DISASTER DAMAGE DETECTION AND ITS RECOVERY SUPPORT SYSTEM OF ROAD AND RAILROAD USING SATELLITE IMAGES

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KEY WORDS: Damage detection, Emergency transportation route, Decision support, NDVI, SPOT, 2004 Niigata-ken Chuetsu Earthquake

ABSTRACT:

This paper describes a decision support system based on GIS and satellite remote sensing analysis. Damage triggered by the 2004 Niigata-ken Chuetsu Earthquake was detected using NDVI from SPOT images and texture analysis. Then the emergency transportation route was selected by a cost-based GIS analysis. As the result of the analysis, large-scale damage could be detected with high accuracy. From this information, two types of emergency transportation routes, roads and railways, were identified and evaluated. These results also contribute knowledge for reference in decision making for both recovery support and prevention of secondary disaster.

1. INTRODUCTION

Recently much damage has been caused by earthquakes. In particular, huge disasters such as landslides, slope failures and debris flows have been observed in hillside or mountainside regions. In such locations, there are many important lifelines such as road and railway networks connecting urban and rural areas. In order to prepare for a huge disaster, the lifelines have to be precisely monitored. Each government administration in Japan is preparing disaster prevention plans to prevent disasters and to establish emergency procedures for such huge disasters. In these emergency procedures, top priority is to grasp the damage situation and to maintain effective traffic flow. In general, field survey or photogrammetric techniques are used to comprehend the damage situation and traffic conditions. These kinds of monitoring methods, however, take a lot of time to cover a wide area. Consequently a remote sensing approach by satellite was employed in this study. Finally this paper proposes a decision-making process for selecting the emergency transportation route using the two approaches of image analysis and GIS analysis.

2. EARTHQUAKE-INDUCED DAMAGE TO CASE STUDY AREA

2.1 2004 Niigata-ken Chuetsu Earthquake and the damage

On October 23, 2004, at 17:56 on JST (18:56 on GMT), a heavy earthquake with a magnitude of 6.8 in JMA (Japan Meteorological Agency) Magnitude occurred in Chuetsu region of Niigata prefecture of Japan. One of the most heavily damaged town was Kawaguchi with an intensity of 7 on the intensity of JMA scale as shown in Figure 1. Not only Kawaguchi town but also Tokamachi, Ojiya city and Yamakoshi village were heavily damaged due to large number of slope failures induced by the earthquake. The earthquake caused the loss of more than 37 lives and injured more than 2500 people. Because the deep granite layer was covering the area, risk to the collapse and the interception of the road/railway was very high. On the Route 291 connecting Kashiwazaki city and Ojiya city in Niigata prefecture, some manholes rose out of the ground. The earthquake also inflicted heavy damage to Kanetsu Expressway and Joetsu Shinkansen (Super Express) Line and Joetsu railway line.

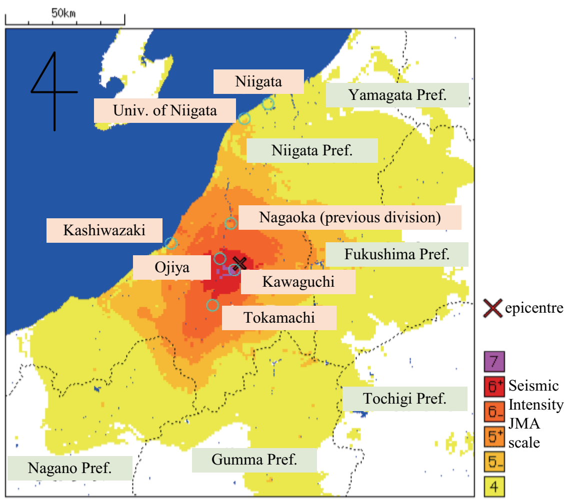


Figure 1. Seismic intensity of JMA scale triggered by 2004 Niigata-ken Chuestu Earthquake

(a)slope failures

(b)damage to roads

Figure 2. Damage triggered by 2004 Niigata-ken Chuetsu Earthquake

The Shinkansen train traveling at a speed of 200km/h was derailed. Many rock and soil slope failures took place, particularly in the mountainous area. These slope failures destroyed roads and railways. The large slope failures were directly associated with structural discontinuities in rock mass such as existing faults, bedding planes, and folds. Figure 2(a) shows the examples of the slope failure.

