The Potential of Satellite SAR Imagery for Mapping of Flood Inundation

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Abstract

To assess the flood damages and to provide necessary information for preventing future catastrophe, it is necessary to appraise the inundated area with more accurate and rapid manner. This study attempts to evaluate the potential of satellite synthetic aperture radar (SAR) data for mapping of flood inundated area in southern part of Korea. JERS L-band SAR data obtained during the summer of 1997 were used to delineate the inundated areas. In addition, Landsat TM data were also used for analyzing the land cover condition before the flooding. Once the two data sets were co-registered, each data was separately classified. The water surface areas extracted from the SAR data and the land cover map generated using the TM data were overlaid to determine the flood inundated areas. Although manual interpretation of water surfaces from the SAR image seems rather simple, the computer classification of water body requires clear understanding of radar backscattering behavior on the earth's surfaces. It was found that some surface features, such as rice fields, runaway, and tidal flat, have very similar radar backscatter to water surface. Even though satellite SAR data have a great advantage over optical remote sensor data for obtaining imagery on time and would provide valuable information to analyze flood, it should be cautious to separate the exact areas of flood inundation from the similar features.

Introduction

Flood is a major natural disaster in Korean Peninsula, that causes enormous amount of property damages and human lives. Flood mapping, which provides valuable information for the damage assessment and the future efforts to prevent such disaster. Mapping of flood inundated and susceptible areas has been mainly relied on ground survey, which is not very effective from the aspects of cost, time and accuracy. Remote sensing can be an attractive tool to appraise and monitor flood inundated area by providing a synoptic view over the area. In early years, Landsat imagery have shown the potential to map the distribution of flood-inundated area in different regions (Phillipson and Hafker, 1981; Robinove, 1978; Williamson, 1974; Rango and Salomonson, 1974).

Although optical remote sensor data can be effectively used for flood-inundation mapping, it has a major drawback in obtaining necessary imagery on time. In general, the cloud condition during the flooding obscures the inundated area and makes it difficult to acquire good quality imagery even though the satellite orbit pass matches with the flooding time. Active microwave remote sensor data can be an alternative to overcome such problem in data acquisition. In recent years, several satellite-based imaging radar data have been available and the use of synthetic aperture radar (SAR) data is expected to increase for diverse applications. Imaging radar systems have many unique characteristics, including the ability to obtain earth resource data when the ground is obscured by clouds, or to obtain data at any time of day or night. The objective of this study is to test the potential of spaceborne synthetic aperture radar (SAR) data for mapping of flood inundated area. The characteristics and analysis procedure of SAR data are main topics to be discussed in the application of flood mapping case.

Study Area and Data Used

To identify and map the flood inundated area, it is critical to obtain a proper imagery at the time of inundation. The study area was selected by examining the data archives of satellite SAR data that corresponds to the time of flood-induced heavy rainfall during the summer of 1997. The closest combination between SAR data acquisition and rainfall was found near Chinju in southern part of Korea. The annual precipitation in this region is higher than the other part of the country and, therefore, this region has been frequently flooded. The precipitation in Chinju was about 150 mm during the three days before the SAR data acquisition on July 18th. Although there was no official flood damages reported with this amount of rainfall, it was expected that some places like sand bar and floodplain within stream banks and rice paddies in low region might be inundated by the increased water level. As can be seen in Figure 1, there was a continuing rainfall in July, which actually raised the water level significantly.

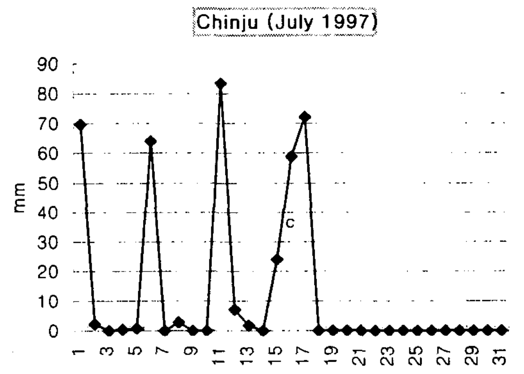

Figure 1. Precipitation during the July of 1997 in Chinju

The remote sensor data used for the study were JERS SAR and Landsat thematic mapper (TM) imagery (Table 1). The L-band SAR data were obtained on July 18, 1997 by the JERS satellite and would be used for the delineation of water surfaces. JERS SAR data received at the ground station in Korea consisted of HH-polarized, L-band wavelength, obtained at incidence angle of 35°. Figure 2 shows the SAR imagery for the selected study area. It covers approximately an area of 40x40km^2 and includes Chinju, Hadong, Sanchung in southern Kyungsang province. In order to detect the correct areas of flood inundation and to analyze the previous state of flooded areas, the pre-flood condition of land cover should be known. Such information can normally be obtained from the existing land use maps. Since no recent land use maps were available for the study area, however, Landsat TM data obtained on June 1, 1994 were used to generate the land cover map of pre-flood time.

