

Construction of 3D models of buildings damaged by earthquakes using UAV aerial images

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ABSTRACT: Unmanned aerial vehicles (UAVs) are becoming very popular recently due to their accessibility to targets, promptness of dispatch, and high-spatial resolution of acquired images. In this study, the authors tried to obtain digital images from air and ground for a turned-down and washed-away building in Onagawa Town, Miyagi Prefecture, Japan due to the 2011 Tohoku earthquake and tsunami. A small multirotor-type UAV was used in this aerial survey. Then 3D models were constructed in computer using the acquired images based on the Structure-from-Motion (SfM) technique. The most accurate model was made when both the aerial and ground images were used for 3D modelling. As the second example, an aerial video taken from UAVs was used to model affected districts in Kathmandu, Nepal, due the Mw7.8 Gorkha earthquake on April 25, 2015. The video was taken by the Canadian humanitarian organization and released on Internet. The 3D models were developed from the video footage, and they show the details of damage situation in the urban districts.

1 INTRODUCTION

When a natural disaster strikes, gathering the information on damage situation of affected areas is quite important in disaster response. Remote sensing became one of the most important tools in 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 (Yamazaki & Matsuoka, 2007; Rathje & Adams, 2008; Dell'Acqua & Gamba, 2012). The platforms, which mean vehicles or structures on which remote sensing instruments are mounted, are categorized into satellite, airborne, and ground-based one. Although satellite remote sensing became quite powerful and popular recently, airborne platforms (Mitomi *et al.*, 2001; Maruyama *et al.*, 2014; Fernandez Galarreta *et al.*, 2015) have advantages in rapid deployment to target areas with higher-resolution image acquisition. It is noted that a new type airborne platform has been revealed; that is unmanned aerial vehicle (UAV) or drone.

UAVs have already 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 multirotor-type UAVs changed the situation (Nonami *et al.*, 2010). 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 have been issued or are in preparation in several countries (Federal Aviation Administration, 2015; The Drone Info, 2015).

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. In this study, using the acquired aerial images and ground photos, 3D models of buildings are produced based on the Structure-from-Motion (SfM) technique (Snively *et al.*, 2007; Crandall *et al.*, 2011). An aerial video taken by the Canadian humanitarian organization (CBC News World, 2015) from a UAV is also used to model an affected district in Katmandu, Nepal, due the Mw7.8 Gorkha earthquake on April 25, 2015 (National Society for Earthquake Technology-Nepal, 2015). These examples highlight the usefulness of UAVs in information gathering of disaster stricken areas.

2 AERIAL SURVEY OF ONAGAWA TOWN USING UAV

2.1 The 2011 Tohoku earthquake and Onagawa Town

The Mw 9.0 Tohoku earthquake occurred on March 11, 2011, off the Pacific coast of northeastern (Tohoku) Japan, and caused gigantic tsunamis, resulting in widespread devastation (Suppasri *et al.*, 2012; Liu *et al.*, 2013). Onagawa Town, approximately 50 km northeast of Sendai city, is one of the most severely affected municipalities in the 2011 Tohoku earthquake. Onagawa is located along the ria coast of the Pacific Ocean and a part of the Oshika Peninsula, and is surrounded by Ishinomaki City. The town was hit by repeated tsunamis after about 15:30 on March 11, 2011. The maximum tsunami height (from the sea level) observed at Onagawa Hospital was higher than 18 m (Suppasri & Mas, 2013). Even the ground floor of the hospital, located on a hill, was inundated up to about 2 m. **Figure 1(a)** shows an aerial photograph taken by the Geospatial Survey Institute (GSI), Japan on March 19, 2011.

The most remarkable observation in this area is that six reinforced-concrete (RC) buildings were overturned by the tsunami, and some of them were washed away from their original positions as shown in **Figure 1(b, c)**. These ground photos were taken by the first author on March 29, 2011 in his first visit after the disaster. The authors have visited Onagawa Town several times in the last 4 years after the 2011 Tohoku earthquake and monitored the stage of restoration.