2.2 Damage to Roads and Railways

Roads in the earthquake stricken area were heavily damaged due to ground settlement or uplift of manholes due to liquefaction. The damage was also caused by slope failures in the hillside area. Route 17, 117, 351, 291 and 352 pass through the area of epicentre. These highways built on existing ground or embankments were damaged in various parts due to either the failure or settlement of embankments and slope failure. The highways leading to Yamakoshi village were extensively damaged by the slope failure as shown in Figure 2(b). The settlements were quite amplified at the locations where embankments are in contact with rigid bridge platforms.

(a)SPOT-5 color composite (R:G:B=band 2:3:1)

(b)road features(red line)

(c)railway features(blue line)

Figure 3. Study area

Name of data	Format	Supply
SPOT-5 image	Raster format ERDAS IMAGINE img format	Spot image
DEM		Geospatial Information Authority of Japan
Slope inclination	Vector format Converted to shape format using a converting tool	
Digital Map 2500 (including Spatial Data Framework)		

Table 1. GIS data used in this study

The relative settlement at such locations was more than 30cm. The damage to Joetsu local line was quite extensive in the area of epicentre. The damage to the railway was mostly associated with the lateral spreading of ground, the failure or settlement of embankments and slope failure.

2.3 Study Area and Data Used in This Analysis

The Great Merger of the Heisei Era has completed in March, 2006. In corresponding to the Merger, several administrative units in Niigata prefecture have changed. This paper, however, uses previous administrative units and names. As shown in Figure 3, the study area of this paper is in and around Ojiya city, Nagaoka city, Kawaguchi town, Horinouchi town and Yamakoshi village which is about 2263 × 3609 pixels (almost 11km × 18km) of SPOT-5 image. The data format is shown in Table 1. The data used in this study has been unified as raster or vector type for convenience of calculation and management.

3. EXTRACTION OF ROAD/RAILWAY DAMAGE

Damage to roads and railways can be classified as several types. This study attempted to detect the damage by using both NDVI and texture analysis based on the damage type.

3.1 Damage Detection using NDVI

In order to extract earthquake-induced damage to roads due to slope failures, it is effective to see land cover changes, particularly vegetation cover changes, rather than to see the base courses or the subgrades of road directly. Therefore established index *NDVI* shown in eq.(1) , well known as an index for vegetation activity, is used in this study. Figure 4 is the *NDVI* image of this study area.

$$NDVI = \frac{NIR - Vred}{NIR + Vred} \tag{1}$$

where NIR = reflectance of near infrared band
$Vred$ = reflectance of visible red band

SPOT-5 has 5 bands including a panchromatic band and a SWIR band. The band 2 and 3 images correspond with *Vred* and *NIR* respectively. Figure 5 shows the histogram of *NDVI*s in the study area concerning to before and after the earthquake. By using the histogram of *NDVI*, masked image was calculated where threshold value of *NDVI* is 0. In this study we assumed that vegetation cover has been lost by slope failures after the earthquake and then soil has covered the collapsed area. Based on the assumption, the masked image was merged, and removed agricultural area and flat area (domain of less than 9 degrees of slope). Finally predicted damage polygons were generated as shown in Figure 6.

3.2 Damage Detection by Texture Analysis

As shown in previous section, damaged area (polygon) can be generated from *NDVI* difference between before and after the earthquake. The method can't extract damage when target area has originally no vegetation cover. Therefore a statistical texture analysis which calculates image difference of *NDVI* was applied.

At the phase of training, three test case areas were prepared. Initially texture characteristics (e.g. the range, the standard deviation) for three bands were calculated using the segment polygon derived by a segmentation analysis. Based on damage characteristics as shown in Figure 7, two damage detection parameters which depend on damage type were decided as follows;

