2016, we brought a small multi-rotor-type UAV and the flights over affected rural areas were carried out. **Figure 1** shows five locations of our UAV flights in the Kumamoto area, together with the flight restricted zone due to Densely Inhabited Districts (DIDs) and the Kumamoto Airport. The five flight locations are as follows:

a. Surface faulting: Dozono district, Mashiki town (V)

b. Cemetery: Komori district, Nishihara village (V)
c. Bridge and slope failure: Nishihara village (P)
d. Building collapse: Kawayo dist., Minami-Aso vill. (P)
e. Slope failure: Daikanbo view point, Aso city (V/P)

where "V" denotes images were taken by the video-mode and "P" the still-photograph-mode. In the P mode, geo-location information from the GPS on the UAV was stored in the header of image files.

The UAV that we used was Phantom 3 Professional (DJI co.) with a Sony EXMOR 1/2.3”4K camera. The UAV was manually operated with the altitude of about 40 m. The camera was directed downward or to oblique angles. **Figure 2** shows the UAV and a scene of manual flight.

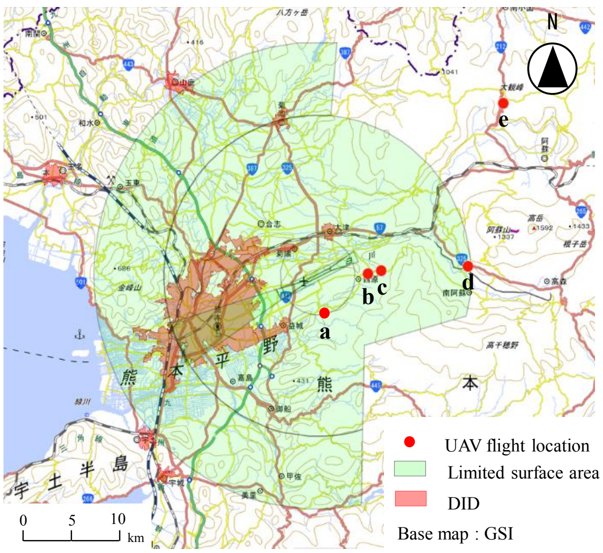

Fig. 1 Locations of UAV flights in this study and flight restriction areas using a GSI map [11]

Fig. 2 Phantom 3 Professional UAV used in this study (left) and a scene of manual flight (right)

The Structure-from-Motion (SfM) is a range imaging technique to reconstruct 3D structures and camera positions and orientations simultaneously from 2D image sequences. The method has been studied extensively in the fields of computer vision and visual perception. A large number of studies have also been carried out to construct 3D models of buildings and various objects [12-13]. In this study, Agisoft’s *PhotoScan* software was used for constructing 3D models based on the SfM.

3. UAV FLIGHTS AND DEVELOPED MODELS

3.1. Surface faulting

Due the main-shock on April 16, 2016, a clear surface faulting appeared on the ground surface of Mashiki town and other places. Especially in Dozono district of Mashiki, a right lateral strike-slip surface rupture with a 2-m gap appeared. **Figure 3** shows a 3D model developed using 154 images captured from a UAV video footage. Four ground control points (GCPs) obtained from the GSI's map [11] were assigned to the 3D model. Compared with the ortho-photo (c) made from the airplane photo-shooting from 1000-m altitude, the product from the UAV flight from 40-m altitude is seen to have much higher spatial resolution.

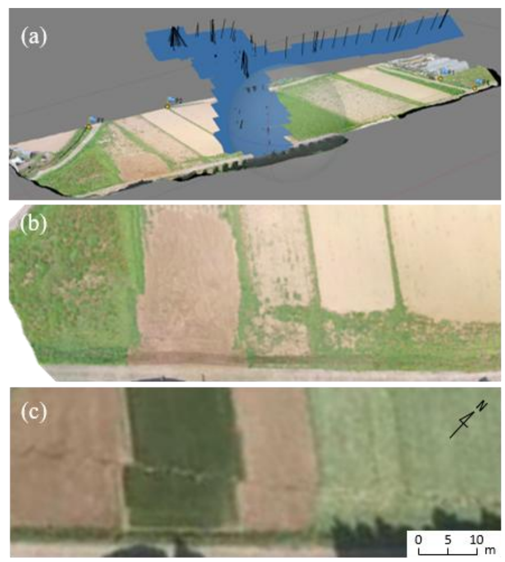

Fig. 3 Surface faulting in Dozono district, Mashiki town: Developed 3D model with estimated camera positions (a), an orthomosaic image made by SfM (b), and the ortho-photo made by GSI, taken on April 29 (c).