Figure 1 Aerial photograph of Onagawa Port area by the Geospatial Survey Institute (2011) on March 19, 2011 (a) and ground photos of overturned buildings by the tsunami taken on March 29, 2011 (b) & (c)

2.2 UAV flight in Onagawa in 2014

When the authors revisited the town on November 14, 2014, only the overturned building B was left and the other overturned buildings had been demolished and removed. Thus we selected the building B in **Figure 1** as the target of UAV aerial shooting and 3D-model reconstruction. In this visit, we brought small multicopter “DJI Phantom 2 vision +”, the most selling drone in the world, for aerial surveying.

Figure 2 shows the scene of the take-off and the flight route of the drone. A GPS-guided auto-pilot function was used to fly over the building with the altitude of 30 m from the ground. The camera angle was set to the vertical direction, and thus the upper surface of the turned-down structure was seen well. But by this shooting condition, the side-faces of the structure could not be captured well. Since the building was stand (left) alone, we took the photos of all the side-faces from the ground.

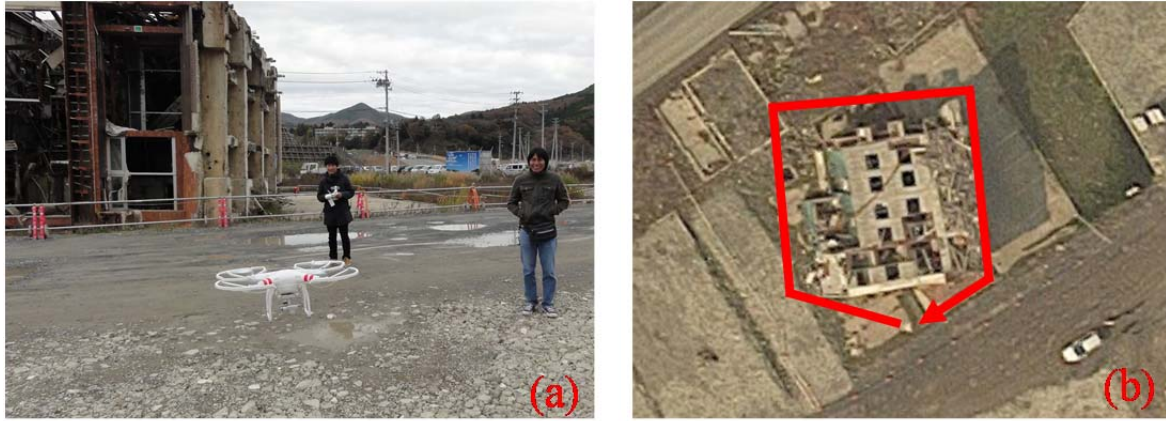


Figure 2 Scene of the take-off of the drone (a) and the flight route over the building B in Onagawa on November 14, 2014.

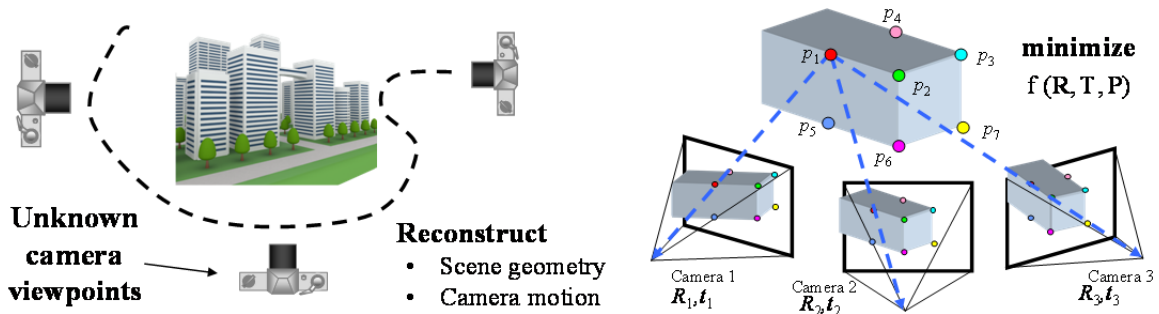


Figure 3 Schematic concept of the Structure-from-Motion (SfM)

