On the use of Radarsat and JERS-l Satellite SARs for Trail and Road Detection in Tropical Rainforests

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Abstract

The basic imaging geometry of the SAR is considered for the study of trail and road detectability in imagery of rainforests with no significant topographic relief, as a function of the SAR parameters and trail (or road) shape. It is shown that the visibility of these features on SAR images depends mainly on the SAR resolution, trail (or road) widths and their orientation relative to the SAR viewing direction. The results are confirmed experimentally on a dense forest site in the south of Sumatra, Indonesia, using the multi-resolution capability of Radarsat. The best trail detectability was obtained with the fine modes at the highest incidence angle. The use of both ascending and descending fine modes permits even the detection of 5 to 6 m wide trails under particular conditions. The same trails could not be detected using JERS-l satellite SAR of coarser resolution. The resolution dominates trail detectability and the use of a longer wavelength (L-band for JERS-l) does not allow the resolution of narrow trails.

1.INTRODUCTION

Forest monitoring remains an important activity, especially in tropical regions. The presence of new roads and trails in rainforests might provide an indication of active logging, and considerable effort is concentrated on detecting and mapping trails and roads in these areas. During the rainy season, the presence of clouds limits the use of optical sensors such as those on board the Landsat and SPOT satellites, and favours the use of Synthetic Aperture Radars (SARs) for all-weather, day or night imaging capability. Satellite SARs (Radarsat, ERS 1-2, and JERS-l), which can provide less expensive imaging than airborne SARs, are becoming very popular in these regions.

In this paper, the potential of the C-band, Radarsat SAR for trail and road detection in rainforests is studied. The SAR imaging of a trail in rainforests {with no significant topographic relief) is modelled in Section 2 as a function of the SAR parameters; trail (or road).width and orientation, and tree height. The model is validated in Section 3 using Radarsat data. The potential of Radarsat for trail and road detection is assessed with reference to ground truth data collected over dense forests in the south, of Sumatra (Indonesia), which consist mainly of rubber and oil palm trees.

II. SAR IMAGING OF A TRAIL IN RAINFORESTS WITH NO SIGNIFICANT TOPOGRAPHIC RELIEF

A. Presentation of the trail imaging model

To study trail detect ability on SAR images, the sensor imaging geometry with respect to the backscattering coming from the trail (ground and trees on the two sides of the trail) has to be well understood. In the following, a simplified geometrical model is introduced for C-band SARs, Figure 1 shows a ground range projection of a trail parallel to the along track direction. The trail is illuminated by a C-band SAR wave at the incidence angle θ. Trees on the two sides of the trail are assumed to be of the same height *h*. *A'*, *O'*, *E'* and *F'* are the radar projected images of the elevated points *A*, *O*, *E* and *F*. The radar projected images are obtained using a rectilinear projection under the assumption that *h* is of small values compared to the distance to the SAR [2]. O_O and E_o are the orthogonal projection of the trail's near and far points *O*, and *E*. The wave path length inside the trail is noted as *d* (*d* = *OE*). For the trail in Figure 1, which is parallel to the along-track direction, the wave path length *d* is identical to the trail width *w*. In the following, O_O will be taken as the origin of the ground range projection axis (i.e., O_O is the coordinate origin noted as (O_O: 0)).

The height variation from the tree crown layer (of height *h*) to the trail ground (of height 0) results, for a sufficiently wide trail, in three distinguished areas on the ground projection image: a layover area (*E'F'*), a shadow area (*O'O"*), and a ground direct backscattering area (*O" E'*) .In the following, the C- band forest backscattering mechanisms are analyzed to justify the choice of the geometrical model of Figure 1, and to determine the length of each area as a function of the trail parameters and the wave illumination angle.

B. Layover area

The segment *E' F'* (of length $d - h/\tan\theta$) is a layover area which consists mostly of the direct backscattering from the crown layer (*EF*), multiple specular scattering from the ground and trunks, and a less significant direct backscattering from the ground segment ($E' E_o$).

