Warning system for landslide disaster combined with remotely sensed image and geospatial data and terrestrial X band MP radar data

Yuzo Suga*[1] and Tomohisa Konishi[2]
[1]Professor, Department of Global Environment Studies, Hiroshima Institute of Technology
2-1-1, Miyake, Saeki-ku, Hiroshima, 731-5193, Japan; Tel: +81-82-922-5204
Email: y.suga.mi@it-hiroshima.ac.jp

[2]Nihon CADIC Co. Ltd.,
5-33-12-102, Inokuchi, Nishi-ku, Hiroshima, 733-0842, Japan; Tel: +81-82-270-3351
E-mail: konishi@cadic.co.jp

KEY WORDS: Hazard estimation for landslide, Earth observation satellite data, Terrestrial X band MP radar

ABSTRACT: This study focuses on the construction of the warning system combined with the hazard estimation system by using satellite remote sensing and geographical information systems and the terrestrial X band multi-parameter (MP) (or polarimetric) radar system for landslide disaster reduction and mitigation. The algorithm and analysis method for the hazard estimation of landslide using earth observation satellite data and digital elevation model were proposed in this study. This method is based on two hydraulics elements, the amounts of hill slope flow (discharge) and the time (time of concentration) that the flow reach stable, which are represented by upstream area and specific coefficient calculated from land cover and slope angle, respectively. Then, the hazard mapping of landslide could be performed. On the other hand, the terrestrial X band MP radar has been installed in Japan Island by Ministry of Land, Infrastructure, Transport and Tourism (MLIT). There are 26 radar sites in Japan mainly distributed around urban area and/or densely built-up area in Japan. The radar system generates rainfall image with 250m grid in every minute for detecting the quite localized torrential rainfall. The acquisition range is 80 km and the effective range is 60 km. X-band MP radar has the higher sensitivity and spatial resolution of heavy rain and strong wind in urban area at real time. We are able to acquire the X-band MP radar rainfall data through internet for the validation campaign of its application. We generated an accumulated rainfall dataset based on X-band MP radar data in Hiroshima city. Finally, the warning system is experimentally constructed by combining the hazard estimation mapping and the X band MP radar data provided by MLIT. As the result, it is clarified that the warning system has an efficient performance for the advanced quick response in real time monitoring for landslide disaster.

1. INTRODUCTION

Japan has many kinds of disasters such as landslide, debris flow, flood, earthquake, and tsunami, so far. Japan is also over 70% mountainous terrain. Thus, landslide monitoring and forecasting are important issues for prevention of disaster (Suga, et al., 2008, 2012). Actually, landslide devastations have occurred every year in Hiroshima, Japan.

Terrestrial X band MP radar has been installed by Ministry of Land, Infrastructure, Transport and Tourism (MLIT), Japan. In the days before the coming of the X band MP radar, it was not sufficiently detected by operational C band radar or the rain gauge network of the Automated Meteorological Data Acquisition system (AMeDAS) operated by the Japan Meteorological Agency (JMA). The X band MP radar is able to detect the localized rainfall with high temporal and spatial resolutions (MLIT, 2012).

The investigation based on the maps, the aerial photographs and field surveys are carried out for the prediction of landslide, so far. Earth observation satellite data has an advantage that the present land cover type can be grasped based on the characteristics and performance of each satellite. If satellite data is utilized to predict the landslide, the latest hazard information can be obtained. The algorithm and analysis method for the landslide hazard estimation using earth observation satellite data and digital elevation model were proposed in this study. This method is based on two hydraulics elements, the amounts of hill slope flow (discharge) and the time (time of concentration) that the flow reach stable, which are represented by upstream area and specific coefficient calculated from land cover and slope angle, respectively (Suga, et al, 2003).

In this paper, the construction of the warning system combined with the hazard estimation system by using satellite remote sensing and geographical information systems and the terrestrial X band MP radar system for landslide disaster reduction and mitigation were examined. The rapid impact assessment after the catastrophic disaster is crucial for initiating effective emergency response and disaster mitigation.

