

ESTIMATING DIKE ELEVATION FROM MUTLI-TEMPORAL SAR IMAGES FOR EFFICIENT DIKE MANAGEMENT

Takaya Kusakabe¹, Junichi Susaki¹, Takuma Anahara²

1: Graduate School of Engineering, Kyoto University,
C1-1-206, Kyotodaigakukatsura, Nishikyo-ku, Kyoto, 615-8540, Japan
kusakabe.takaya.47c@st.kyoto-u.ac.jp, susaki.junichi.3r@kyoto-u.ac.jp

2: Earth Observation Research Center (EORC), Japan Aerospace Exploration Agency (JAXA),
2-1-1 Sengen, Tsukuba, Ibaraki 305-8505, Japan, anahara.takuma@jaxa.jp

ABSTRACT

In Japan, dikes along rivers are legislated to be managed by periodically conducting survey every 200 m interval. Because Japan has so many dikes to be surveyed, it is expected to develop an efficient survey approach. In this paper, we present the results and their accuracy of the dike elevation estimated from multi-temporal Synthetic Aperture Radar (SAR) images. First, we calculated the displacement along the radar line-of-sight (LOS) direction by implementing Permanent Scatterers Interferometry (PSI) to SAR images observed on ascending and descending orbits. Then, we applied the least square method to those results, and estimated the east-west and vertical displacement velocities by assuming that no north-south displacement occurred. Finally, we multiplied it with the period, and obtained the elevation by adding the initial elevation at a certain date. The experimental results demonstrated that the root mean squared error (RMSE) of the elevation on the crown of the dike was 5.3 cm whereas that on the slope of the dike was more than 25 cm. It is concluded that the presented approach is effective for monitoring the dike crown, and it is expected to improve the accuracy of the elevation of the dike slope.

Index Terms— Synthetic aperture radar (SAR), dike displacement monitoring, multi-temporal SAR image analysis, PSInSAR

1. INTRODUCTION

Recently, Japan is facing the issue of efficiently maintaining a huge amount of aging infrastructure, e.g. road, bridge and dam in a cost-effective manner. In this research, we focus on management of river dike and the survey. According to the regulation by The Ministry of Land, Infrastructure and Transport, the periodical survey is required for the river dike management. Fig. 1 represents the geolocations of the survey with Global Positioning System (GPS) on the dikes along Maruyama River in Toyooka, Hyogo, Japan. The survey follows the regulation that points along the dike every 200 m should be monitored. However, such sparse points may miss the serious displacement of the dike. Instead, airborne laser scanning

can increase points of surveying and cover the area of interest. However, it is highly costly, and thus the periodical update of the survey data is quite difficult.

Satellite-borne synthetic aperture radar (SAR) can observe a wide area within a very short time and provide the data with a high spatial resolution periodically. In addition, differential interferometric SAR (DInSAR) technique is widely known as wide range of land displacement measurement method. As one of the most effective algorithm, Permanent Scatterers Interferometry (PSI) [1][2] has been reported to measure land displacement from multi-temporal SAR images.

In this paper, we examine the feasibility of PSInSAR technique for estimating the elevation of dike instead of the traditional survey, and present the accuracy obtained by applying the presented technique. Hereafter, Section 2 explains the method presented in this paper, and Section 3 describes the study area and data used in the experiment. Section 4 reports the experimental results. After Section 5 discuss the obtained results and the limitation, we conclude this paper in Section 6.

2. METHOD

PSInSAR is a method to select PSs that are phase-stable pixels by using multiple SAR images, reduce the main errors caused by atmosphere, Digital Elevation Model (DEM), and so on and calculate the deformation of PSs in the radar line-of-sight (LOS) direction accurately [1][2]. Most of PSs include artificial structure. In this research, our interest is within the river dike monitoring, and we assume that the crown is paved and the slope is covered with vegetation. Therefore, the area to be analyzed has much less artificial structure, accordingly much less PSs than urban areas. For solving the problem, we used Distributed Scatterers (DS) [3][4]. DS is a kind of virtual scatterer that includes homogeneous areas. By taking average of the signal, the phase noise of DS can be reduced [5]. So we can consider DSs as PSs. This is how to calculate deformation of selected pixels in LOS direction.