C. Shadow area

Scattering by the crown layer is found to dominate the backscattering coefficient for all forest types at C-band [1], [3]. This justifies the presence of the shadow area ($O'O''$) on the ground range projection axis. The backscattering from the trail's near side O (elevated at the tree height h) is imaged on the ground range projection axis with a relief displacement towards the nadir of $h/\tan\theta$. The length of the shadow area $O'O''$ is $2h/sin2\theta$. Therefore, the shadow length is minimum at $\theta = \pi/4$, and not at the nadir as it might be thought. The shadow area can be imaged entirely if the trail wave path length $d = OE$ is sufficiently large: $d \gg 2h/\sin\theta$. For 20 m high trees, this corresponds to a minimum trail width w of 40 m (at $\theta = 45°$) for a trail parallel to the along track direction. As the width of the trail decreases, the shadow area $O'O''$ is partially covered with the layover area $E'F'$. The minimum shadow width will be equal to the segment $O'E'$ where O' and E' correspond to the backscattering from the crown layer at the elevated points O and E respectively.

It is worth noting that, at L-band, the shadow area may be weaker or absent. The increased penetration of L-band radiation into the canopy will result in volume scattering from the region $OO'O_o$ in Figure 1. When projected on the ground, the radiation from this volume will "fill in", or brighten the shadowed area.

D. Direct ground backscattering area

The ground direct backscattering from the trail is imaged on the segment $O''E'$ (of length $d-(h\tan\theta+h/\tan\theta)$). The trail surface can be imaged if the length $O''E' = d - 2h/\sin 2\theta$ is larger than the ground range resolution $r_g = \Delta_r/\sin\theta$, where Δ_r is the range resolution. For a trail bordered by 20 m high trees which is imaged with Radarsat fine mode at 45°, this corresponds to a minimum trail width of about 50 m for a trail parallel to the along-track direction. This result is very significant, since in practice it means that for the trails of interest ($w \leq 12$ m), the trail surface is not generally imaged, and hence rain conditions should not influence trail visibility. The trail image is mainly composed of a shadow area $O'O''$ (fixed by the height of the trees and the wave incidence angle) and the layover backscattering area $E'F'$.

E. Minimum detectable trail wave path

Since the ground range projection transformation is scale invariant, the ground projection segment ($O'E'$) of the wave path ($d = OE$) of the trail is of the same length: $OE = O'E' = d$. The minimum distance that can be resolved by the SAR is the ground range resolution r_g. The trail should be readily observed when $d > r_g$. In the case of a trail parallel to the along-track direction, this would correspond to a minimum trail width $w_{min} = d_{min}$ approximately equal to the ground range resolution r_g.

It is worth repeating that the model introduced in Section 2.1 assumes that the trees on the two sides of the trail are of the same height h. If $EE_o = h + \Delta h$ is larger than $OO_o = h$, the minimum trail wave path detectable would be larger: $d_{min} = r_g + \Delta h$. One way to improve trail detectability is to view the trail from the opposite side using the ascending - descending mode SAR viewing capability.

F. Trail orientation relative to the along track direction

If the trail is oriented with an angle β from the along track direction (Figure 2), the wave path is longer than the trail width: $d = w/\cos\beta$, and the minimum trail width detectable is smaller than the ground range resolution: $w_{min} = r_g \cos\beta$.

In the extreme case of $\beta = \pi/2$, the trail is parallel to the across-track direction, and its detectability is fixed by the SAR azimuth resolution Δ_a. In this particular case, the trail surface might be imaged. Therefore, rain conditions might influence the visibility of trails that are parallel to the across-track direction.