2. STUDY AREA AND DATA SET

A hazard estimation targeting Hiroshima prefecture was experimentally performed in a test site as shown in Figure 1. Actually, the landslide devastation occurred in Hiroshima prefecture due to the localized torrential downpour every year, so far.

As for the satellite data, ALOS/AVNIR-2 data were used for landslide hazard mapping. Each data were geometrically corrected referred to 1:25,000 scaled topographic maps. Then, AVNIR-2 mosaicked imagery covered Hiroshima prefecture was generated as shown in Figure 2(a). Digital Elevation Model (DEM) data generated by Geospatial Information Authority of Japan (GSI) was used as shown in Figure 2(b). The resolution of DEM is 10 × 10 m in XML format. We converted the XML into GRID format, which is applicable to ArcGIS.

In addition, MLIT is providing X band MP radar data to our facility through internet based on the validation campaign of its application. There are 26 radar sites mainly distributed around urban area and/or densely built-up area in Japan. The radar data was processed to composite estimation of rainfall intensity by MLIT. The radar system generates rainfall image with 250m grid size in every minute for detecting the quite localized torrential rainfall. The acquisition range is 80 km and the effective range is 60 km. X-band MP radar has the higher sensitivity and spatial resolution of heavy rain and strong wind in urban area at real time.

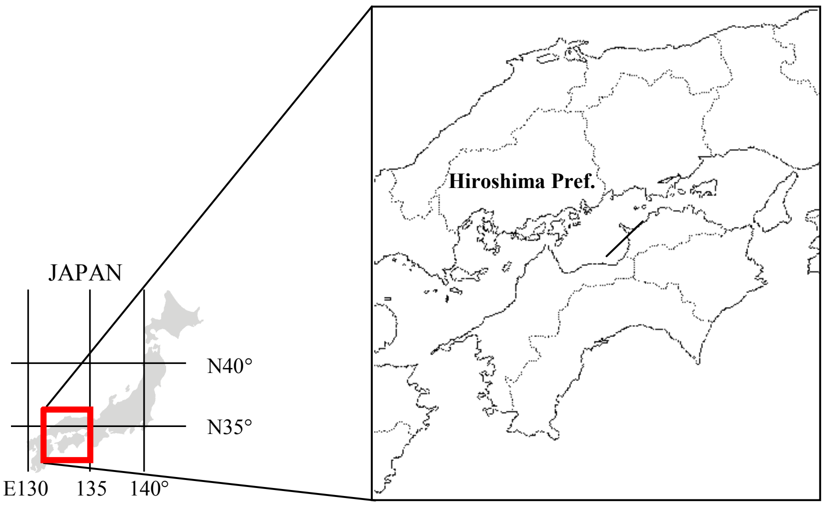
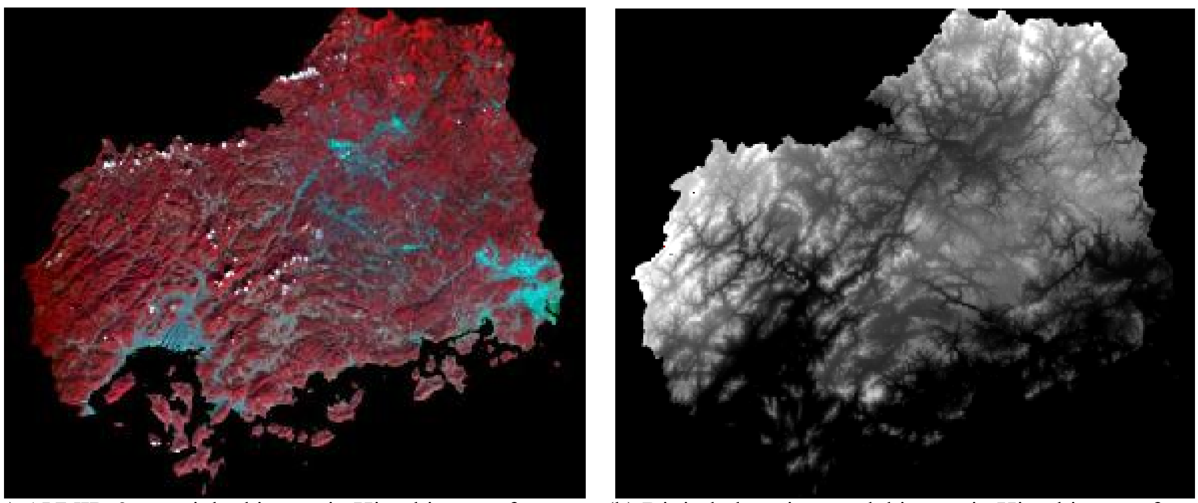


Figure 1: Location of the test site.



