Surveying of the landslides in the Mid Niigata Prefecture Earthquake by an Unmanned Helicopter

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Abstract: Due to the Mid Niigata Prefecture Earthquake occurred in the end of 2004 in Japan, a lot of slope failures or landslides occurred in these areas. Immediately after the earth quack, high-resolution satellite images and aerial photographs were acquired by the private surveying companies and a lot of information about the situation of the disaster have been provided. Though these data are good to grasp a whole stricken area quickly, the data are insufficient in a point to get detailed information of the certain landslide site. Several ground surveying, such as using a laser scanner or a total station, were carried out to acquire detailed landslides data, but these techniques are in danger of a secondary disaster, and a lot of expenses and time are consumed for the surveying. Thus, in this study, we had mounted a digital camera and a laser scanner on an unmanned helicopter to acquire detailed information from low altitude which is different from a satellite or a plane. The surveying is carried from the sky, but the resolution and accuracy are the same level of the ground surveying. Because of the utilization of an unmanned helicopter, the data of the landslide site can be easily acquired collectively with safety and mobility. We proposed a new method to acquire the data in landslide site in different scale from a satellite image or an aerial photograph.
Keywords: landslide, disaster, unmanned helicopter, laser scanning, bundle adjustment.

1. Introduction

On October 23rd, 2004, a huge earthquake with a magnitude of 6.8 in JMA Magnitude (Japan Meteorological Agency Magnitude) hit the Mid Niigata area in Japan. The center of the main shock located in 37, 17.4N in latitude, 138, 52.2E in longitude with a depth of 13 kilometers in the central part of Niigata prefecture. Niigata is located on the Japan Sea coast, which is approximately 200km north from Tokyo, as shown in Figure 1. The tremor was also felt in Tokyo where tall buildings shook. The JMA named the earthquake "The Mid Niigata Prefecture Earthquake in 2004". 31 people were killed, more than 2,200 people were injured and more than 100,000 people were in evacuation, according to the report of the Niigata prefecture.

A huge number of landslides can be triggered by the earthquake. Landslides are an abrupt movement of soil and bedrock downhill in response to gravity. Approximately several hundreds of landslides, uncountable number of shallow landslides, and more than ten landslide dams were occurred due to the Mid Niigata Prefecture Earthquake. Then, because of the landslides, 4 people were killed and 1 person was injured. The area of landslides hazard was just only 15 by 30 km, but the damaged area is a hilly to mountainous area. So, it is very difficult to access to the site for investigation of the all landslides.

Therefore, immediately after the earthquake, the aerial surveys were conducted by using high-resolution satellite images, aerial photographs, and laser data. Though the whole damaged area of what had happened became clear by the aerial surveys, the data are insufficient in a point to get detailed information of the certain landslide site. Then, several ground surveying, such as a ground laser scanning, a total station survey, and GPS survey were carried out to acquire detailed landslides data, but these techniques are in danger of a secondary disaster because of the aftershocks immediately after the earthquake, and need to consume a lot of expenses and time for the surveying.

In this research, we would like to propose new methods for landslides survey by reconstructing of digital surface model. We had mounted a digital camera and a laser scanner on an unmanned helicopter to acquire detailed information from low altitude [1]. The surveying is carried from the sky, but the resolution and accuracy are the same level of a ground surveying. Because of the utilization of an unmanned helicopter, the data of the landslide site can be easily acquired collectively with safety and mobility. This new survey can be intermediate method between aerial surveys and ground surveys.

Figure 1. The location of Niigata area

2. Experiment

In this research, surveying of the landslide took place at Nigiri-iri area of Ojiya city, located in the central part of Niigata prefecture. The target landslide of Nigiri-iri area is one of the biggest landslides which are triggered by the Mid Niigata Prefecture Earthquake. Figure 2 shows the overview of the landslide. Red square is the survey area which is approximately 500m × 300m. Figure 3 shows the landslide view from the ground.