III. Analysis of satellite SAR data and discussions

A. Ground truth data collection

The study site is located on the North West of Palembang (02° S latitude, 104° E longitude) in the south-east of Sumatra. The area with no significant topographic relief is covered by dense equatorial forests consisting mainly of rubber tree and oil palm tree plantations. The rubber trees grow to a height of 12 to 20 m, depending on soil and terrain conditions. The oil palm trees grow to a height of between 12 and 16 m. The planting densities are approximately 500 rubber trees or 140 oil palm trees per hectare [T. Said (Mapindo Parama, Indonesia), personal communication]. Several trails 4 to 12 m in width were selected for the study. The width and direction of the trails were recorded, as were the GPS coordinates and the surrounding tree heights and diameters. Ground truth measurements were also collected along the 30 m wide main road which joins Palembang to Jambi.

B. Analysis of the Radarsat data and results

JERS-1 SAR data and various Radarsat mode data (S1 at 23°, F1 at 38°, F3 at 43°, F4 at 47°, and EH6 at 58°) covering incidence angles from 20° to 59° were collected over the study site. The meteorological conditions on these dates were also recorded during the data acquisition. The visual analysis of the 25 m resolution JERS-1 and standard (and extended) Radarsat images with reference to the ground truth data collected over the study site yielded the following conclusions.

- The coarse ground range resolution of the standard mode 1 (about 25 m), which is the same as ERS-1 and 2, gives the worst results. Even the 30 m main road can hardly be seen in certains places. Most of the trails of 12 m width cannot be seen.
- The performance of the JERS-1 SAR was very similar. The 25 m coarse resolution limits the edge detection capabilities of the L-band SAR.
- The 18 m ground range resolution of the extended mode EH6 of Radarsat permits better trail detection. The 30 m main road is well detected and the use of both ascending and descending modes permits the detection of most of the trails of 12 m width (under ideal orientation conditions).

The finer azimuth (9 m) and ground range resolution (8 to 9 m) of Radarsat fine modes yields the best results. The following points are noted.

- The use of both ascending and descending modes is ideal. It permits trail imaging with different orientation, and hence increases the detectability of trails of interest. Moreover, if the trees on the two sides of the trail are not of the same height, trails that might be missed by one (ascending or descending) mode can easily be detected by the other as they are imaged from the opposite side (see Section 2.5).
- The 30 m main road is perfectly detected.
- Trails 10 m in width (or wider) that are parallel to the along-track direction (the worst orientation condition, as explained above) can be detected easily.
- The ascending-descending mode combination permits the detection of all trails of 6 to 8 m width selected in the study site.
- A trail of 5 m width in a 12 m rubber tree plantation could be detected in the F4A Radarsat image with an orientation practically orthogonal to the along-track direction ($\beta \simeq \pi/2$). The trail was detected more clearly using the F3D mode with a different orientation angle ($\beta \simeq 50°$).
- F1A mode Radarsat images under dry and rain conditions were compared. These conditions did not influence the detectability of the trails under consideration.