Table 1. Characteristics of satellite data used for the study.

satellite	sensor	data acquisition	wavelength	resolution	비고
JERS-1	SAR	July 18, 1997 (during flood)	single microwave band (L-band, 23㎝)	18m	HH polarization 35° incidence angle
Landsat-5	TM	June 1, 1994 (before flood)	7 optical bands (0.45 ~ 12.5 μm)	30m (120m)	

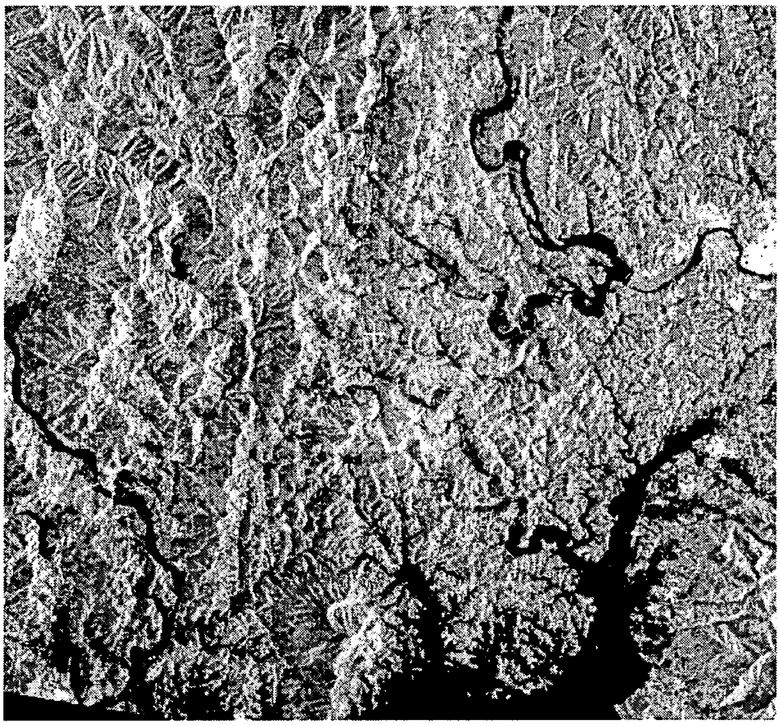

Figure 2. L-band SAR imagery acquired the day after heavy rainfall for the study area near Chinju.

Methods

The analysis procedure of flood inundation mapping applied in this study is very similar to the post-classification comparison method in digital change detection that has been one of the major applications in remote sensing era (Jensen, 1996). Post-classification comparison method is often used for the cases in which there is apparent distinction between two data sets to be compared. The difference could be seasonal, yearly, or both. In this study, the two data sets have more obvious distinction than just for temporal variation. Two data sets were obtained from quite different sensor systems, radar and optical sensors, so that they cannot be directly compared by other normal change detection methods such as image algebra. Figure 3 shows the data analysis procedure to map the flood inundation. Each of the SAR and TM data were independently classified to determine the land cover types before and after the flood. Once the water surface area was delineated from the 1997 SAR data, it was overlaid to the TM derived land cover maps to determine the actual areas of flood inundation.

Initially, the L-band SAR and TM data were geometrically corrected and registered together in a plane rectangular coordinate system with a same pixel spacing. Co-registration of the two data sets were performed by using a set of ground control points (GCP) that were identifiable on both image and topographic map. Unlike in the TM imagery, it was not quite obvious to identify GCP in the SAR imagery. Common target used for GCP was bridge that appears very brightly on SAR imagery due to the high backscattering by corner reflection. Precise geocoding of SAR image requires digital elevation model (DEM) data because of the inherent geometric distortions caused by topographic undulations (Guindon and Adair, 1993). Such geometric distortions are foreshortening, layover, and shadow and they are mostly found on slope areas in mountainous topography. Since the area of interest in this study, the flood inundation areas, are mostly found on relatively flat terrain in low elevation, it is believed that the precise geocoding of the SAR data is not necessary. The coordinate transformation using a set of GCP was enough to rectify and register the portion of flat areas in the SAR imagery.