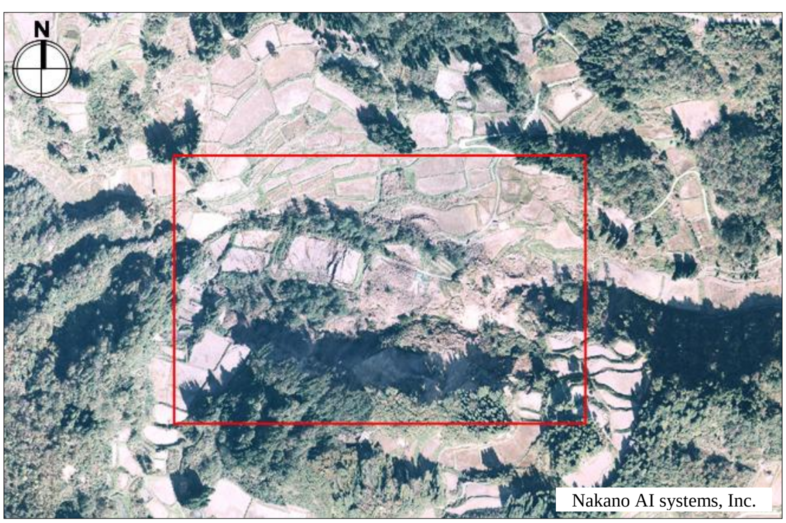

Figure 2. Landslide over view

Figure 3. Landslide

3. Ordinary methods

Generally, to acquire information about landside after disasters, two kinds of ordinary surveying methods are conducted, an aerial survey and a ground survey. An aerial survey is conducted from the sky by using satellites and/or aircrafts. On the other hand, a ground survey, by using a laser scanner, a total station, and/or GPS, is carried out to acquire detailed data on the actual spot from the ground. In this chapter, advantages and disadvantages of ordinary methods to acquire landslide data are discussed for considering to create a newer method.

1) Aerial survey

Aerial survey to acquire the Earth’s surface is usually conducted by taking image from satellites or aircraft. Aerial survey involves the use of remote sensing equipment. A remote sensor, such as an image sensor or a laser scanner, is any instruments that gather information about an object or area from a distance. Aerial survey has become very valuable method in mapping, agriculture, environmental studies, military operations, and especially for disaster monitoring. The benefits of the survey are fast and inexpensive investigation immediately after disaster. By conducting an aerial survey, a target area is covered widely the scene of the landslides. The survey avoids hazardous to acquire data or can get data at the region where is difficult to reach. Moreover, it has possibility to compare with previous data, which can identify disaster area and grasp the situation of damaged area. Figure 4 shows the changing detection by aerial photographs at our targeted site. The landside can be identified by comparing with these images. However, an acquired data by aerial survey is relatively low resolution because of a distance and this survey is weather dependent. Thus more detailed data would be necessary for landslide survey depending on the situation.

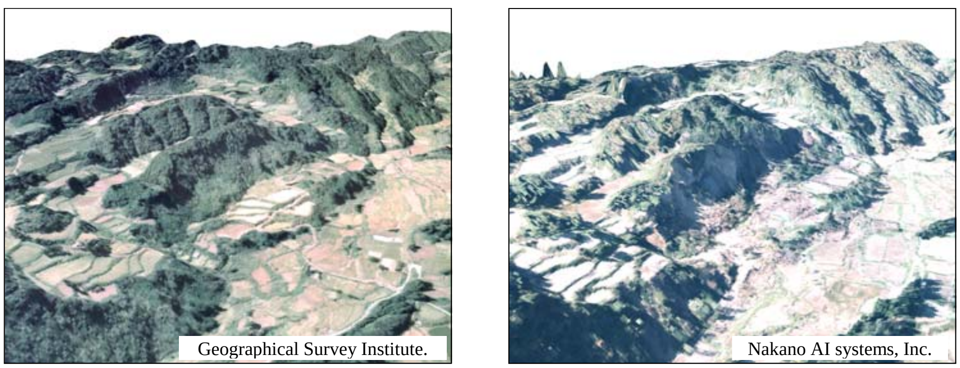

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Figure 4. Change detection by aerial photographs at experimental area

2) Ground survey

Ground surveying utilizes an instrument such as a total station (a small telescope equipped with an electronic distance-measuring device), GPS, a laser scanner, digital camera and so on. Ground surveying is conducted from the ground, so generally it is very close to, or on, the site. By a ground survey, it is easy to get detailed and accurate data, because of a close distance, as shown in Figure 5 which is the fixed-point observation from the ground at our targeted site by National Institute for Rural Engineering (NIRE). However, it covers only small area and it is very difficult to cover whole target area. That is, this survey is relatively high cost. Moreover, this survey is sometimes inaccessible or not safety, if a second disaster occurred.