(a) AVNIR-2 mosaicked image in Hiroshima prefecture. (b) Digital elevation model image in Hiroshima prefecture.

Figure 2: Used data set in the test site.

3. WARNING SYSTEM FOR LANDSLIDE DISASTER

3.1 Warning system for landslide disaster

Figure 3 shows a concept of warning system for landslide disaster. The prediction algorithm of landslide using land cover information and geographical features acquired from satellite data was examined (Suga, 2003). In addition, we attempted to integrate with localized torrential rainfall by means of X band MP radar data for producing and providing a quasi-real time landslide hazard estimation map through a warning system proposed by this study.

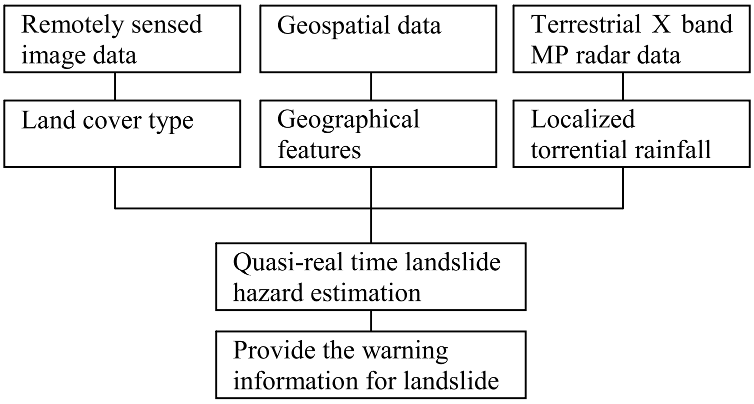


Figure 3: A concept of warning system for landslide disaster.

3.2 Hazard estimation of landslide

Following two elements are adopted for the hazard estimation of mass movement:

The discharge of slope flow caused by rainfall,

The time required for the flow reaching stable.

We call these elements 'discharge of slope flow' and 'attainment time'. Here, we calculate these elements at every pixel using satellite image and geographical data according to kinematic wave method.

In kinematic wave method based on the equation of motion and continuity in slope flow, a foundation equation to calculate slope flow in a unit width is defined as follows:

$$h = kq^p \tag{1}$$

$$\partial h / \partial t + \partial q / \partial x = r \tag{2}$$

where, x is distance from the top of slope, h is water depth, q is discharge of slope flow in an unit width, r is effective intensity of rainfall, k and p are constants derived from equivalent roughness coefficient and gradient pitch.

Manning formula is experimentally often used:

$$k = (N / \sqrt{\sin\theta})^{0.6} \tag{3}$$

where, N is equivalent roughness coefficient, θ is gradient pitch.

The discharge of slope flow q when the flow reaches stable under the constant rainfall depth is computed as follows:

$$q = \sum k\Delta x = r\sum \Delta x \propto \sum \Delta x \tag{4}$$

In case of satellite data, Δx corresponds to the distance of each pixel. Here, for simplification, the number of pixels which are equal to the area of upper basin is represented as discharge of slope flow.

The time t until the slope flow reaches stable under constant rainfall depth is computed as the maximum value of $\sum k\Delta x$ along every stream under the linear assumption that p=1. Δx is a distance of each pixel and can be assumed to be a constant value, so that the necessary time t is computed as by following equation:

$$t = \sum k\Delta x = \Delta x \sum k. \tag{5}$$

k is a constant value at each pixel and $\sum$ is done along the stream. In case of satellite data, the time at each pixel is computed as the maximum value of $\sum k$ along every stream flowing into the object pixel. In this paper, the attainment time at each pixel is set as the mean of constant k over all pixels within the upstream for simplification. In generally, the hazard ranking of landslide is higher in more discharge and in shorter on the attainment time.

