MAPPING SELECTIVE LOGGING IN TROPICAL FOREST WITH SPACE-BORNE SAR DATA

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ABSTRACT

A technique was developed for the mapping of selective logging in tropical forest using PALSAR imagery acquired before and after the logging operations. The technique is based on automatic detection of new forest roads and unsupervised classification of textural features, which were computed from a backscatter ratio image. The technique was adapted for TerraSAR-X and ENVISAT/ASAR data.

The accuracy of a PALSAR-based map of selective logging was assessed against reference plot data interpreted from GeoEye-1 imagery. The user's accuracy of selective logging was 95 %. The overall accuracy was 70.4 %. This is affected by the limited size of the area, which was chosen to include a large proportion of selectively logged forest. The accuracy of a TerraSAR-X-based map of selective logging was 53.6 %, but the user's accuracy of selective logging was 100 %.

ALOS-type L-band radar data could be applied in an operational system over country-wide datasets to map newly constructed roads. The 40 % underestimation does not make direct reliable mapping of the area of selective logging possible. Instead, L-band derived maps of selectively logged area and new roads can be used in a wider system to pin-point areas of recent logging activity (as a proxy for forest degradation). The detected areas can then be covered by satellite or airborne optical data or ground surveys. The L-band map of areas with logging activity can also be used for stratification for sampling in a statistical area assessment.

Key words: radar; forestry; logging; TerraSAR-X; ALOS; ASAR.

1. INTRODUCTION

Besides deforestation, forest degradation forms one of the most significant sources of green house gases today.

Optical satellite sensors are of limited utility in mapping forest degradation in cloud-obscured rain forest regions of Equatorial Africa. As a weather-independent sensor, radar offers flexibility in forest monitoring applications, when results are requested in a fixed (e.g. yearly) schedule.

The selective logging in the study site is done in concession areas where sustainable forestry is practised. Selective logging follows certain recognizable patterns. Typically a road network is made first. Within a few months, areas within a radius of 200 ... 500 m from the road are selectively logged. Our work on the mapping of selective logging demonstrates the potential of SAR data for finding the actual degraded areas.

2. MATERIALS AND METHODS

2.1. Study Site and Ground data

The study site (centre 1°11'10" north, 16°13'43" east) was in the Republic of the Congo (Fig. 1). The area is mostly covered with rain forest, some of which is on swamp where the forest canopy is lower. Some rivers, agricultural areas, and towns are also present in the study site. Agricultural areas cover only a small fraction of the study site.

In absence of reliable ground data on selective logging in the study site, optical VHR satellite imagery was used to verify the mapped areas of selective logging. Two GeoEye-1 images were ordered from year 2012: on 2012-02-21 09:12 GMT (centre 0.830, 16.500) and on 2012-04-08 09:25 GMT (centre 0.926, 15.795).

A digital elevation model (DEM, [1]) was obtained for the ortho-rectification of SAR data from:

http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp

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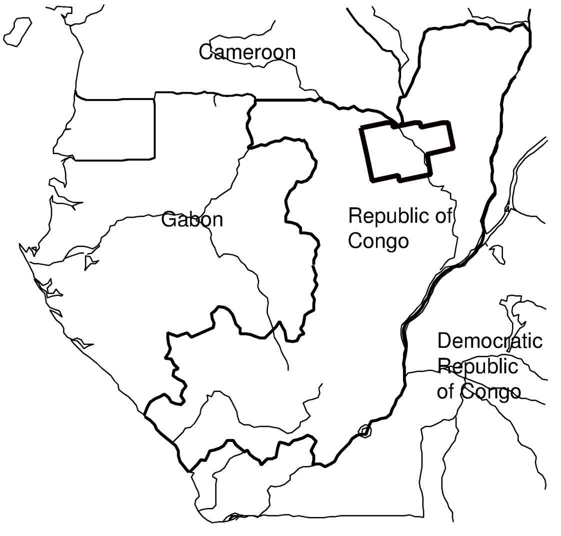

Figure 1. Location of study site in The Republic of the Congo.