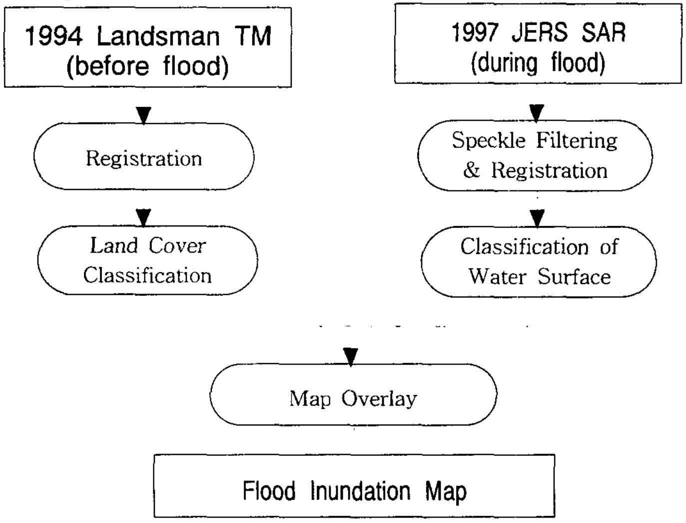

Figure 3. Process to determine flood inundated area using L-band SAR and Landsat TM data.

Speckle noise is one of the most distinct characteristics observed on SAR imagery and has been studied for many years to develop proper techniques to reduce speckles from the image. Speckle can be a major obstacle for analyzing the SAR data, particularly in digital processing such as computer classification. Among the earth surface features, water surface can be considered to be very homogeneous in terms of surface roughness and reflection pattern. If speckle effect is not significant, tone of water surface should be very uniform in SAR image and can be separated from other surface features. However, speckle noise is not usually target-dependent and it is randomly distributed throughout the image. To reduce speckle noise, the SAR data were filtered by using a spatial filter developed by Kuan (1987). This filtering algorithm has been known to be very effective for reducing speckles while maintaining the image sharpness.

Classification of the TM and SAR data have slightly different goals each other. The TM data were classified to obtain a land cover map of the pre-flood while the SAR data were used to capture only for the areas of water surface. These data sets were independently classified by a standard maximum likelihood classification algorithm. The number of cover type classes were minimal so as to increase the classification accuracy. By using topographic maps and field corrected data, several fields were delineated to get training statistics. The areas of water surfaces determined from the 1997 SAR data were then overlaid with the land cover map generated by the classification of the 1994 Landsat TM data. Overlaying the two maps enable us to define the exact location and size of inundated areas.

Results and Discussions

Figure 4 shows the co-registered SAR and TM images over a small portion of study area. Water surfaces, that appears dark, can be clearly seen on both the speckle filtered SAR image of

1997 and the TM image of the pre-flood. time. However, it is apparent that the size of water covered area in the SAR image is larger than the one in the TM image. Newly developed water surfaces in the SAR data are mostly found along the river, which appears bare soil or sand in TM image with bright tone. This area consists of mainly floodplain within stream banks and is not generally used for agriculture or other intensive land use practices although some areas in small terraces has been used for crop cultivation.

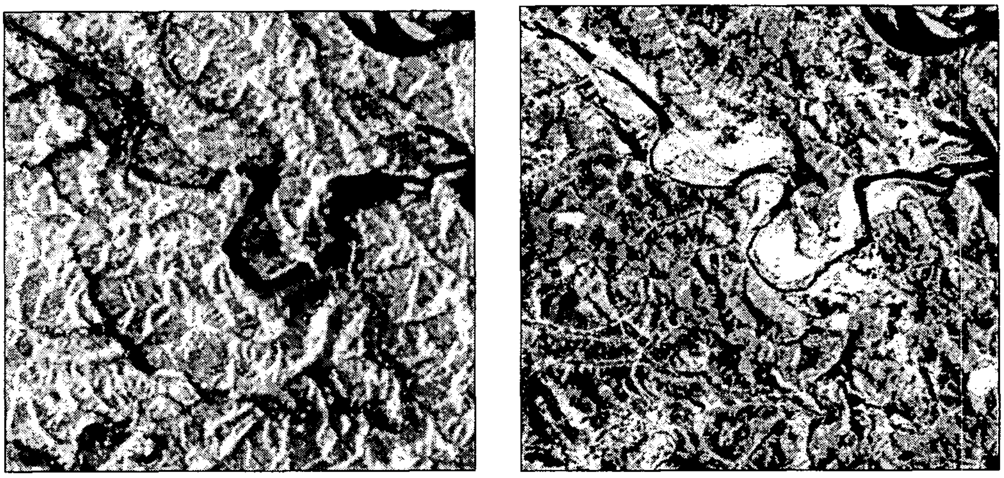

Figure 4. Comparison of water surfaces observed between SAR and TM imagery.