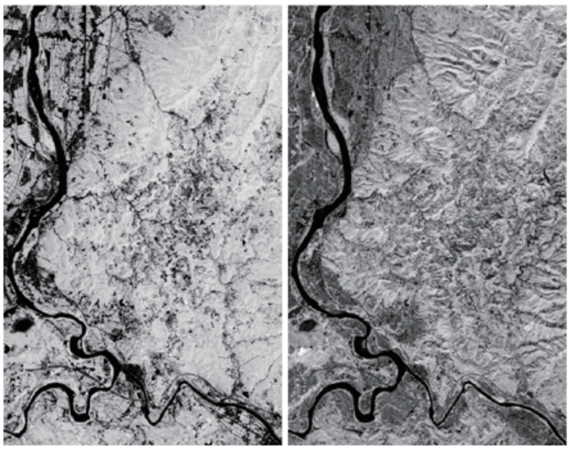
for collapse of road/railway and the surface

$$\begin{aligned} &RANGE\_NIR > 0 \text{ and} \\ &RANGE\_Vred > 20 \text{ and} \\ &RANGE\_Vgreen > 0 \end{aligned} \tag{2}$$

for subsidence of road/railway, slope failure and sediment

$$\begin{aligned} &RANGE\_NIR < -10 \text{ and} \\ &RANGE\_Vgreen < -10 \text{ and} \\ &SD\_\ Vred < 0 \end{aligned} \tag{3}$$

where $RANGE$ = difference between before and after the earthquake of max-min value
SD = difference between before and after the earthquake of standard deviation .



(a)before the earthquake (b)after the earthquake

Figure 4. *NDVI* images of the study area

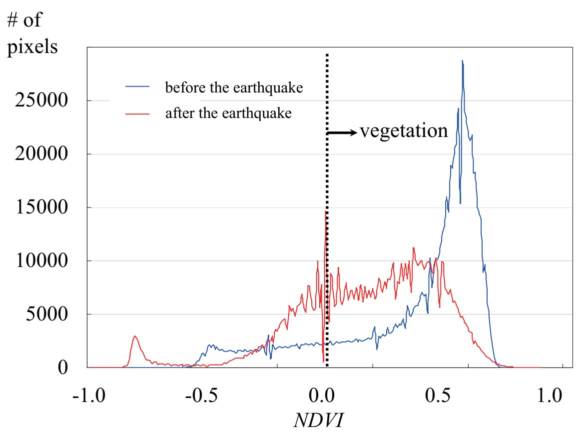


Figure 5. Histogram of *NDVI*

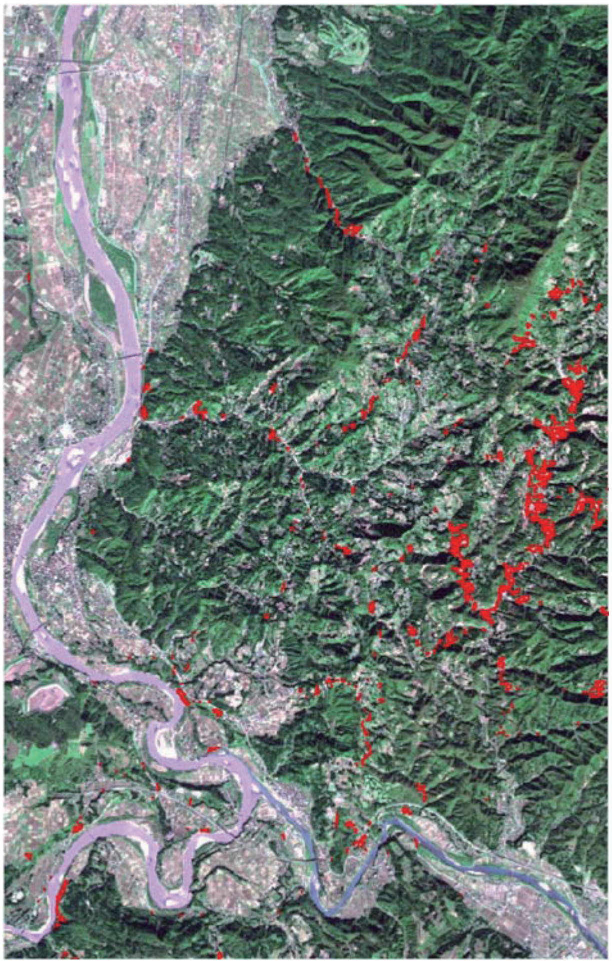
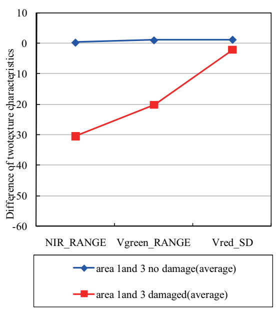
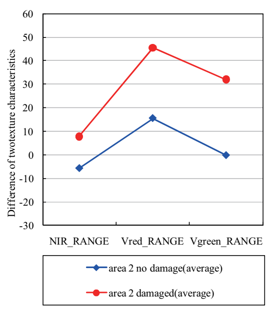


