Taikichiro Mori Memorial Research Grants Graduate Student Researcher Development Grant Report

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Research Project: Detection and delineation of water bodies using Synthetic Aperture Radar data

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In recent years, water availability has become high-profile national and global issue. The importance of fresh water is reflected in the decision of the United Nations General Assembly to proclaim the year 2003 as the International Year of Freshwater. Water bodies like man-made reservoirs, lakes, ponds, etc. are key tools for the management of water resources. Even though these water bodies constitute a relatively small portion of the total available water on the Earth surface, they are important freshwater features because they are main resources for drinking water. Accurate information on the extent of water bodies is important for flood prediction, monitoring, and relief. So, management and monitoring water bodies is worthwhile in many aspects considering that the number of water storage constructions is growing, Chao reports a total of more than 33,000 large dams are included in the World Register of Dams. In spite of this large number of reservoirs consistent observations of reservoir storage are limited mostly to developed countries and even there the records are often difficult to access due to difficult accessibility of reservoirs, high cost of recording data and time consuming. Satellite remote sensing images, which can be used for rapid and accurate extraction of water information, have become important mean of detecting water resources.

Remote sensing technology provides advanced technical means for detecting the spatial distribution of water bodies, monitoring them and extracting other information. It overcomes many shortcomings of traditional ground based surveys, such as high cost, time-consuming and influence of many other unknown factors in the field. Synthetic aperture radar (SAR) satellite offer the most reliable data stream for monitoring water bodies, because they are independent of cloud and smoke cover, able to operate day and night, and not subject to sun glint.

Moreover, only microwave sensors enable consistent detection through clouds, and with some limitations, through rainfall.

While SAR images are widely used for water detection and monitoring, surface water mapping studies have been limited to specific areas and have often been user intensive. For example, Annor used SAR images for delineation and monitoring of small reservoirs in Ghana, or that monitors changes in surface water dynamics in the Yukon Flats region of east central Alaska. Developing a general algorithm for detection and monitoring surface water which will be applicable for different water bodies with different sizes and characteristic can improve using of SAR data and their applicability. A contextual pixel based algorithm introduced by E. Goumehei where applied Support Vector Machine instead of Maximum Likelihood Classification to improve SAR images classification results. This algorithm provided good results that can be used for water detection as well, where using a smoothness parameter also can help to regulate algorithm for different water bodies.

Figure 1: Sarab_Niloofar Kermanshah, Iran in normal situation after precipitation.

Figure 2: Saran_Niloofar, Kermanshah, Iran in dry season when the pond dried up.

There are several studies which used SAR data from different sensors for water detection and monitoring. Hahmann used high resolution TerraSAR-X data to delineate land and water boundaries with semi-automatic models. Also, Brisco presents a semi-automated tool for mapping surface water with RADARSAT-1 data and provides results of monitoring seasonal and annual changes in surface water distribution using RADARSAT-1 imagery. ENVISAT ASAR images were considered too for delineation of small reservoirs in a semi-arid environment by Eilander. In case of ALOS-PALSAR images, Evans applied ALOS-PALSAR imageries to monitor the spatial and temporal dynamics to create spatial-temporal maps of flood dynamics in the Brazilian Pantanal. An object-based image analysis (OBIA) classification was defined for four classes including open water class with accuracy results of 81%.