In this research, we used Anatis, i.e. a software of PSInSAR developed by Earth Observation Research Center (EORC), Japan Aerospace eXploration Agency (JAXA) [6]. Anatis calculates the displacement velocity

from multi-temporal SAR images. Users can select the one-dimensional (1-D) displacement along LOS or the two-dimensional (2-D) displacement by combining the 1-D displacements from SAR images on ascending and descending orbits. The displacement velocity in LOS direction estimated by Anatis can be showed as follows:

$$V_{ps} = V_{ps}^e \cdot u_e + V_{ps}^n \cdot u_n + V_{ps}^u \cdot u_u \quad (1)$$

where V_{ps} is the estimated displacement velocity of PS in LOS direction, V_{ps}^e, V_{ps}^n and V_{ps}^u are unknown components of the velocity in east-west, north-south and vertical direction, u_e, u_n and u_u are unit vectors pointing from a PS toward the satellite. If we solve the equation (1) in a condition that $V_{ps}^e, V_{ps}^n = 0$, we can estimate vertical velocity V_{ps}^u . We call this 1-D analysis.

SAR images are observed on ascending and descending orbit, so we can also solve the equation as follows

$$\begin{bmatrix} V_{ps}^{ASC} \\ V_{ps}^{DES} \end{bmatrix} = \begin{bmatrix} u_E^{ASC} & u_N^{ASC} & u_U^{ASC} \\ u_E^{DES} & u_N^{DES} & u_U^{DES} \end{bmatrix} \cdot \begin{bmatrix} V_{ps}^E \\ V_{ps}^N \\ V_{ps}^U \end{bmatrix} \quad (2)$$

where V_{ps}^{ASC} and V_{ps}^{DES} are the estimated displacement velocity of PS in ascending and descending LOS direction, V_{ps}^E, V_{ps}^N and V_{ps}^U are unknown components of the velocity in east-west, north-south and vertical direction, u_E^{ASC}, u_E^{DES} and u_U^{ASC} are unit vectors pointing from a PS toward the satellite on ascending orbit, u_E^{DES}, u_E^{DES} and u_U^{DES} are unit vectors pointing from a PS toward the satellite on descending orbit. If we solve the equation (2) by LS method in a condition that $V_{ps}^n = 0$, we can estimate velocities in vertical and the direction of east-west. The reason why we solve it in a condition that $V_{ps}^n = 0$ is that PSInSAR cannot observe the displacement in north-south direction. We call this 2-D analysis.

After estimating the displacement velocity, we estimate the elevation as follows

$$\begin{aligned} \widehat{H}_2 &= H_1 + \Delta H \\ \Delta H &= V_{ps}^U \cdot (t_2 - t_1) \end{aligned} \quad (3)$$

where $\widehat{H}_2$ is an estimated elevation, H_1 is the known elevation, V_{ps}^U is the vertical displacement velocity estimated, t_1, t_2 are points of time.

3. STUDY AREA AND DATA USED

In this research, we focused on the dike along Maruyama River in Toyooka, Hyogo, Japan. The crown is paved and the slope is covered with vegetation. This means that there is difference of scattering between the crown and the slope. To assess the accuracy of the estimates separately, we split the dike to the crown and slope by delineating the boundaries of each region.

We used 21 Advanced Land Observing Satellite (ALOS2) / Phased Array type L-band SAR (PALSAR2) level 1.1 (L1.1) images observed from June 2015 to March 2018 on ascending orbit and 24 ALOS2 / PALSAR2 images during the same period on descending orbit. We also used the 10 m grid DEM published by Geographical Survey Institute (GSI) to remove the effect of topography.

Because LiDAR data observed in 2009 and 2015 were available, we used the LiDAR data in 2009 as the initial elevation data. For validation, we used the LiDAR data in 2015.

4. RESULTS

We estimated the displacement velocity of dikes from 2009 to 2015 by 2-D analysis. We calculated the displacement by multiplying the velocity with the period and estimated the elevation by adding the initial elevation from the LiDAR data observed in 2009. The estimated elevation was assessed with the elevation from LiDAR observed in 2015.

Fig. 2(a) shows the vertical displacement of the crown estimated by 2-D analysis. Fig. 2(b) represents the vertical displacement of the crown calculated by subtracting the elevation data observed by LiDAR in 2009 from that in 2015. Fig. 3(a) shows the vertical displacement of the slope estimated by 2-D analysis. In the same manner, Fig. 3(b) shows the vertical displacement of the slope calculated by subtracting the elevation data observed by LiDAR in 2009 from that in 2015. In Fig. 2 and Fig. 3, positive and negative values of ΔH indicate uplift and subsidence of the dike, respectively. Finally, we estimated the elevation of the crown and slope by 2-D analysis. They are shown in Fig. 4(a) and 4(b). The root mean squared errors (RMSEs) for the crown and slope were 5.3 cm and 26.1 cm, respectively.