Figure.6 Detected damage area by *NDVI* analysis
Red polygon : detected damage polygons
(background image : SPOT-5)



(a)damage type A -area 2- for collapse of road/railway and the surface



(b)damage type B -area 1,3- for subsidence of road/railway, slope failure and sediment

Figure 7. Change in characteristics of texture(difference of texture) between damaged area and no damage area

Two damage detection parameters were applied to whole image of the study area. Similar to the *NDVI* analysis, the domain of less than 9 degrees of slope has deleted. Then damaged area by the texture analysis is detected. Figure 8 shows the result image of texture analysis. The number of detected polygons by texture analysis was it of 5 times of *NDVI* analysis.

Figure 8. Detected damage area by texture analysis
Red polygon : detected damage polygons
(background image : SPOT-5)

3.3 Accuracy Assessment

Two detected images were merged (Figure 9) and the damage area affecting to 45 routes or Joetsu local line were extracted by comparing road/railway polylines. Accuracy assessment of this merged image has done with two indices as follows;

(1)Detection Accuracy, *DA* (accuracy for detected polygons)

$$DA\left(\%\right)=\left(Nd\,/\,Nv\right)\times 100 \tag{4}$$

where Nd = total number of polygons of $Pd \cap Pv$
Pd = detected damage polygons in verification area
Pv = polygons for verification in verification area
Nv = total number of verification polygons in verification area

(2)Total Accuracy, *TA* (reliability of detected polygons)

$$TA\left(\%\right)=\left(Nvs\,/\,Nds\right)\times 100 \tag{5}$$

where Nvs = total number of polygons of $Pds \cap Pvs$
Pds = detected damage polygons in study area
Pvs = polygons for verification in study area
Nds = total number of detected damage polygons in study area

Figure 9. Post processed (merged) damage area
Red polygon : damage of road
Blue polygon : damage of railway

