Analysis of Forest Stand Heights Extracted from the Interferometric AIRSAR Data

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Abstract

The use of interferometric SAR data has been expanding to the estimation of the structural parameters of vegetation from the primary application of topographic mapping. This study attempts to analyze the characteristics of C-band interferometric SAR data for the estimation of the stand height at various forest types. The JPL AIRSAR data obtained during the PacRim 2000 mission were compared with the DEM data generated from the 1:5,000 scale topographic maps over the forested terrain in the southeastern part of Korean Peninsula. The forest stand heights estimated from the TOPSAR DEM data were then analyzed with the actual tree heights obtained by the ground measurements on the 78 sample stands. The discrepancies between the TOPSAR DEM and the actual tree height were analyzed by the stand characteristics.

1. Introduction

The increasing number of imaging radar systems have provided new approaches to retrieve information on the surface features of interest. Interferometric SAR (InSAR) system is one of such new tools that have a great potential to be used in many applications. The use of InSAR data has been primarily focused on the topographic mapping and the construction of digital elevation model (DEM) data since it was introduced (Graham, 1974; Gens and Van Genderen, 1996). In recent years, the applications of InSAR have expanded to the estimation of ecological parameters such as tree height, biomass, species, stand density, and stocking volume.

Interferometric SAR data have been analyzed in different ways to extract information on the vegetation structure. The first method to estimate the vegetation parameters has been the use of interferometric coherence, which is basically the correlation between two SAR images. In several studies, the coherence data were used to relate the vegetation parameters of crop heights (Engdahle et al., 2001), tree species and stem volume (Koskinen et al., 2001), and tree heights (Hagberg et al., 1995; Askne et al., 1997). The second method of using interferometric data was the direct interpretation of the elevation value of the DEM data derived from the two SAR images. Assuming that the height of the phase center of the radar scattering in canopy were directly related to the height and crown density of the vegetation, the elevation estimates of the interferometric SAR in forested terrain may reflect the structure of forest stand. The height of the phase center determined from the InSAR DEM was closely related to the actual tree heights that were estimated by the subtraction of the ground level elevation that is measured by ground positioning system (GPS) (Kobayashi et al., 2000). The height difference between InSAR DEM and the ground level elevation would be the height of forest stand, if the InSAR DEM is accurate and the scattering center is the top of the tree canopy.

This study is primarily related to the second method of using InSAR data in which the InSAR generated DEM data were compared with the ground level elevation for extracting tree heights. Although there have been a few studies of using InSAR image for the estimation of structural parameters of forest stands, it is only a beginning to understand the relationship between the stand height and InSAR measured elevation. The objectives of this study are to analyze the characteristics of the elevation values derived from the C-band InSAR data in forested area and to relate them with the stand height over various forest types.

2. Methods

2.1 Study area and ground measurements

To analyze the characteristics of InSAR derived DEM over forested terrain, we conducted an experiment during the Jet Propulsion Laboratory (JPL) AIRSAR mission of the Pacific Rim countries in 2000. The study area is located in Kyungsang Province of the southeastern part of Korean Peninsula and covers approximately 10x10km^2. Landscape of the area is mostly hilly terrain covered by forest. The forests in the study area are consisted of relatively young trees that are mostly less than 30 years old. Plantation and natural forests occupy about the same proportions. The plantation forest is mostly coniferous stands of pitch pine (*Pinus rigida*), Korean pine *(Pinus koraiensis),* and larch *(Larix leptolepis)* and partially mixed with some deciduous species like black locust (*Robinia pseudo-acacia*) and Manchurian alder (*Alnus hirsuta*). Although the natural forest has rather diverse group of coniferous and hardwood species, black pine (*Pinus thunbergii)* and Korean red pine *(Pinus densiflora)* are primary species of coniferous forest. The natural stands of deciduous forest are occupied by mostly oaks *(Quercus mongolica, Quercus serrata, Quercus dentata*).