5. DISCUSSION

Here, we discuss the difference of the accuracy between the crown and slope of the dike. As for the crown, most of the estimates of the displacement velocity are consistent with the LiDAR data. However, we observed inconsistency in some areas shown in Fig. 2(a) and (b). For example, the subsidence estimated by 2-D analysis in the right crown in the north is more than 12 cm, but that derived from LiDAR data is approximately 4 cm. It may be due to the difference of period of the observations; SAR images were observed from 2015 to 2018, but LiDAR observed the elevation in 2009 and 2015 influences the results.

On the other hand, the results of the slope of dike are not the case. For the reason, we have to pay attention to Fig. 3(b). The displacement is random, and this indicates that the LiDAR data in the slope may not be as accurate as that in the crown part. One of the reasons is that LiDAR uses shorter wavelength than SAR, and thus the vegetation prevented the wave from reaching ground. The result

observed by LiDAR includes the noise by vegetation covers the slope. Another reason why the displacement by 2-D analysis isn't same as by LiDAR that we consider DS for PS. We average the interference signals of one DS and DSs surrounding it. So, maybe the result of 2-D analysis is more accurate than LiDAR.

In Japan, Ministry of Land, Infrastructure and Transport regulates the accuracy limit for the river dike survey, and not more than 25 cm of error is required. In this regard, the RMSE for the crown, i.e. 5.3 cm, is acceptable. Therefore, the approach presented in this research is executable for the operational survey. However, the RMSE for the slope, i.e. 26.1 cm, is not acceptable. As mentioned above, this accuracy may depend on the error of the LiDAR data. As a result, further investigation is desirable for operational use of multi-temporal SAR images for dike management.

6. CONCLUSION

In this research, we estimated the elevation of dike by 2-D analysis, using PSInSAR. We demonstrated that we can achieve a higher spatial resolution than GPS survey and can save the cost compared to airborne LiDAR. It was found that the accuracy of the estimates in the crown are acceptable. However, the accuracy of the estimates in the slope is larger than the public limit. Because this may depend on the validation data, we need further investigation in future.

7. REFERENCE

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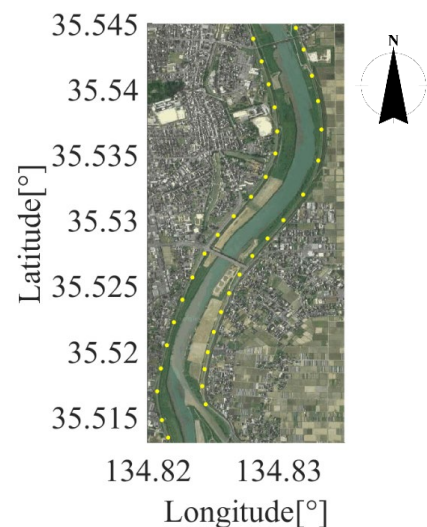


Fig.1 Study area. The yellow points represent GPS location.