2.2. SAR Data

A total of ten ALOS/PALSAR dual-polarized (HH+HV) scenes (Tab. 1) were obtained to cover the whole study area with two acquisitions. The ALOS/PALSAR scenes had an incidence angle of 39°and pixel spacings of 3.2 m in azimuth and 9.4 m in slant range in an SLC (Single Look Complex) product called Level 1.1 product (nominal single look resolution 4.5 m in azimuth and 15 m in ground range). All PALSAR scenes were acquired in ascending orbits.

Table 1. SAR data of the study site.

No.	Date	Scene ID	Centre (Lat., Lon.)
2010			
1	12.7.2010	ALPSRP237890000	(0.921, 16.350)
2	12.7.2010	ALPSRP237890010	(1.418, 16.246)
3	10.8.2010	ALPSRP242120010	(1.417, 16.786)
4	29.7.2010	ALPSRP240370010	(1.418, 15.712)
5	29.7.2010	ALPSRP240370000	(0.921, 15.816)
2007			
6	17.9.2007	ALPSRP087790010	(1.416, 16.782)
7	4.7.2007	ALPSRP076850000	(0.923, 16.353)
8	4.7.2007	ALPSRP076850010	(1.420, 16.249)
9	21.7.2007	ALPSRP079330010	(1.419, 15.710)
10	21.7.2007	ALPSRP079330000	(0.924, 15.818)

A dual-polarized mosaic was compiled for the years 2007 and 2010, both including 5 ALOS/PALSAR scenes. Automatically measured tie points (527 points) were used between the scenes within a layer and between the layers of 2007 and 2010 [2]. Ground control points (GCPs) between PALSAR scenes and Google-Earth were used to bind the mosaic to the WGS-84 datum.

The 527 tie points and 10 GCPs were submitted to a block adjustment, where 6 parameters of an affine transformation were determined for all 10 scenes simultaneously. The Residual Mean Square Error (RMSE) of tie points was 5.6 m in northing and 5.5 m in easting (max 34.8 and 31.3). The corresponding figures for GCPs were 21.2 m and 18.7 (max 49.7 and 35.2). UTM zone 33 (central meridian 15 degrees East) was used as the reference system for the mosaic data. SRTM DEM [1] data were interpolated from 90-m pixel spacing to 12.5 m pixel spacing using cubic splines and re-sampled to the UTM projection. In connection with ortho-rectification, a radiometric correction was made to PALSAR data [3]. Before ortho-rectification, ALOS/PALSAR data were averaged over 5 lines (in azimuth) to obtain a pixel spacing of 15.9 m in azimuth and 15.0 in ground range. Bi-linear interpolation was used in connection with ortho-rectification.

Radiometric differences between neighboring PALSAR scenes were balanced with a technique developed for polarimetric SAR data [4].

2.3. Mapping Methodology

After some initial studies, the following algorithm (see Fig. 2) was designed for mapping selective logging with ALOS/PALSAR (or similar SAR) data:

1. Find newly constructed roads by a technique using Hough trasform of a backscatter ratio image,
2. Make a land cover map (using the newly constructed roads as training data) by dividing the service area into two categories: forest types where selective logging is likely (potential area for selective logging) and other types of land cover (including swamp forest, water, agriculture and all other land cover types in the area),
3. Compute texture features from the 2010/2007 HV ratio, and
4. Make a selective logging map by clustering the texture features using the newly constructed roads as training data.

2.4. Evaluation of Mapping Performance

The PALSAR-based maps (and TerraSAR-X-based maps as well) of selective logging were compared to a set of reference points derived using GeoEye-1 data. The adopted validation technique was previously applied in the LaoSilva study [5]. Generally, the VHR optical images should be located in such a manner that they represent the whole area of interest. Confusion matrices were computed between visually interpreted plots (100 m by

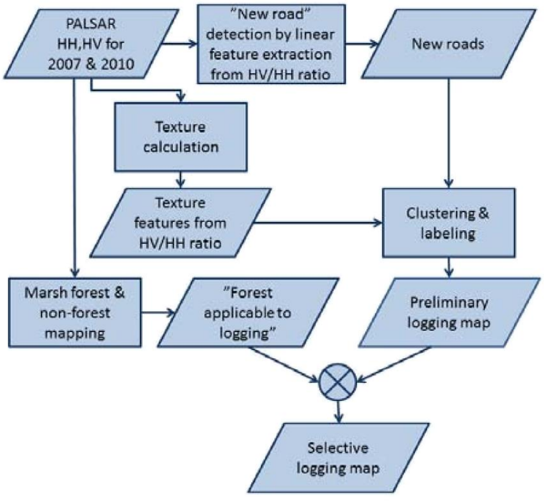

Figure 2. An algorithm for mapping selective logging with SAR data.