Extensive ground measurements were conducted over the study sites during the fall of 2000 and 2001. The species, tree height, and diameter at breast height (DBH) were measured at the 78 sample stands. Each sample forest stand has an area of about a quarter hectare and has very homogeneous stand structure within it. The 78 sample stands were chosen to represent diverse group of forest types and tree size. The location of the sample stands was measured by using global positioning system (GPS). Although we tried to locate the exact coordinates of the sample stand by GPS, it was not always possible to use the GPS because of the lack of signals covered by the thick layer of tree canopy. In such cases, we located the sample site by inferring the 1:5,000 scale topographic map and the nearby open space where the GPS measurements were made.

In addition to the field measurements of the stand parameters, we used the forest stand map over the study area to collect and to verify the additional stand characteristics of the sample sites visited. The forest stand maps were produced by the national program of forest inventory and showed rather detailed information on the stand. Black-and-white aerial photographs are used to make the forest stand map. These aerial photographs were taken to have a scale of 1:15,000 and had adequate resolution to interpret the dominant species group as well as other stand characteristics such as stock density, tree height, and diameter (KFRI, 1999). Aerial photographs were initially interpreted by a group of very skillful and experienced analysts. During the interpretation, many sites were visited to verify the interpretation. After the photo-interpretation was finished, the results were transferred to the base map of 1:25,000 scale and digitized to build a thematic layer of geographic information system (GIS). The forest stand map of this area was made using 1998 aerial photographs and, therefore, we believed that it did not show much different stand condition from the InSAR image of 2000.

The TOPSAR data were acquired in XTI1P mode on September 30, 2000 during the PacRim 2000 mission (Table 1). Once the raw data were processed by JPL, we have received the DEM data processed from the C-band VV polarization interferometric data. Although there were other data sets, such as C-band VV power, correlation, incidence angle, and P-L-band polarization data, this study dealt with the DEM data only.

Table 1. Characteristics of JPL TOPSAR data (XTI1P) data used for the study.

Data acquisition date	September 30, 2000
Data acquisition time	17:40 in local time (08:40 GMT)
Flight altitude	8 km
Wavelength	C-band (5.6 cm wavelength, 5.3GHz)
Polarization	VV
Incidence angle range	28.2 – 64.1^{o}
Pixel spacing	5 m

2.2 Extraction of height difference

To analyze the heights of the scattering phase center from the TOPSAR DEM data and to relate them for the estimation of the stand heights, it is required to obtain the exact elevation of the ground level for the forest stand. For this purpose, we built the DEM data that represent the elevation of ground surface by using the 1:5,000 scale national topographic maps. The 1:5,000 topographic maps were constructed by photogrammetric technique and have been digitized by the Korean Geography Institute (KGI). The map has contour lines of 5m and 2.5m intervals and also includes many point elevation of benchmarks and triangulation reference points. Approximately 81 sheets of 1:5,000 topographic maps cover the whole study area. Once the contour lines and the elevation points were extracted from the each of the 81 digital maps, they were joined together. Interpolating the contours and elevation points has generated the grid type DEM data, which had the comparable pixel spacing with the TOPSAR image.

If the map-generated DEM is accurate enough to represent the ground elevation of the forest floor, the difference between the map-generated DEM and TOPSAR DEM would be the height of scattering phase center that is closely related to the tree height. We have generated the height-difference (ΔH) image that is a simple subtraction of TOPSAR DEM from the map-generated DEM.

$$\Delta H = DEM_{TOPSAR} - DEM_{map} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Initially, we interpreted and examined the height-difference (ΔH) values over several types of land covers to assess the relative accuracy of the TOPSAR DEM. After the verification of the TOPSAR DEM, we extracted the ΔH values from the 78 sample forest stands and compared with the actual tree heights measured on the ground.