3.2. Overturned tombstones in a cemetery

Tombstones in Japanese-style cemeteries are tend to be overturned or displaced under strong seismic motion [14]. The overturning ratio of tombstones in a cemetery has been used as an estimate of strong motion in Japan for a long time. An attempt to estimate the overturning ratio of tombstones was carried out before based on the image analysis of aerial photographs [15]. But ordinary aerial photographs do not have enough spatial resolution and the field surveys to count the overturning ratio are time-consuming. In this regard, aerial surveys from UAVs are considered to be very efficient.

Figure 4 shows a 3D model of a cemetery in Nishihara village, made from 130 snapshots captured from a UAV video footage. In this cemetery, more than half of the tombstones were overturned or displaced. The developed 3D model depicts this situation quite well.

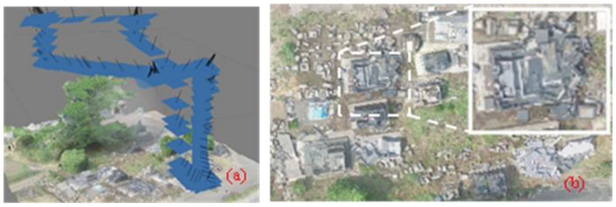

Fig. 4 Developed 3D model with estimated camera positions (a), and the orthomosaic image created by SfM (b) for a cemetery in Nishihara village.

3.3. Damaged bridge and slope failure

Ohkirihata-ohashi is a five-spanned continuous-girder bridge with 265-m length. Due to the earthquake, the rubber bearings of the bridge were damaged and it was displaced to the transverse direction [16]. Thus the bridge has been closed for traffic. Our UAV flight around the bridge was carried out on its roadway (**Fig. 2**) in the still-photograph-mode. A 3D model was developed using 51 still-photos taken from the UAV. **Figure 5** shows a snapshot, the developed 3D model and digital surface model (DSM), where the bridge and neighboring slope are modeled clearly.

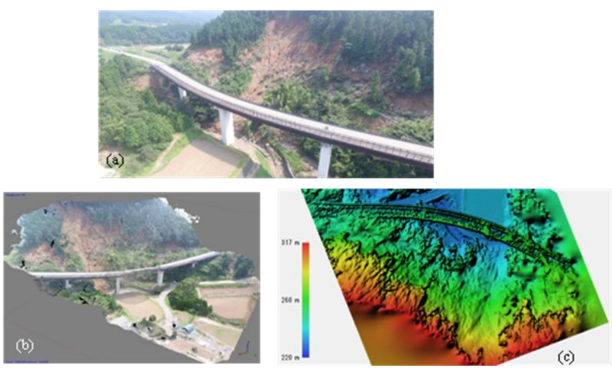

Fig. 5 A still-photo from UAV (a), 3D model (b), and DSM (c) created by SfM for Ohkirihata bridge area.

3.4. Collapsed buildings

Kawayo district in Minami-Aso village was one of the most severely affected area in the Kumamoto earthquake. Many buildings collapsed due to strong motion and Aso-ohashi bridge fell down due to the largest landslide [10]. In this area, we made a UAV flight over collapsed buildings in the still-photograph-mode. Using 172 images, two 3D models were developed by SfM, one without GCP and anther with five GCPs (P1-P5) as shown in **Figure 6**. In this site, we also measured the distances between the reference points (GCPs) by a measuring tape. **Table 1** compares the distances in the developed 3D models and the measured one. Note that the case without GCP uses only the onboard GPS data obtained during the flight. The RMS error without GCP was 0.26 m while that with GCPs was 0.18 m. A slight improvement of accuracy was observed.