100 m area, spacing 400 m) and the PALSAR-derived selectively logged area. This approach is considered to give a realistic figure on the performance of the mapping of selective logging.

In order to ascertain more objective evaluation of the mapping accuracy, the VHR image was interpreted by two remote sensing experts. They assigned each plot to one of two land cover categories:

1. selective logging, or
2. other land cover type.

The assignment of the plots was made based on the area proportions of these cover types within the 100 m by 100 m area.

3. RESULTS

A sample of PALSAR-derived network of new roads is shown in Fig. 3. The roads are shown in red on top of the HV ratio 2007/2010. The right sub-figure of Fig. 3 shows the map of selective logging for the same area.

Results of the accuracy assessment are shown in Tab. 2. The whole number of plots in the visual interpretation was 272. Among these plots, ALOS/PALSAR-based map showed 137 plots as selective logging after applying majority voting for the mixed plots category. The two experts detected 208 and 185 plots as selective logging plots, respectively. The obtained confusion matrices for both interpretations are shown in Tab. 2. While the overall accuracy ranged from some 64 to 74 %, the users accuracy was at the level of about 95 % for both assessments. The ALOS PALSAR-derived map underestimated the selectively logged area by 37.5 % (average of the two experts).

Table 2. Confusion matrices for the map of the selective logging (from PALSAR data) against a set of reference points interpreted by two remote sensing experts.

1st Expert		Reference VHR (GeoEye-1)			
		Selective logging	Other	Total	User's accuracy
PALSAR map	Selective logging	123	6	129	95.3 %
	Other	85	58	143	40.6 %
	Total	208	64	272	
	Producer's accuracy	59.1 %	90.6 %		66.5 %

2nd Expert		Reference VHR (GeoEye-1)			
		Selective logg	Other	Total	User's accuracy
PALSAR map	Selective logging	122	7	129	94.6 %
	Other	63	80	143	55.9 %
	Total	185	87	272	
	Producer's accuracy	66.0 %	92.0 %		74.3 %

The mapping of selective logging with TerraSAR-X data followed a similar approach as described earlier for PALSAR data. Fig. 4 shows a sample of detection of new roads.

The TerraSAR-X-based map of selective logging was assessed in the same manner as the PALSAR-based map. Just one expert made the visual interpretation of the GeoEye-1 image. The spacing of sample plots was reduced to 200 m in order to obtain enough plots. Tab. 3 shows the confusion matrix.

Table 3. Confusion matrix for the map of the selective logging (from TerraSAR-X data) against a set of reference points.

		Reference VHR (GeoEye-1)			
		Selective logging	Other	Total	User's accuracy
TerraSAR-X map	Selective logging	16	0	16	100.0 %
	Other	32	21	53	39.6 %
	Total	48	21	69	
	Producer's accuracy	33.3 %	100.0 %		53.6 %