Figure 5. Fixed-point observation at experimental area

4. Utilization of an unmanned helicopter

Utilization of an unmanned helicopter for landslide survey is proposed for this research. As mentioned above, both an aerial survey and a ground survey have advantages and disadvantages. The survey with an unmanned helicopter is intermediate method between an aerial survey and a ground survey. That is, an unmanned helicopter can survey wide area easily and safety from the sky. At the same time, data is very high resolution and accurate because it is very close to the site from low altitude. In this experiment, some measurement tools are loaded on the unmanned helicopter, RPH2, which is made by Fuji Heavy Industries Ltd., shown in Figure 6. The size of RPHS is a length of 4.1m, a width of 1.3m, and a height of 1.8m. And Table 1 shows the main specification of RPH2.

Figure 6. RPH2

Table 1. Specification of RPH2

Weight	330 kg
Pay load	100 kg
Motor	83.5 hp
Main Rotor	2 rotors, diameter 4.8m
Tail Rotor	2 rotors, diameter 0.8m
Operational	3km or over
Endurance	1 hour
Ceiling	2,000m

1) Advantages of an unmanned helicopter

There are several advantages to utilize an unmanned helicopter compared with ordinary aerial and ground survey. Advantages of unmanned helicopter utilization are listed below. Advantage of unmanned helicopter suits the purpose of direct-georeferenced mapping. Direct-georeferencing does not require ground control points with accurately measured ground coordinate value. In dangerous zone, it is impossible to set control points unlike normal aerial surveys. Therefore, combination of this direct-georeferencing method from an unmanned helicopter might be ideal tools for dangerous monitoring purpose, such as landslides survey.

Advantages:

- Fly over dangerous zone, such as disaster, floating ice, land mines.
- Any observation positions, from top to side, any observation angles.
- Only few regulations, not like a manned helicopter.
- Easy to transport, carrying by a small truck.

2) Flight conditions

The experimental condition for the flight is listed on Table 2. This fight condition is determined by the sensors which are mounted on the unmanned helicopter in this experiment, as referring to the following section for further details. Especially, flight speed and course interval depend on the angle of view of the mounted digital camera in order to maintain certain overlaps of images. And flight altitude trades off resolution of data.

Table 2. Flight condition

ITEM		NOTE
Altitude	100 m – 150 m	from the lowest ground in the area
Speed	5 m/s	60 % overlap in the direction of movement
Direction	To West	parallel to the slope
Course interval	20 m	40 % overlap in the side

5. Measurement system

In this research, laser scanner and digital camera with IMU and GPS are used to reconstruct digital surface model for landslides survrey. In order to construct digital surface model automatically, it is necessary to develop the high precision positioning system in all circumstances for determining the movement of sensors. Integration of GPS and IMU (GPS/IMU) is very effective for high accuracy positioning of mobile platform. 3D shape is acquired by laser scanner as point cloud data, and texture information is acquired by digital camera from the same platform simultaneously. List of sensors which is used in this research is shown in Table 3.

Table 3. List of sensors

Sensors	Model	Specification
Digital Camera	Canon EOS 10D	3,072 × 2,048 pixels Focus length: 24.0mm Intervals: 9 seconds Price: 1,500US$
Laser Scanner	SICK LMS-291	Angular resolution: 0.25º Max. Distance: 80m Accuracy (20m) : 10mm Frequency: 17Hz Price: 4,000US$
IMU	Tamagawa Seiki Co., Ltd TA7546	Fiber Optic Gyro Accuracy: Angle: ±0.01° Angle velocity: ±0.005°/s Acceleration: ±0.002G Frequency: 200Hz Price: 25,000US$
GPS	Ashtech G12	Accuracy : 30cm Velocity Accuracy: 0.1(95%) Frequency: 1Hz Price : 4,000US$

All the sensors are tightly fixed on the unmanned helicopter to have constant geometric relationship in all circumstances. Calibration of digital camera and laser scanner is conducted to estimate relative position and attitude. Also, all sensors are synchronized by 1 pps (pulse per second) GPS data to integrate. Figure 7 shows the system design that sensors are mounted on the unmanned helicopter.