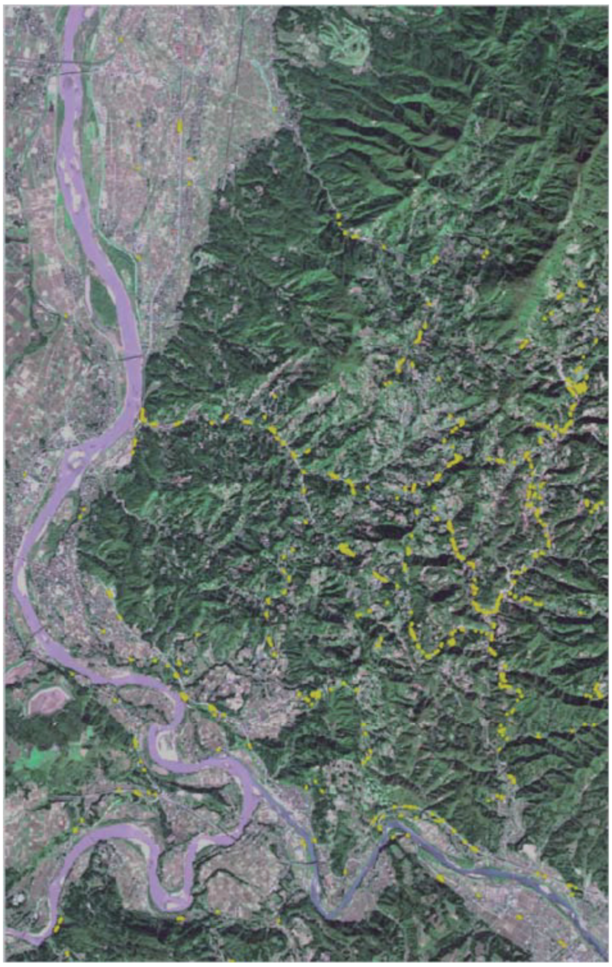


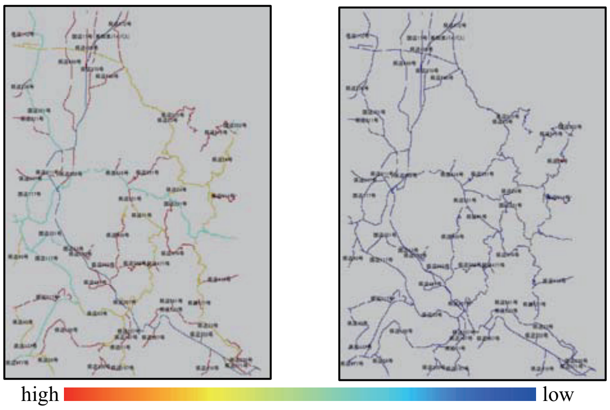
Figure 10. Verification polygons (yellow polygon)

category	Nv	Nd	DA(%)	Nds	Nvs	TA(%)
Road	337	231	68.5	894	234	26.2
Railway	9	6	66.7	20	6	30.0

Table 2. Accuracy of this analysis

Damage level	Nv	Nd	DA(%)
Level 1 (x ≧ 1000 m^2)	37	35	94.6
Level 2 (1000 m^2 > x ≧ 500 m^2)	47	44	93.6
Level 3 (500 m^2 > x)	262	158	60.3

Table 3. Accuracy according to the damage scale

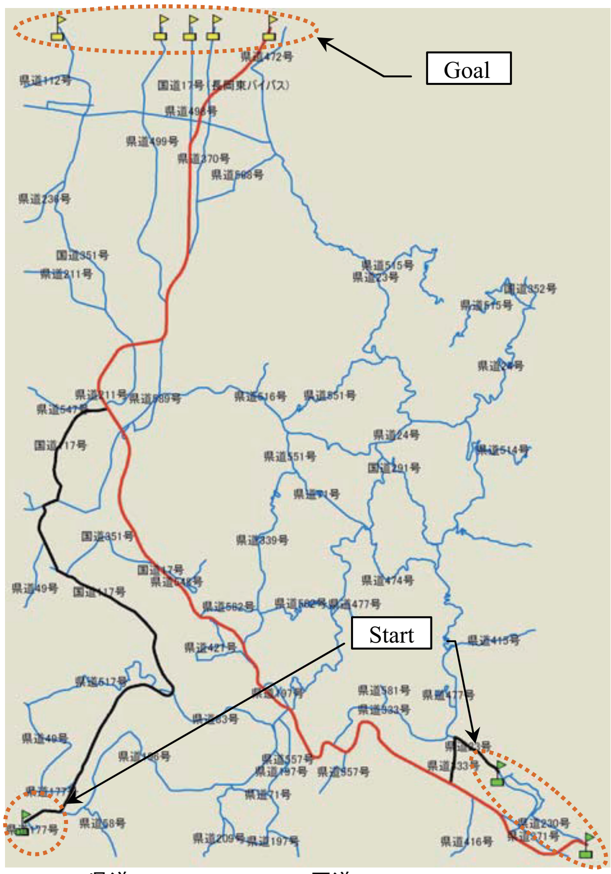


(a)road importance cost and convenience cost

(b)area of damage cost

Figure 11. Examples of cost-raster (cost grid)

Figure 10 shows the verification data for accuracy assessment. The accuracy assessment result is shows in Table 2. The percentage of detection accuracy was about 66-68%. The total accuracy that means a reliability of the analysis was almost 26%. It is a reason that this had little number of the verification polygons. The road damage extraction results for Yamakoshi village located in the mountainous area had a better accuracy. Nevertheless, road damage extraction results for flat and hilly area do not have enough accuracy and many miss-detection pixels were identified. One of the reasons why the accuracy was not well is considered the satellite condition such as a satellite orbit or the incidence angle. In other words, it is that a change similar to the damage in flat area occurred by the influence of the incidence angle. For the Joetsu Line, polygons of both damaged area and verification area were smaller than in the case of road, but the accuracies both road and railway results