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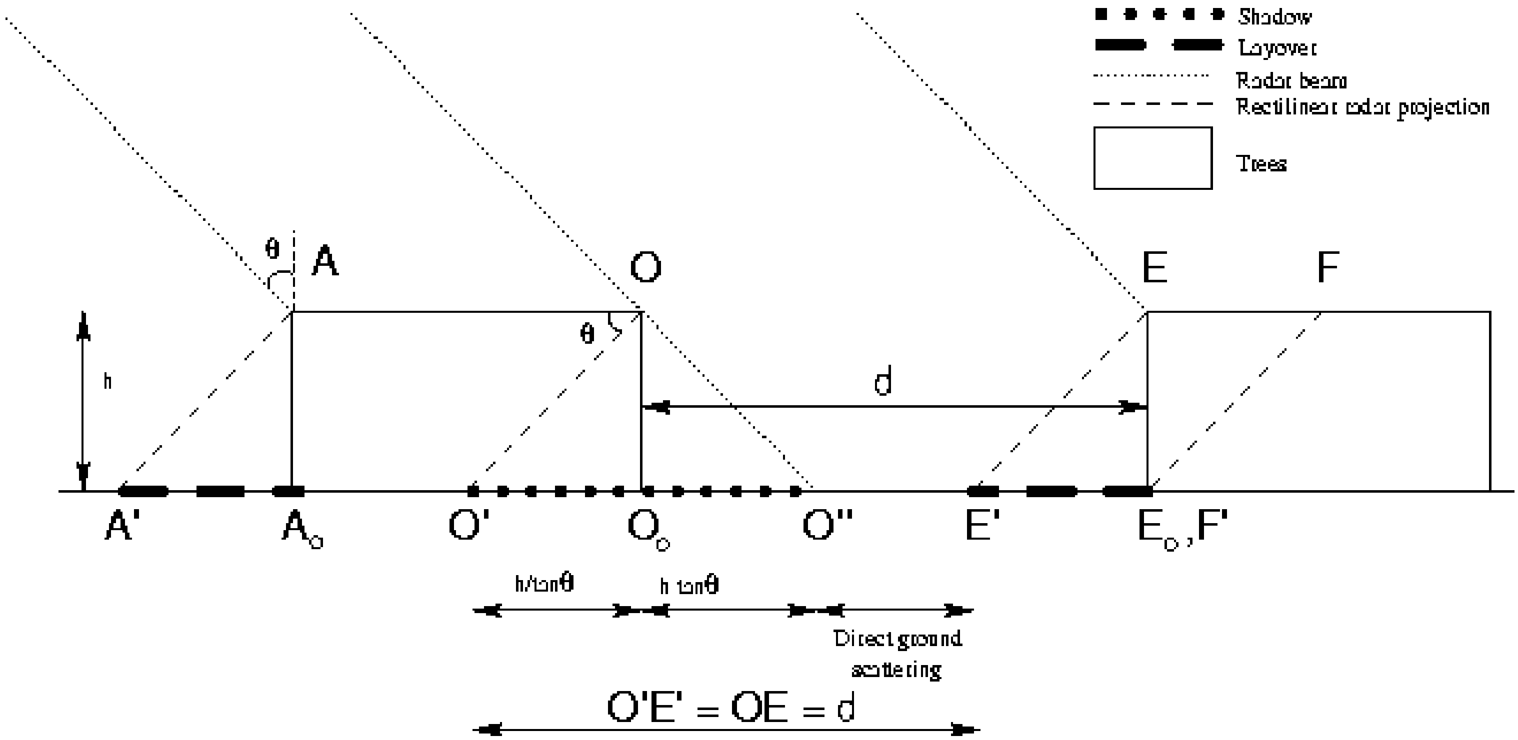

Fig. 1. SAR image of a trail in ground range presentation

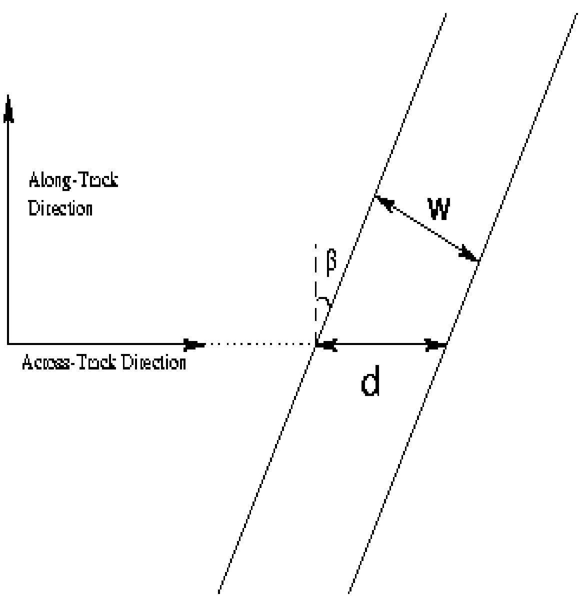

Fig. 2. Trail orientation