3 DEVELOPMENT OF 3D-MODEL OF BUILDING IN ONAGAWA BY SFM

3.1 Structure-from-Motion (SfM) technique

The Structure-from-Motion (SfM) is a range imaging technique to reconstruct three-dimensional structures and camera positions and orientations simultaneously from two-dimensional image sequences as shown in **Figure 3**. The method has been studied extensively in the fields of computer vision and visual perception (Lowe, 2004). A large number of research works have been carried out to construct 3D models of buildings and various objects (Snavely *et al.*, 2007; Daffry *et al.*, 2015). In this study, the Agisoft's *PhotoScan* software is used for constructing 3D models of buildings based on the SfM technique.

3.2 3D model construction from aerial images

Using a set of aerial images taken from the UAV over the building B in Onagawa Town, a 3D building model was developed. One hundred (100) snapshots were captured from the aerial video and they were used for this purpose. **Figure 4** shows the estimated camera positions and developed 3D model. Since the camera angle was almost to the vertical direction, the top surface of the building was modelled well. But the side faces of the building could not be modelled so well. In order to produce a more complete 3D model, the drone should fly also at a lower altitude with an oblique camera angle.

3.3 3D model construction from ground photos

A 3D building model was also produced using only photographs taken from the ground. **Figure 5** shows the estimated camera positions and developed 3D model using 45 ground photos. Since the top face of the building could not be seen from the ground, and thus that part of the building was not

modelled. But the model has much more detailed side-face texture since the ground photos were taken from close distances.

3.4 3D model construction using aerial and ground images

A 3D model was also made using both the aerial images and ground photos, and assigning a few ground control points (GCPs) as shown in **Figure 6**. By combining the two sets of images, the constructed 3D model was found to be most complete, compared with the previous two cases. This example demonstrates the usefulness of the SfM technique to depict damage situation of buildings.

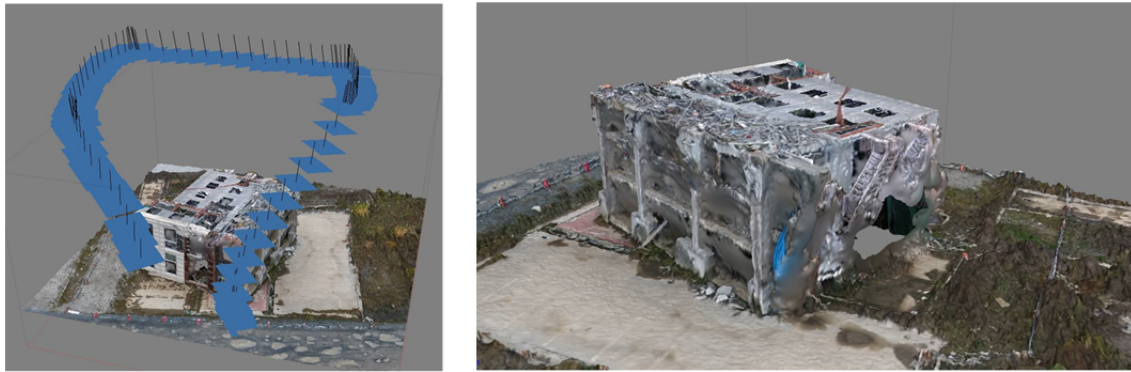


Figure 4 Estimated camera positions (left) and developed 3D model (right) from the aerial images.