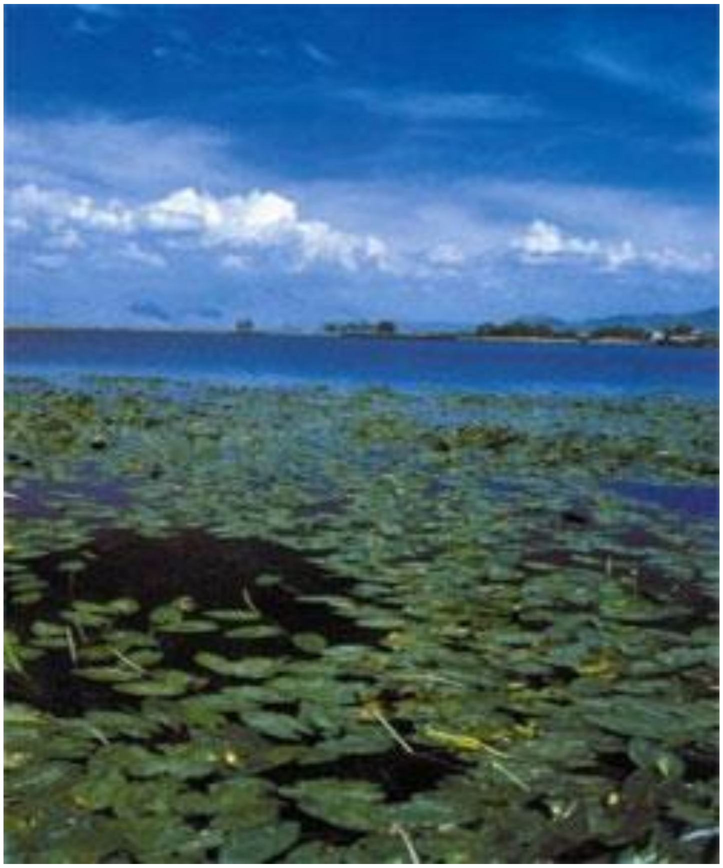

Figure 3: Sarab_Niloofar Kermanshah with reeds on the surface of the pond

Considering methods used for water extraction from SAR images, many researches used pixel based approach for image classification. A traditional pixel-based approach (global threshold) was used for water surface detection by Heine, Francke where a threshold for assigning a pixel to a water or non-water class based on its value. The validation of the threshold classification indicates a regular and significant underestimation of the reservoir area compared with GPS in situ measurements. The results of analysis for a quasi-continuous monitoring of differently sized reservoirs are promising, but the study recommends the acquisition of additional data like combination of SAR and optical imagery and a high-resolution DEM to improve the classification results by reducing misclassifications. Eilander use a Bayesian approach for monitoring small reservoirs with radar satellite images. The newly developed growing Bayesian classifier has a high degree of automation and reduces the confusion error to the land-water boundary pixels. The newly developed growing Bayesian classifier (gBC) classifies a pixel based on the maximum a posteriori probability (MAP), which is calculated from a multivariate Gaussian likelihood function, multiplied by one or more conditional priors. The newly developed model is able to delineate open water throughout the dry season with high accuracy.

The detection of surface water on radar images is usually described as a simple task. Smooth water surfaces act as specular reflectors and reflect most of the incoming radar signal away from the sensor. This is equivalent to very low radar backscatter signal returning to the sensor, which makes surface water bodies usually appear dark on radar images. This, however, is an oversimplification, as the surface roughness of water bodies is very variable, both spatially, within a water body, and temporally, leading to a wide range of backscatter. As will be shown here, this variability in backscatter can greatly affect the operational value of radar images for monitoring of small reservoirs. It is necessary to understand in some detail how contrast in backscatter between open water and surrounding land surface changes as a function of wind speed and direction, and vegetation density.

Wind-induced regularly spaced waves and ripples can lead to Bragg scattering, which results in elevated backscatter signals from the water surface. While wave crests oriented orthogonally to the look direction can produce Bragg scattering, wave crests oriented in line with the look direction may have no significant effect on the radar backscatter. The threshold wind speed value causing Bragg scattering in C-band is estimated to be at $\sim 3.3 \text{ m} \cdot \text{s}^{-1}$ at 10 m above the surface. This corresponds to a wind speed of $2.6 \text{ m} \cdot \text{s}^{-1}$ at 2 m, using Sutton's equation for wind speed profiles.

Figure 4: study area in ALOS 1 PALSAR data

Literature on open water delineation focuses on flood detection and presents various methods. Henderson presented a study on the extraction of lakes from X-band radar in different environments, using manual interpretation to allow the inclusion of context and other interpretation clues in the analysis. Barber and Brakenridge visually interpret flood extents for the 1993 Assiniboine River flood in Manitoba, Canada, and the 1993 Mississippi River flood, respectively. Henry use band thresholds to classify inundated areas of the 2002 Elbe river flood. Likewise, Brivio map the extent of the flooded areas of the 1994 flood in the Regione Piemonte, Italy, based on visual interpretation and band thresholds. Giesen mapped flooding in a West

African floodplain during the dry and wet seasons with L- and C-band SIR images, distinguishing between open water and water with reeds. A study compares flood detection from amplitude change detection to coherence methods from multi pass SAR data. Horrit use a statistical active contour model to delineate flood boundaries, and Heremans compare flood delineation results from and active contour model to that of an object-oriented classification technique. Context is an important factor for the delineation of water bodies. The degree of accuracy that small water bodies can be extracted from the radar images largely depends on the land–water contrast. For a distinct land–water contrast, a low and coherent backscatter from the water body is desirable that stands in distinct contrast to its surroundings, ideally producing higher signal returns.

Due to the high dielectric constant of water, the penetration depth of the radar signal into the water and, hence, volume scattering and depolarization is low. Reflections off of the water surface are thus predominantly like-polarized. The return from the water bodies in the HV band is therefore expected to be low. Tall reeds growing on the sides of the reservoirs during the rainy season can act as corner reflectors, which lead to high backscatter signals in radar images due to double bounces which can also partially depolarize the radar signal. In the radar image, this accentuates the land–water boundary and facilitates its detection. In the HH band, water bodies can also be classified well when the water surface acts as a specular reflector, i.e., ideally under calm conditions. The vast portion of the radar burst is then scattered away from the sensor, leaving the water body to appear dark in the image. Under windy conditions, however, a rough water surface reflects more of the incoming radar signal back to the sensor. These elevated returns under windy conditions, particularly in the like-polarized bands, are again due to the high dielectric constant of water. As wind speeds are not always uniform over the entire water body, elevated backscatter can occur in patches or affect larger parts of the reservoir. Although elevated backscatter from the water surface is detrimental to its classification in most cases, it can also be seen as a signal typical for water bodies, which can be helpful in classifying reservoirs.

Images acquired in dual-polarization mode can therefore provide further clues for the land–water separation. In general, like-polarized images have a better overall image contrast, but VV is affected much more by Bragg scattering relative to the HH and HV response.