One of the key points of the system design are to realize “handiness” and “mobility”. “Handiness” means low cost, easy method, and so on. Utilization of a small laser scanner, a commercial digital camera, and an inexpensive IMU (fiber optic gyro) are proposed to use in this research and these sensors are relatively low cost in comparison with existing 3D measurement tools. These low cost equipments are easy to find in market.

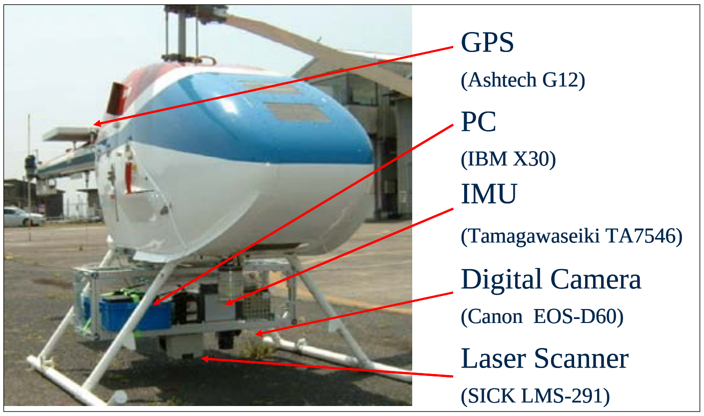

Figure 7. RPH2

6. Data Processing

1) GPS and IMU

In order to measure the position of the platform and sensors, GPS and IMU are utilized by integration of them. The integration of GPS and IMU is implemented using Kalman filter. Kalman filter can be used to optimally estimate the system states [2]. In Kalman filter, the final estimation is based on a combination of prediction and actual measurement. IMU has a rising quality, but it is still affected by systematic errors. Here, GPS measurement is applied as actual measurement in order to aid IMU by correcting this huge drift error. Through Kalman filter operation, an optimal estimate of the sensor position and attitude is determined from GPS and IMU. Figure 8 shows the trajectory of the platform in this experiment. Integration of GPS and IMU can compute high frequent data by GPS accuracy

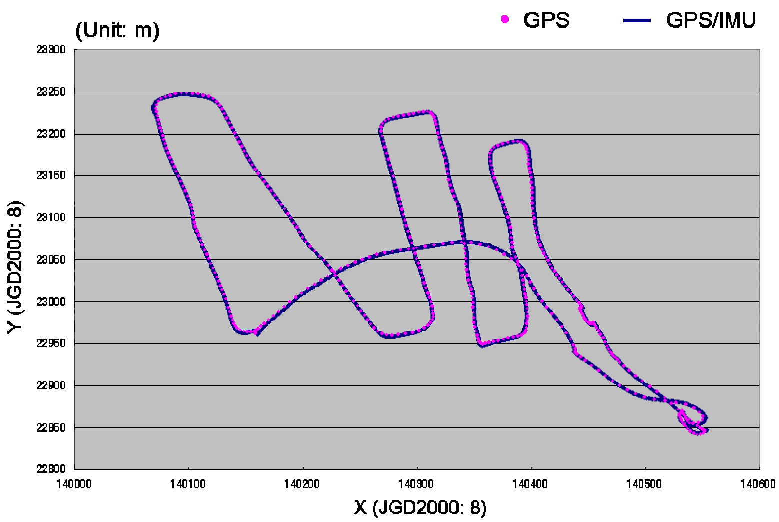

Figure 8. Trajectory of the unmanned helicopter

2) Images

A series of images are taken from an unmanned helicopter under the condition of Table 2. Meanwhile, orientation of digital camera image is determined by bundle block adjustment. Bundle block adjustment is a non linear least squares optimization method using tie-points of inside block. Bundle block adjustment is used for the determination of the orientation parameters of all images. Bundle block configuration increases both the reliability and the accuracy of object reconstruction. An object point is determined by intersection from more than two images, which provides local redundancy for gross error detection and which makes a better intersection geometry as a result. So, in this research, digital camera images are taken for more than 60% overlapping in forward direction, and more than 40% overlapping in side. GPS/IMU allows automatic setting of tie-points and it reduces the number of tie-points and searching time of tie-points by the limitation of searching area. Figure 9 shows a series of image orientation with tie points which overlapped each other approximately. Resolution of those images is approximately 3cm - 5cm. This is super high resolution image. So it is not difficult to detect small gaps or cracks as shown in Figure 9.