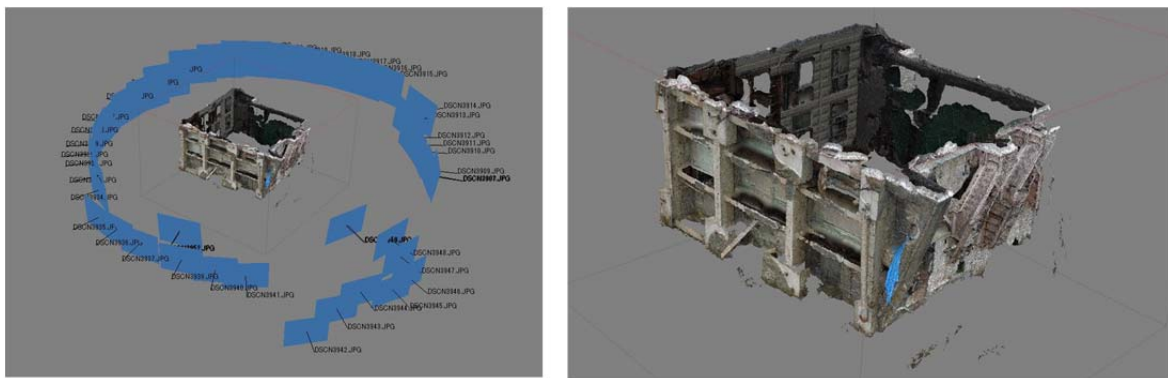


Figure 5 Estimated camera positions (left) and developed 3D model (right) from the ground photos.

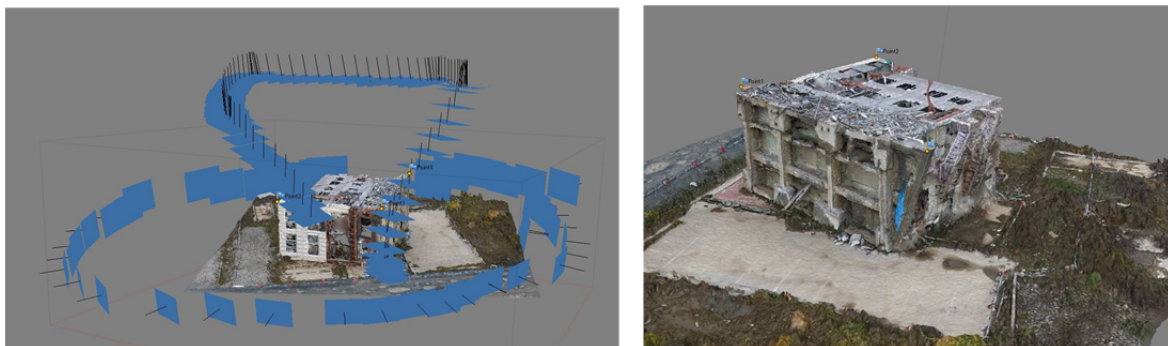


Figure 6 Estimated camera positions (left) and developed 3D model (right) using both the aerial images and ground photos.

4 DEVELOPMENT OF 3D-MODEL OF DISTRICTS IN KATHMANDU AFTER THE 2015 GORKHA EARTHQUAKE BY SFM

4.1 The 2015 Gorkha, Nepal earthquake

An Mw7.8 earthquake struck the central part of Nepal at 11:56 local time, on April 25, 2015. The earthquake occurred by thrust faulting on the interface between the subducting Indian plate and the overriding Eurasia plate to the north (United States Geological Survey, 2015). The fault rupture was triggered at 28.230°N and 84.731°E, 82 km northwest of Kathmandu, with the depth of 8.2 km. **Figure 7** shows the location of the epicenter and the contour of ShakeMap (MM Intensity) produced by USGS.

The total number of deaths was counted as 8,686, that of injured as 16,808, and that of fully destroyed buildings over a half million (NSET, 2015). The capital city, Kathmandu, is located just above the south edge of the causative fault-plane and the estimated MM intensity was in the range of VI to IX. The population in Kathmandu was about 1.7 million before the event, and 1,203 people were killed and 4,634 injured (NSET, 2015). Mass media broadcasted the situation of severely damaged buildings repeatedly, including historical monuments in Kathmandu Valley, the capital city was thought completely reduced to ruin. But the Japanese investigation team reported that the most parts of the city were in rather minor damage situation (Japan Society of Civil Engineers, 2015).