While the TM image shows the clear difference between water and other features, the SAR image has many features that look very similar to water in tonal value. Strength of reflected radar signal depends on basically surface roughness. Flat and smooth water surface behaves like mirror, in which the reflected radar wave is bouncing away from the antenna, so that the reflected radar signal is minimal. If a certain surface feature has very similar roughness to water, it should have similar backscattering behavior and appears like water. The dark areas that are similar to water in the SAR image turned out to be rice fields, playing ground, runaway, and tidal flat. Figure 5 shows the relative radar backscatter from the sample pixels of water and water-like features. The differences are not significant, particularly between water and rice fields.

During the growing season from June to August, rice field is well irrigated and, therefore, the ground is usually covered by water. After the heavy rainfall of the day before the SAR data acquisition, the ground water level would be even higher than normal season. Although the height of rice crop is approximately 30cm at the middle of July, it does not seem to have significant influences on radar backscattering. The JERS SAR data are obtained with L-band radar having a wavelength of 23.5cm, which is the longer than other satellite imaging radar system. It has been well known that the longer wavelength radar has a better penetration capability that can see through plant canopy. Probably, shorter wavelength SAR data, such as C-band RADARSAT, could have provided more contrast between water and rice fields. Separation of water surface from the other similar features was partially successful. In particular, the airport runaway have shown almost the same pixel values as water so that it was not well classified from water surfaces.

The overlay analysis between the SAR classified water surface and the TM classified land cover indicated that the total size of inundated areas was 2,412ha. Among the inundated areas, rice fields take the largest portion (1,332ha). The other flooded areas were bare soil and tidal flat. This type of inundation may not be indeed flooding and cannot be counted on official flood record

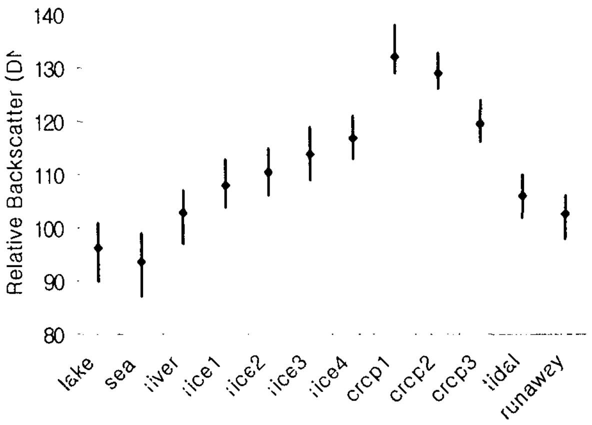

Figure 5. Relative radar backscatter from water surfaces and similar targets.

although the areas were truly covered by water. Even though it was difficult to determine the exact areas of flooded rice fields among the 1,322ha without reliable ground truth, certain portion of them might be considered as rice fields that were not completely flooded. These fields might have relatively short canopy with increased ground water level. It would be necessary to define the characteristics of radar backscatter of rice crop according to the growing stage and ground water level in order to correctly discriminate them from water surface.

Conclusions

It has been well known that water surface can be classified without much difficulty when using SAR data. Based on the analysis for mapping flood inundation using L-band SAR data and Landsat TM data, satellite radar imagery shows the potential to classify the inundated area by analyzing with Landsat TM imagery obtained before the flood. Although the study area near the Chinju did not have an official record of flood damages at the time of SAR data acquisition, the flooded sites (primarily tidal flat and sand bar within stream bank) identified were indeed covered by water. L-band SAR data have shown a partial success to discriminate certain cover types (runaway and rice field) from water surface. Therefore, it is crucial to choose appropriate SAR data that can provide a maximum separation between water surface from the targets having similar radar backscattering behavior. To be used for flood mapping, the radar imagery should be obtained at the time of flooding. With increased availability of imaging radar systems, satellite SAR data can be an effective alternative to monitor and analyze flood disaster on time.

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