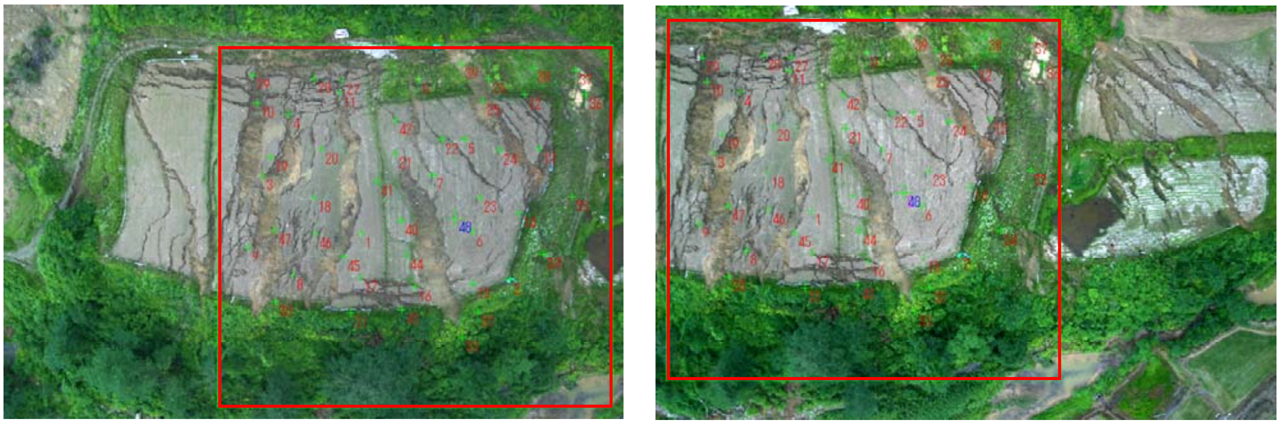

Figure 9. Image orientation with tie points

3) Laser Data

Geo-referencing of range data is determined by 3D Helmert's transformation which is computing rotation matrix, shift vector with GPS/IMU and calibration parameters as offset ([3], [4]). All the points scanned by the laser scanner (x) are converted to the common coordinate system (X_c) which is the same as digital camera image coordinate system as given by Eq.(1). Rotation matrix (R_h) and shift vector (S_h) from GPS/IMU, which are corrected drift error are used with respect to time. Offset values ($R_{l\text{-}d}$ and $S_{l\text{-}d}$) are already estimated in sensor calibration before the experiment. Figure 10 shows 3D point cloud data which is acquired from the laser scanner and color information is acquired from the oriented images in the previous section. This 3D point cloud data shows clearly the shape of the landslide, including gaps and cracks, which are enclosed by the square in Figure 9.