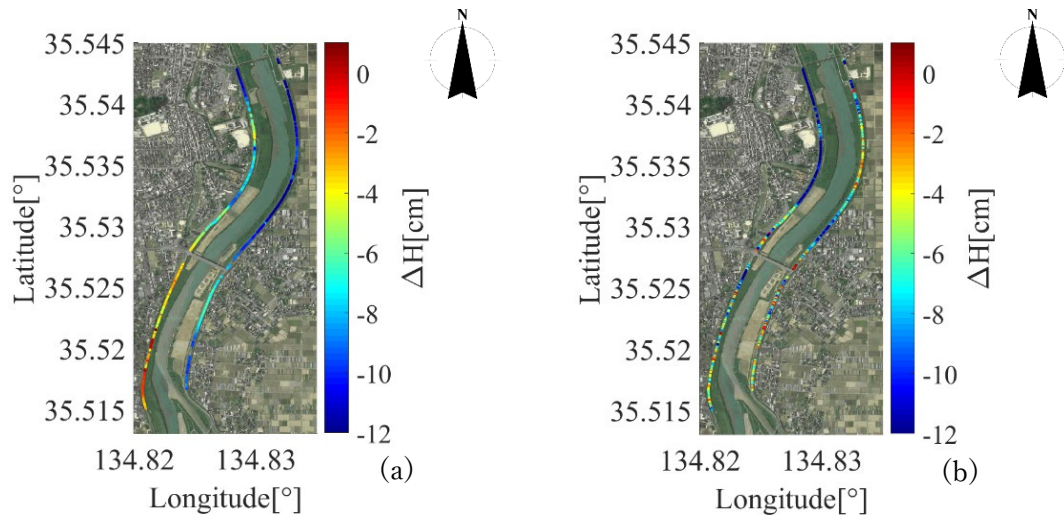


Fig. 2 Vertical deformation of crown. (a) Estimated by 2-Danalysis, and (b) estimated by LiDAR

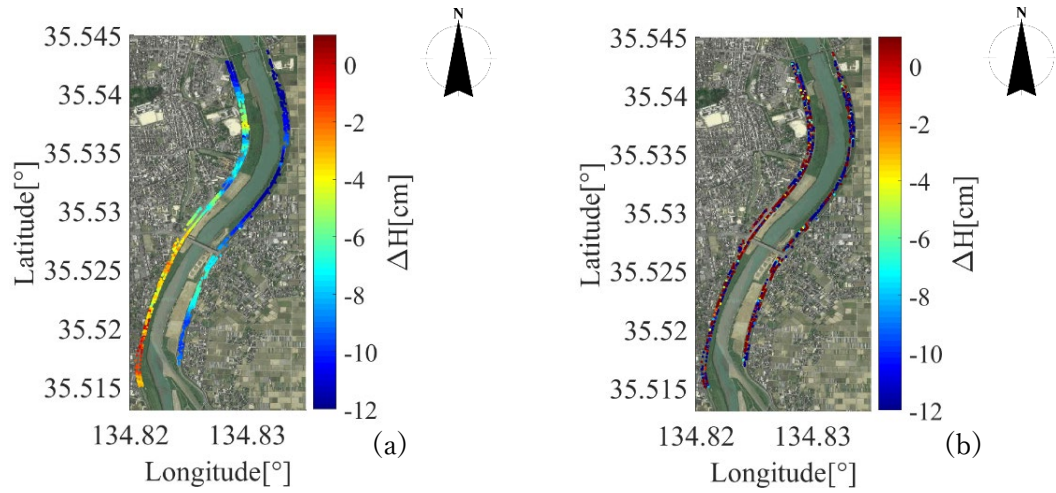


Fig. 3 Vertical deformation of slope. (a) Estimated by 2-Danalysis, and (b) estimated by LiDAR

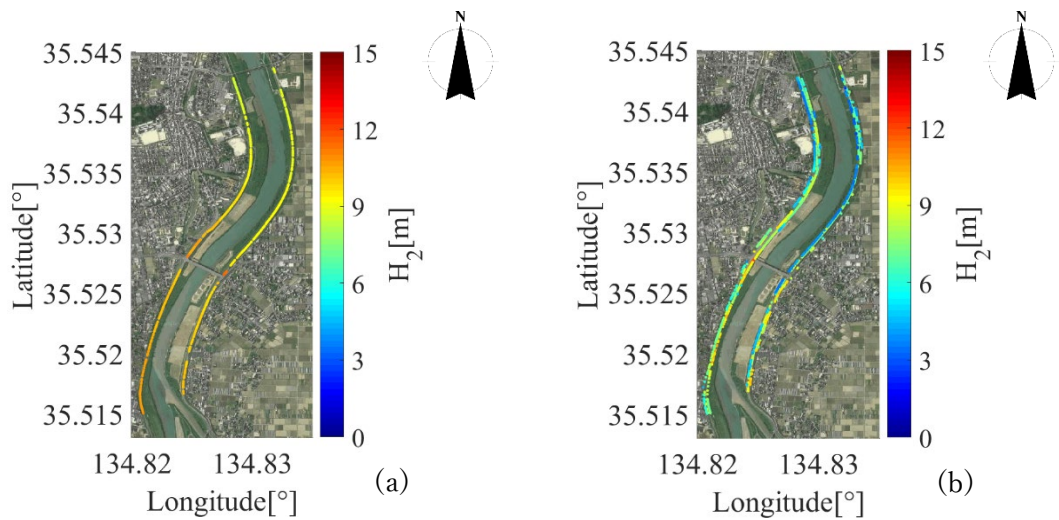


Fig. 4 Elevation obtained by 2-D analysis. (a) Crown, and (b) slope