Hazard estimation map was produced by using DEM and land cover information derived from ALOS/AVNIR-2. It can be defined that the danger of devastation is high as much as there are large amounts of discharge by rainfall and attainment time is short. Both parameters are ranked into six-step (1 to 6) degree of hazard ranking, respectively. Then, hazard estimation map is produced according to the summation of two-dimensional matrix that is defined as the degree of hazard ranking from 1 to 6, respectively.

Here, we confirmed effectiveness of the hazard estimation map in Syobara-city as a test site where is located the middle part of Hiroshima prefecture. Actually, this site was damaged by landslides devastation due to regional heavy rain. The damaged area is only about 5 × 5 km in mountainous region. Figure 4 shows the landslide hazard estimation map covered with damaged area in Syobara-city. The area of hazard ranking more than rank of 8 is roughly covered with the damage area. This shows that the landslide hazard estimation map successfully forecast the hazard area. However, landslides were not occurred in all area of higher hazard ranking. Therefore, other parameter data is necessary for the warning system such as exact rainfall information.

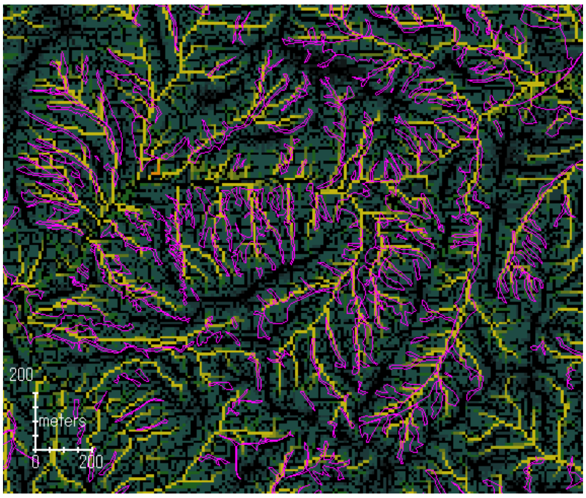


Figure 4: Landslide hazard estimation map covered with damaged area in Syobara-city.

3.3 Composition of landslide hazard estimation map and X band MP radar rainfall data

The authors are developing a warning system for landslide disaster combined with remotely sensed image and geospatial data and terrestrial X band MP radar data. The landslide hazard estimation map was generated as mentioned in section 3.2. And, it is possible to update the hazard estimation map using satellite data for the latest situation of object area. The composite image using landslide hazard estimation map and X band MP radar rainfall data is generated in every 5 minutes. The radar system generates rainfall image color coded with 250m grid size in every minute for detecting the quite localized torrential rainfall as shown in Figure 5. The composite image shows complementary hazard information at the quasi-real time operation. We have examined the generation of the composite image which will quickly support people and public officers who are on the lookout for landslide damaged site. We are able to produce the new type of landslide hazard information at quasi-real time combined with landslide hazard estimation map and terrestrial X band MP radar data proposed in this study.

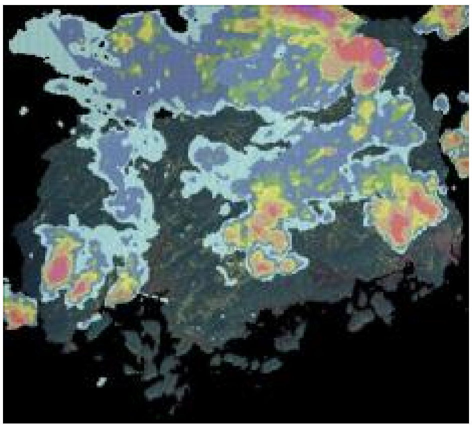


Figure 5: Composite image of landslide hazard estimation map covered with precipitation in Hiroshima prefecture.