3. Results and Discussions

It has been well known that C-band radar backscattering is mainly from the leaves and branches of the canopy layer. The height difference (ΔH) between the C-band TOPSAR DEM and the map-generated DEM could be used to infer the tree height if the InSAR DEM is accurate enough to represent the height of the phase center at the tree canopy. Figure 1 shows the actual image of the height difference (ΔH) of the study area along with the Landsat Thematic Mapper image of the same area. The image brightness is proportional to the magnitude of ΔH in which the flat surfaces like road and bare ground have relatively low values while the forests appears bright. Ideally, the ΔH should be zero at the flat bare ground where the InSAR DEM and map-generated DEM must be the same elevation. Figure 2 shows the actual values of the height difference (ΔH) extracted from the transact lines across the road, bare ground, and forests. The average values of ΔH are 0.9m and 1.2m for the road and the bare ground, which suggests that the JPL processed TOPSAR DEM is rather close to the true elevation at the non-forested surfaces. The average ΔH of the forests is 14.1m and 8.3m, which are significantly higher than the bare surfaces and such difference should have something to do with the tree height. Considering that the height difference is rather small at the non-forested bare ground, the large discrepancies between the TOPSAR DEM and the map-generated DEM should be used to estimate the forest stand heights.

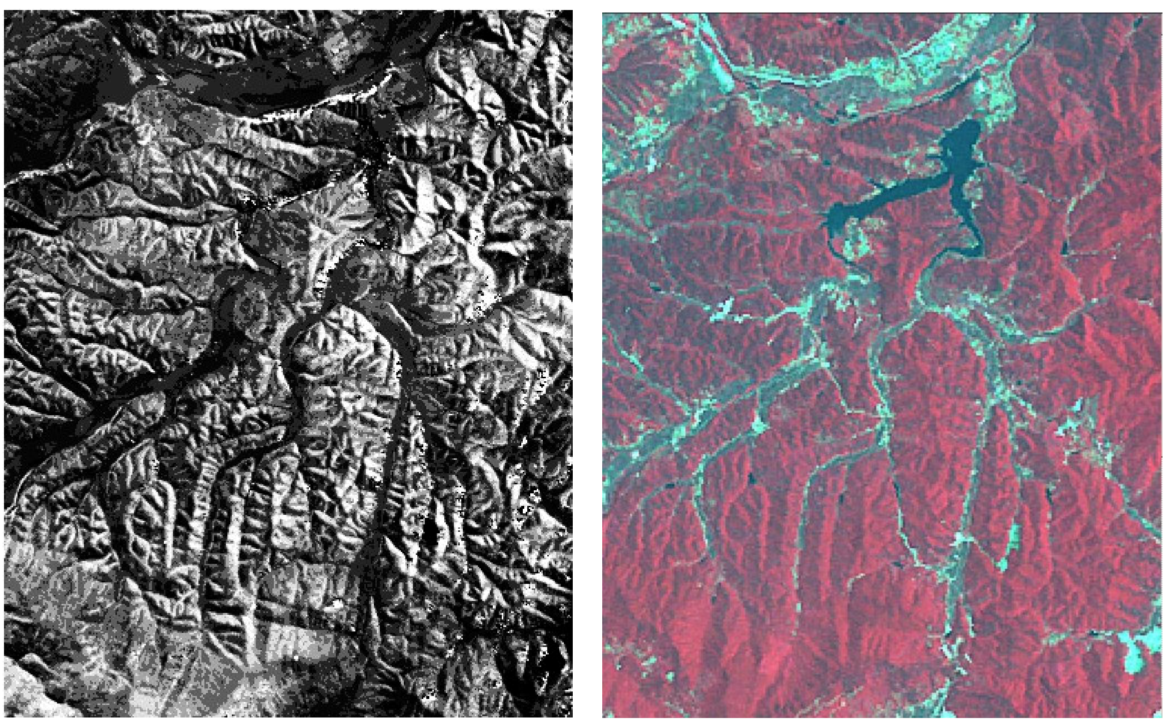

Figure 1. The image of height difference (ΔH) between the TOPSAR DEM and the map-generated DEM. Comparing with the Landsat TM data of the same area (7.5x9.2 km^2), it is clear

that the forested terrain shows high ΔH, while the flat bare ground or rice fields has very low value.