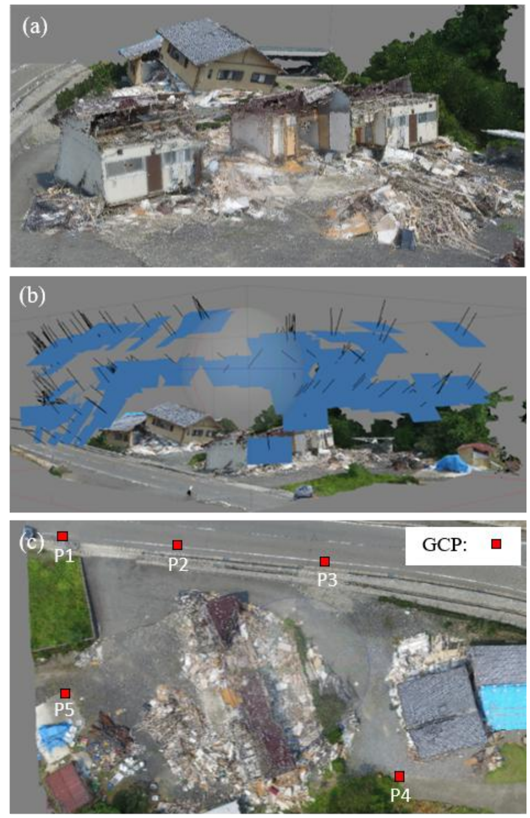

Fig. 6 Developed 3D model of collapsed buildings in Kawayo district (a), 3D model with estimated camera positions (b), and the layout of GCPs (c)

Table 1. Comparison of the horizontal distances of the developed 3D models and by the field measurement (m)

2D Distance	Measured distance	Before adding the GCP		After adding the GCP	
		3D Model	Difference	3D Model	Difference
P1-P2	15.08	15.26	0.18	14.97	-0.11
P2-P3	19.68	19.86	0.18	19.50	-0.18
P2-P5	24.08	24.43	0.35	23.98	-0.10
P3-P4	30.03	30.31	0.28	29.75	-0.28

3.5. Slope failure

In the Kumamoto earthquake, numerous landslides were generated along the causative fault. Aso volcano has the second largest caldera in Japan, with about 20-km diameter. A large number of landslides occurred in the outer rim of the crater. Daikanbo is the highest point of the outer ring with 936 m, a famous view-point overlooking the caldera. **Figure 7** shows the 3D model developed using 46 high-resolution still-photos. Two landslides on a steep slope, which are difficult to observe from the view point, can be recognized clearly in the model.

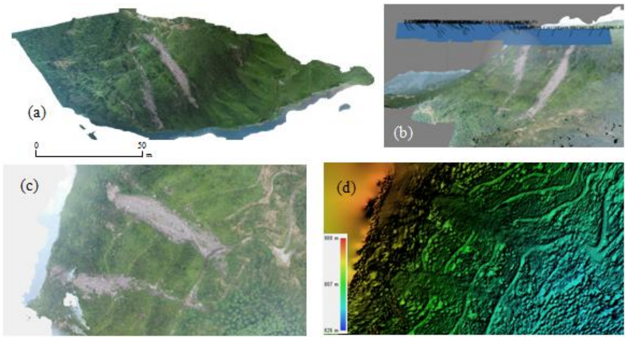

Fig. 7 3D model of Daikanbo view-point in Aso city developed by SfM (a), estimated camera positions (b), orthomosaic image (c), and DSM (d)

4. CONCLUSIONS

A series of earthquake hit Kumamoto prefecture, Japan in April 2016 and serious damages were associated by strong seismic motion and landslides. UAV flights were carried out by the present authors over various damage sites due to the earthquake, such as surface faulting, overturned tombstones, landslides, collapsed buildings, and a damaged bridge. The UAV flights captured high-resolution video footages and still-photos, and using them, three-dimensional (3D) models were developed based on a Structure-from-Motion (SfM) technique. The developed models could depict the damage situations vividly, and their accuracy was evaluated through comparison with aerial photos and field measurement results. This kind of aerial surveys are considered to provide the information on future hazards and its preventive measures.

5. ACKNOWLEDGEMENT

This study was conducted under financial supports of the J-RARID Kumamoto project of the Japan Science Technology Agency (JST) and the Grant-in-Aid for Scientific Research (Project Nos. 25242035, 15K16305) of the Japan Society for the Promotion of Science (JSPS).

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