3.4 Development of 3-D viewing system for the disaster monitoring

For further research, we have attempted a development of user-friendly 3-D viewing system to apply disaster and environmental monitoring (Suga, et al., 2012). This 3-D viewing system has a capability of the bird's eyes viewing by using satellite image, aerial image data and DEM dataset, and combining with 3-D X band MP radar data, in addition, geographical features can be calculated and analyzed on the 3-D viewer such as the distance, the height of selected points, the area of interest, the cross section drawing, and the estimation of disaster damaged area including landscape viewing and image layer construction using a mobile personal computer with interactive operations.

In this study, we produced 3-D image from the raw data of X band MP radar. The radar observation consists of 15 elevation angles from 0.29° to 20.00° with 80 km range in 5 minute. Consequently, the 3-D image of horizontal polarization received power at two radar sites is able to be integrated on the screen. Figure 6 shows the 3-D composite image of 3-D X band MP radar data and LANDSAT-7 image data in Hiroshima prefecture. It is useful as a warning information to confirm the landslide hazard site according to the 3-D composite image proposed in this study.

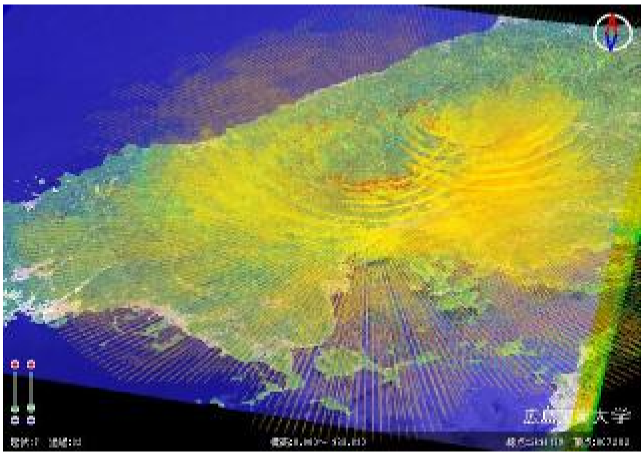


Figure 6: 3-D composite image of 3-D X band MP radar data and LANDSAT-7 image data (Hiroshima prefecture)

4. CONCLUSION

This study performed the development of a warning system for landslide disaster combined with remotely sensed image and geospatial data and terrestrial X band MP radar data. At this time, a landslide hazard estimation map was developed using remotely sensed image and geospatial data. We examined a visual inspection between the landslide hazard estimation map and the existing landslide disaster in Syobara-city. And, we generate a composite image using landslide hazard estimation map and X-band MP radar rainfall data in every 5 minutes. In future work, we attempt a development of a warning system set real time rainfall data into landslide estimation model for a real time disaster response.

Acknowledgement

This study was conducted as a part of Strategic Research Infra-structure Construction Project in Hiroshima Institute of Technology, entitled on "Generation of time-spatial image information using earth observation satellite remote sensing", supported by the Ministry of Education, Culture, Sports, Science and Technology, Japan.

X band MP radar were provided by Ministry of Land, Infrastructure, Transport and Tourism (MLIT) based on the Social experiments on the validation campaign.

ALOS data used in this study were provided through AUIG (Alos UserInterface Gateway) based on the contract with JAXA.

References

Suga, Y., Takeuchi, S., Yamada, K. and Ogawa, H., 2003. A construction of satellite image transmission for environmental and Disaster monitoring. Proc. of AIAA International Communications Satellite Systems Conference (ICSSC), Vol. 2253, pp. 1-14.

Suga, Y., Kawano, M. and Konishi, T., 2008. Detection of landslide damaged area using earth observation satellite. Proc. of the 63th Annual Conference of the Japan Society of Civil Engineers, pp. 445-446 (in Japanese).

Suga, Y., Konishi, T. and Matsumura, R., 2012. Investigation of landslide using optical and microwave satellite data. Proc. of the 67th Annual Conference of the Japan Society of Civil Engineers, IV-050, pp. 99-100 (in Japanese).

Suga, Y., et al, 2012. Geospatial experience by Ganmi 3D, Geo-fest organized by GSI in Geospatial EXPO 2012.

Ministry of Land, Infrastructure and Transport Japan (MLIT), 2012. Social experiments on the validation campaign of X band MP radar data for its application.