$$X_c = (R_h \times R_{l\text{-}d})\, x + (S_h + S_{l\text{-}d}) \qquad (1)$$

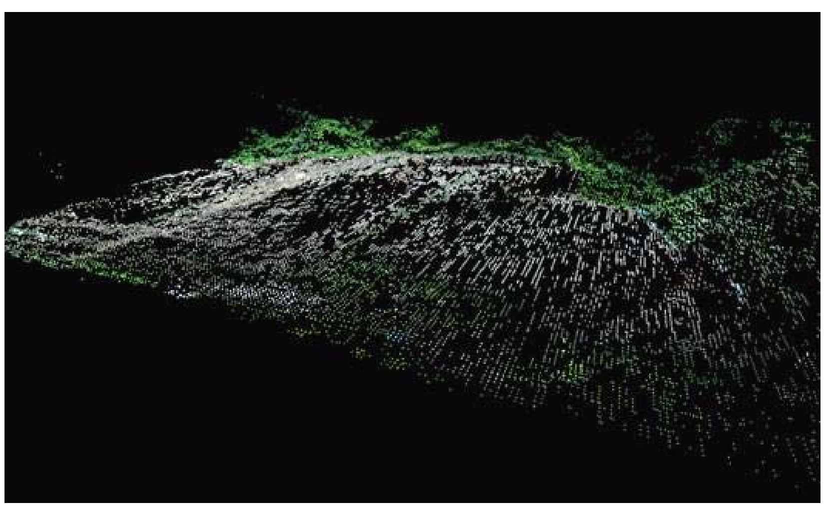

Figure 10. 3D point cloud data

4) Accuracy assessment

Table 4 shows the result of accuracy assessment. “cp” is the control points which is measured by total station from the ground as true values. “ba” is the computation result of image orientation. Accuracy is estimated by comparing with 20 control points and the result of image orientation. Average of errors of its plane (X, Y) is approximately 3cm to 6cm. Average of errors of its height (Z) is approximately 10cm. Thus, the result is quite accurate as compared with satellite images, aerial photographs, or aerial laser data.

Table 4. Accuracy assessment

Num	X (cp:m)	Y (cp:m)	Z (cp:m)	X (ba:m)	Y (ba:m)	Z (ba:m)	Error:X	Error:Y	Error:Z
1	0	0	-12.584	0.094	-0.059	-12.311	0.094	0.059	0.273
2	11.3105	0	-12.3825	11.293	-0.062	-12.48	0.0175	0.062	0.0975
3	20.8395	0.168	-12.4065	20.79	0.111	-12.515	0.0495	0.057	0.1085
4	32.588	0.2885	-12.441	32.527	0.229	-12.564	0.061	0.0595	0.123
5	46.196	0.5035	-12.5105	46.103	0.447	-12.518	0.093	0.0565	0.0075
6	0.074	-8.1735	-12.515	0.173	-8.145	-12.336	0.099	0.0285	0.179
7	11.3245	-7.905	-12.428	11.346	-7.891	-12.458	0.0215	0.014	0.03
8	20.5425	-7.703	-12.4345	20.525	-7.72	-12.499	0.0175	0.017	0.0645
9	30.677	-7.315	-12.406	30.622	-7.341	-12.575	0.055	0.026	0.169
10	46.7025	-7.81	-12.566	46.608	-7.849	-12.459	0.0945	0.039	0.107
11	0.4485	-14.9755	-12.473	0.551	-14.917	-12.376	0.1025	0.0585	0.097
12	11.6895	-15.058	-12.4075	11.734	-15.019	-12.483	0.0445	0.039	0.0755
13	20.3605	-14.902	-12.419	20.361	-14.891	-12.518	0.0005	0.011	0.099
14	30.447	-15.3555	-12.47	30.424	-15.347	-12.503	0.023	0.0085	0.033
15	46.3735	-15.455	-12.5715	46.289	-15.456	-12.401	0.0845	0.001	0.1705
16	0.3535	-24.139	-12.443	0.453	-24.072	-12.522	0.0995	0.067	0.079
17	11.911	-23.7855	-12.455	11.987	-23.721	-12.466	0.076	0.0645	0.011
18	20.594	-23.461	-12.453	20.623	-23.421	-12.507	0.029	0.04	0.054
19	30.176	-23.1665	-12.4505	30.165	-23.13	-12.491	0.011	0.0365	0.0405
20	46.258	-22.5005	-12.5545	46.2	-22.493	-12.39	0.058	0.0075	0.1645
						ave	0.05655	0.0376	0.09915 (Unit:m)

cp: control points ba: image coordinate

7. Conclusions

In conclusion, all the sensors, laser scanner, digital camera, IMU and GPS are mounted on an unmanned helicopter to reconstruct digital surface model for a landslide survey. In this research, a new type of data for a landslide survey is proposed. Compared with an aerial photograph, the acquired data is higher resolution to indicate details of a landslide like a ground survey. Compared with a ground survey, this method is easier and much safer method, and possible to cover wide area like aerial photographs. Because of the GPS/IMU, geo-referencing of laser range data and digital camera images are conducted easily. This paper focuses on how to utilize an unmanned helicopter for landslides survey. As a result, accurate trajectory of sensor is computed and it is used for direct geo-referencing for laser range data and CCD images to construct digital surface model. Finally, an unmanned helicopter has a wide possibility to utilize various disaster or target with variety of sensors.

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