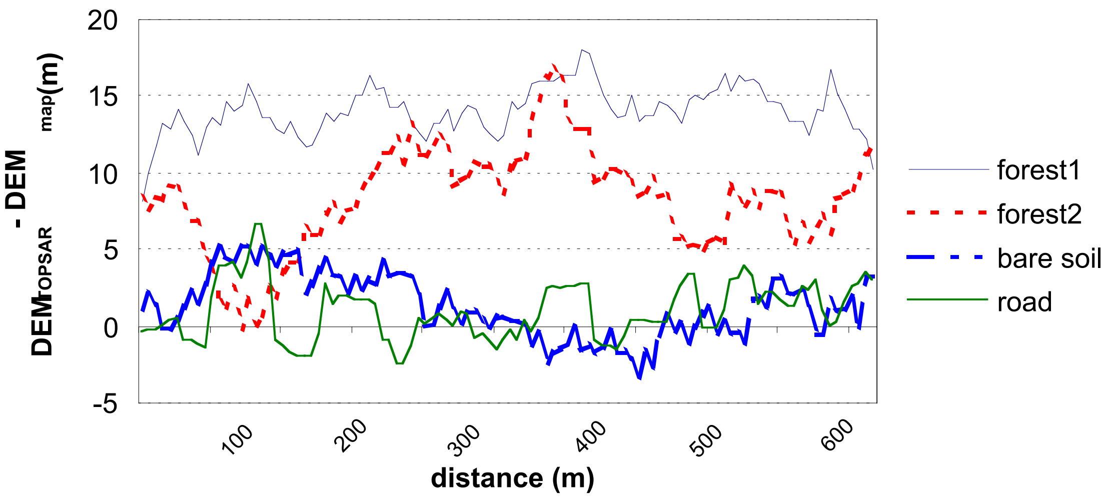

Figure 2. Profile of the height difference (ΔH) along the transact lines of bare surface and forest.

Assuming that the height difference (ΔH) is very close to the height of the scattering phase center, we compared the ΔH with the actual stand heights obtained from the ground measurement. Figure 3 shows the simplified delineation among the elevation points in forested terrain. The true height of forest stand is obtained by measuring A while the map-generated DEM indicates the elevation of the ground level C. The height of the scattering phase center observed in the C-band TOPSAR DEM is B that is somewhere between A and C. The height difference (ΔH) between the TOPSAR DEM and the map-generated DEM is the distance between B and C.

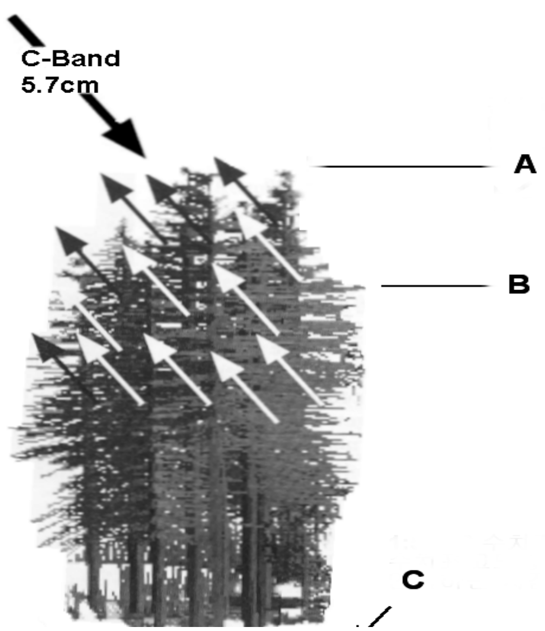

Figure 3. Different elevation points in forested terrain, in which A is the true stand height, B

represents the height of the scattering phase center in InSAR, and C is the elevation of the ground level determined by 1:5,000 scale topographic map.