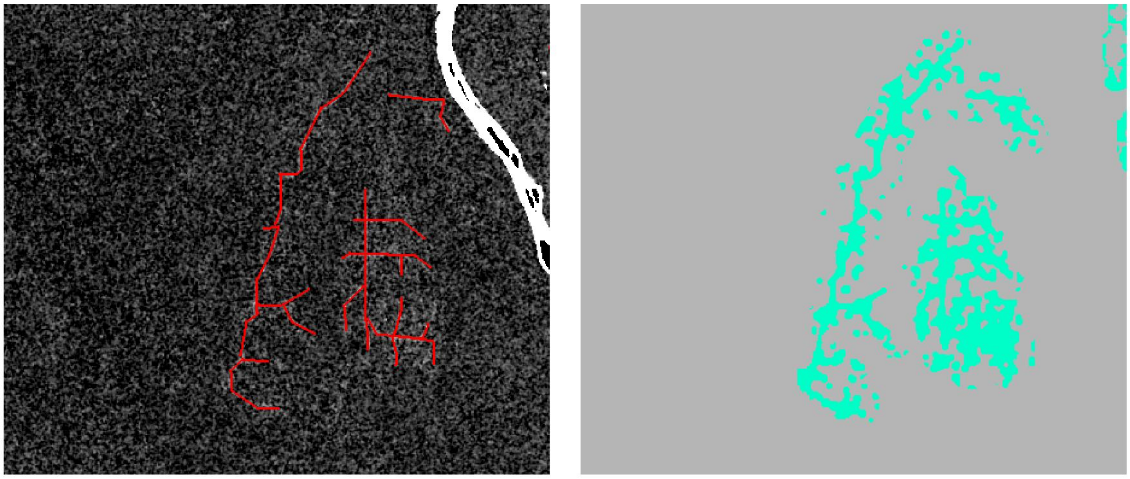

Figure 3. A sample of PALSAR-derived roads (left) and the map of selective logging (right). Image data copyright JAXA and METI 2007 and 2010.

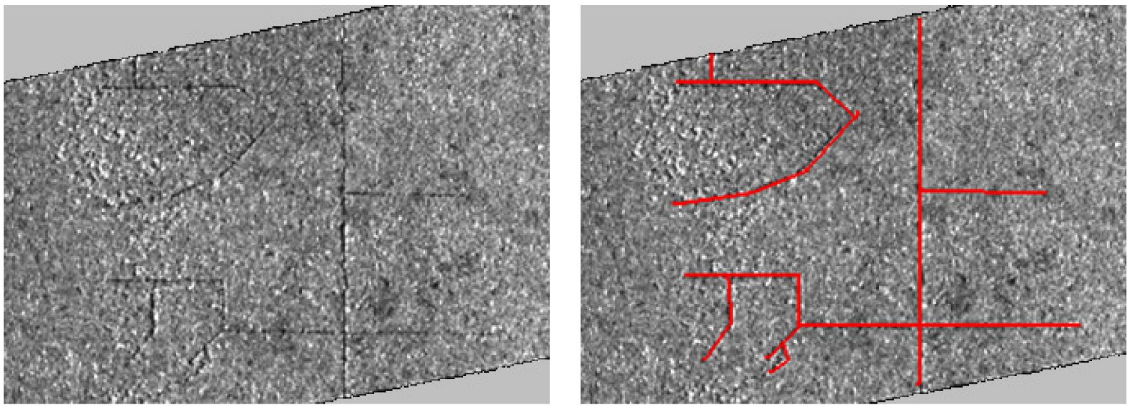

Figure 4. A sample of mapping new roads with TerraSAR-X data. The left sub-figure shows the HH ratio between scenes 19.3.2012 and 23.8.2011. The right sub-figure shows the roads on top of the HH ratio. Image data copyright DLR 2011 and 2012.

4. DISCUSSION

The developed mapping techniques of selective logging contain elements that can be used in operational mapping of selectively logged forest. Detection of new roads (as proxies or indicators of areas with logging operations) with ALOS-type L-band radar data is reliable enough that it could be applied in a routine way over country-wide datasets of such data. For the time being (September 2013) this is prevented by the lack of working L-band SAR satellites. The under-estimation of about 40 % in the area of selective logging is too high for most mapping purposes. L-band derived maps of selectively logged area and new roads can be used in a wider system as a proxy of forest degradation (to pin-point areas of recent logging activity). The detected areas can then be covered by satellite or airborne optical data or ground surveys. The L-band map of logging activity areas can also be used for stratification for sampling in a statistical area assessment.

Very-high-resolution X-band data can also be used for reliable detection of new roads if wide enough areas (wall-to-wall or a dense sampling grid) can be covered with X-band data of very high resolution. The potential of C-band data was explored, but the dataset available in the study area did not allow firm conclusions on its suitability in monitoring selective logging. Evaluation of C-band data in this context is a topic of further research.

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