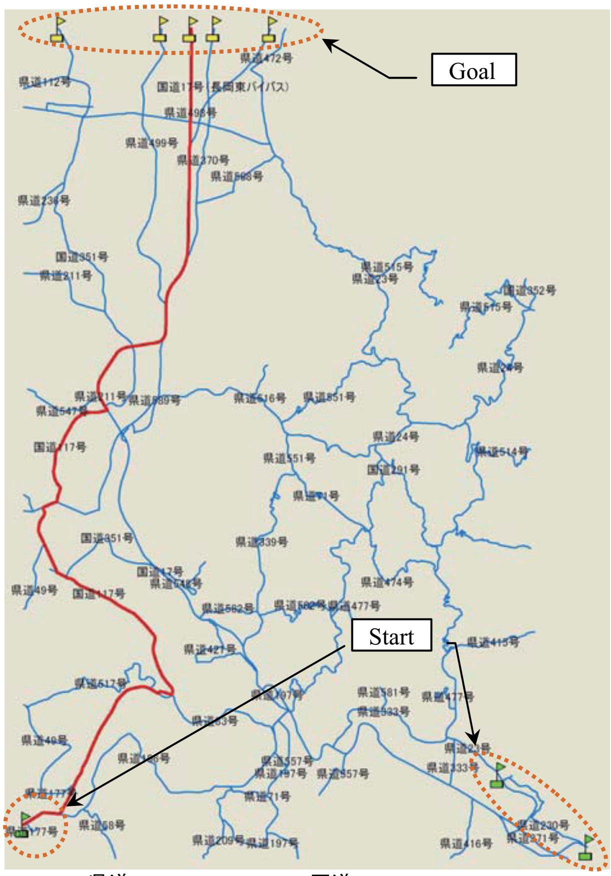
県道：Prefectural road　国道：National highway
—: minimum distance route
—: minimum distance route from each node

Figure 12. Expected minimum distance route for transporting supplies to damaged area
function: (road importance cost)×0.4＋(area of damage cost) ×0.4 ＋ (damage type cost) ×0.4

were almost same. Undetectable polygons were mainly in the area accumulating soils generated from collapsed slope.
Table 3 shows damage detection accuracy according to the damage scale. The accuracy for damaged area of more than 500 m^2 is more than 90%. The emergency procedure immediately after the earthquake is highly important, so that this kind of huge scale damage extraction strategy for transportation management is necessary. Although proposed methodology cannot extract small scale damage correctly, it can accurately detect the huge scale one. From the point of view mentioned above, proposed methodology is particularly effective in case of understanding extent of damage right after disaster occurred.

4. A CASE STUDY OF DECISION MAKING SUPPORT FOR EMERGENCY TRANSPORTATION ROUTE

A GIS using detected road/railway damage data was developed. To support the emergency transportation route decision, a case study of the GIS has carried out. In the case study, the route was calculated by using weighted-cost distance, here the influence of cost-raster (cost-grid) data was as a parameter of the analysis. The aim of this case study is to decide the most suitable emergency transportation route. Figure 12 and 13 show the results. The results show that combination of influence rate controls the transportation route. In general when we transport supplies (reliefs), cost-raster is used and when we secure



県道：Prefectural road　国道：National highway
—: minimum distance route

Figure 13. Expected minimum distance route for transporting supplies to damaged area
function: (area of damage cost)×0.5＋(damage type cost)×0.5

transportation route for residents in isolated district, cost factors both area of damage and cost of damage type are used.
The result of this case study includes several problems to the actual use. In fact much amount of data can't be prepared like this case study. Therefore a GIS using this kind of weighted-cost distance function is useful in obtaining broad overview for understanding the damage and emergency route situation. But, other kind of cost-grid database or detailed cost evaluation method has to be investigated in future. And also wide area analysis is required for emergency route decision.

5. CONCLUSIONS

This paper showed a road/railway damage detection method and basic approaches to select emergency transportation routes. The key results are as follows:

1) The proposed road/railway damage detection approach using satellite data could output results with high accuracy for huge disasters.
2) In applying the proposed GIS to select an emergency transportation route, its weighted-cost distance function was found to be useful in obtaining broad overview for understanding the damage and emergency route situation.
3) This kind of approach can be useful for understanding the extent of damage and for making decisions on disaster mitigation immediately after a huge disaster.