Since we have already known all three values of A, B, and C at the 78 sample forest stands, we were able to analyze the discrepancies (A-B) between the true stand heights and the ΔH, which was obtained by subtracting the map-generated DEM from the TOPSAR DEM. The overall average discrepancy between A and B was 3.3m, regardless of the forest types. In other words, the TOPSAR DEM height was 3.3m lower than the actual height of forest stand. Although the primary sources of the C-band radar scattering are leaves and branches in tree crown, it would not be exactly the top of the trees. Therefore, the 3.3m discrepancy between A and B seems to be reasonable and the C-band InSAR DEM elevation is indeed very close to the forest stand height.

The 78 sample forest stands include several types of forest ranging from the just-planted saplings to the mature natural oak forest. Table 2 shows the simple statistics of the discrepancies (A-B) calculated by the different group of forest type. The least discrepancy between the actual stand height and the TOPSAR DEM height was found at the sapling stands. These stands were mostly suffered by recent forest fires and had been replanted after the site preparation. Although the sapling stands have very young trees of less than five years old, it would behave almost like the bare ground and the discrepancies were close to zero. In the sapling stands, there were not much differences among the heights of A, B, and C. Beside the sapling stand, the natural deciduous stand showed the closest value between the ground measured tree height and the height of TOPSAR DEM. Considering that oaks are the main species of the natural deciduous stand and have rather flat and rounded top canopy of broadleaf crown, the scattering phase center of the C-band TOPSAR should be closer to the actual tree top, as it compared to the needle canopy of coniferous stand.

The highest discrepancy between the ground measured tree height and the TOPDAR DEM was found in the coniferous forests of both natural and plantation pine stands, in which the height discrepancy was over 4 meters. Considering the tree morphology and the needle crown, the scattering phase center would be a lot lower than the top layer of the cone-shaped pine trees. As can be seen in Table 2, it is obvious that the stand height of the TOPSAR DEM varies by the forest type. Analysis of variance (ANOVA) on the discrepancy indicates that the effect of the forest type is statistically significant ($\alpha = 0.05$) to the height of TOPSAR DEM. When we apply the C-band interferometric SAR data for the estimation of tree heights, we should consider the effects of the tree species dealing with.

Table 2. The simple statistics of the discrepancies between the ground measured stand height (A) and the TOPSAR DEM height (B) among the 78 sample stands.

forest type	No. of stands	Mean (m)	Std dev
natural pine	20	4.53281	4.32836
natural deciduous	16	1.39694	2.71942
natural mixed pine and deciduous	18	3.83271	2.85123
plantation pine	17	4.09086	2.24451
sapling	7	0.60067	1.98179
Total	78	3.31357	3.35041

4.Conclusions

With increasing number of imaging radar sensors and the capability of acquiring image data under all weather conditions, it has been a growing interest to use interferometric SAR data for the estimation of forest structural parameters. Tree height has been a primary variable of interest analyzed by using InSAR data. As reported in this study as well as in several previous studies, it was found that the interferometric SAR signals were related to the tree heights to some extent. However, we believe that the use of InSAR data for the estimation of forest parameters is still a beginning stage and needs further studies for achieving practical applications.

In this study, the TOPSAR DEM height derived from the C-band interferometry was closely related to the actual stand heights in the forested terrain. Further, the TOPSAR DEM heights were significantly different by the forest type. Any attempts to estimate the tree height from the interferometric SAR data should consider the species composition of the forest. It could be still premise to say that the species composition is the only major factor to have influence on the estimation of the tree heights using the interferometric SAR data. There are many other structural parameters, such as stand density and stem diameter, that may have related to the InSAR signals. This study reports the initial experiment result of analyzing the JPL TOPSAR data in relating with forest stand height. Further analyses will be focused on the effect of combining other TOPSAR data, such as coherence and incidence angles, for the estimation of forest stand parameters.

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