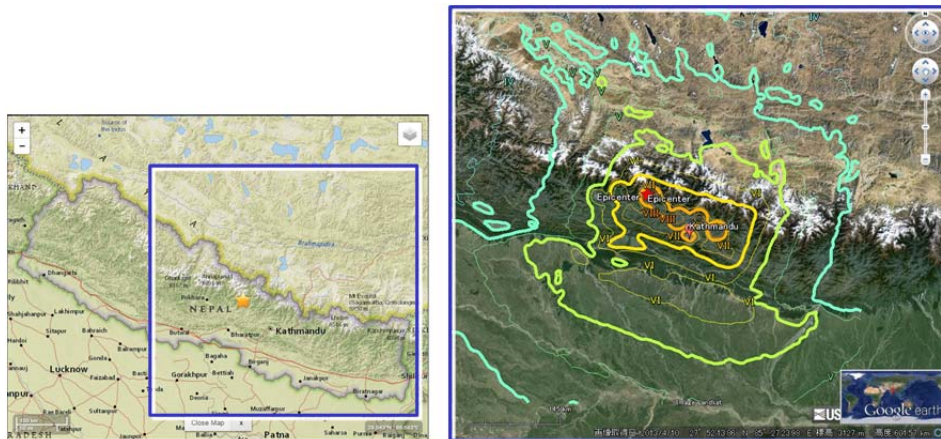


Figure 7 Map of Nepal (left) and the ShakeMap of the blue square region produced by USGS (2015).

4.2 Videos taken from UAVs and construction of 3D district models

After the 25 April 2015 earthquake, a number of international aid groups and countries offered emergency aids to the disaster. Rescue and response teams were dispatched to Nepal from India, China, Pakistan, USA, Canada, Japan etc. Some of the international teams and mass media brought drones for reconnaissance and information gathering. Among others, Toronto-based humanitarian organization GlobalMedic employed three UAVs to survey the affected region and collected many videos and high-resolution snapshots to help aid delivery (CBC News World, 2015). In this study, we used some of such video footage on YouTube to develop 3D models of affected urban areas.

Durbar square in Kathmandu is one of the world heritage sites out of seven monument zones in the Kathmandu Valley. Using a video from UAV (<https://www.youtube.com/watch?v=N52LX1GZYWs>), we produced a 3D model of Durbar square area as shown in **Figure 8**. It is recognized from the video that, the drone flew from the east to the west over the square. The estimated camera positions (**b**) by *PhotoScan* software agrees with this observation. Since the quality of the video is high, the developed 3D model can demonstrate the damage situation of this world heritage zone quite well.

Figure 9 shows another example at Sitapaila (<https://www.youtube.com/watch?v=yWZDv8cz790>) in Kathmandu. The damage condition of each building was modelled in a 3D space, and hence the technique is considered to be useful to assess the damage situation of city blocks in detail.



Figure 8 A snapshot of video footage over Durbar Square in Kathmandu (a), estimated camera positions by SfM (b) and developed 3D model of the district (c).



Figure 9 A snapshot of video footage over Sitapaila in Kathmandu (a), estimated camera positions by SfM (b) and developed 3D model of the district (c).

5. CONCLUSIONS

In this study, the use of UAVs in image acquisition of damaged buildings due to earthquakes and the development of 3D models from the acquired 2D images were attempted. First, the authors obtained digital images from the air and ground for a turned-down and washed-away building in Onagawa Town, Miyagi Prefecture, Japan due to the 2011 Tohoku earthquake and tsunami. A small multirotor-type UAV was used in this aerial survey. Then 3D models were constructed in computer using the acquired images based on the Structure-from-Motion (SfM) technique. The most accurate model was made when both the aerial and ground-based images were used in 3D modelling. As the second example, aerial videos taken from UAVs were used to model affected areas in Kathmandu, Nepal, due to the Gorkha earthquake on April 25, 2015. The videos were taken by the Canadian humanitarian organization and released on Internet. The 3D models were developed from the video footage, and they showed the details of damage situation in the urban districts. These examples highlighted the usefulness of UAVs in information gathering of disaster stricken areas and the capability of the SfM technique to realize the damage status in the 3D space. However, a further research on automated or semi-automated methods for evaluating damage status of structures is necessary till these techniques become more useful in disaster response activities.

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