FOREST CHANGE DETECTION FROM L-BAND SATELLITE SAR IMAGES USING ITERATIVE HISTOGRAM MATCHING AND THRESHOLDING TOGETHER WITH DATA FUSION

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ABSTRACT

For faster updates of large area forest change maps, L-band satellite Synthetic Aperture Radar (SAR) is a potential alternative to present operational methods (such as optical ones). As satellite SAR systems are active systems having repeat pass cycles on the order of weeks and acquire data next to unaffected by weather and lighting conditions, they can provide high-quality images all year around with a high update rate. One downside is the fact that long wavelength satellite SAR images often are poorer in resolution compared to, e.g. optical or hyperspectral data. Also, radar images are affected by speckle noise, as the radar backscatter signal consists of the incoherent sum of all radar responses from scatterers within a resolution cell. In this study, a bi-temporal change detection approach based on image rationing and histogram techniques, both for radiometric/environmental normalization and thresholding, is evaluated. To tackle low resolution and speckle, pre-applied filters are tested in combination with a SAR data fusion method that exploits both spatial and spectral information from multiple SAR channels. HH and HV polarized Fine Beam Dual images acquired 34 degrees off nadir (FBD34) by the Advanced Land Observing Satellite Phased Array type L-band Synthetic Aperture Radar (ALOS PALSAR) are used to find clear-cuts in Swedish boreal forest.

A large area change detection method should be highly automated, computationally cheap and require a low number of input parameters. This is to be combined with robustness and high accuracy. For classification of change and no change areas the automatic histogram based generalized Kittler and Illingworth minimum-error thresholding algorithm (GKIT) for SAR amplitude ratio data proposed in [1] was chosen. More specifically, the lognormal variant LN-GKIT was chosen partly due to its closed form simplicity. Previous work has shown that clear-cuts present backscatter drops in both HH and HV polarized data [2]. Moreover, higher dynamic range or contrast was found for HV polarized backscatter than HH. Nonetheless, the HH polarized component bears information and is included in this study. This is done both separately and in combination with HV, using the Markovian Data Fusion (MDF) approach for SAR change detection proposed in [3], again under a lognormal assumption.

Although data acquisition by SAR systems can be regarded as independent of weather conditions, the radar backscatter is sensitive to differences in environmental conditions such as precipitation, moisture content, frozen/unfrozen, snow cover and season [4]. This combined with possible sensor calibration issues should be accounted and adjusted for through some kind of relative radiometric (or environmental) normalization procedure before comparing images. As signatures from different land cover types potentially respond differently to, e.g. water content, a non-linear approach would be preferred. For this histogram matching was chosen, as it serves good for both non-linearity, is computationally cheap and can even be applied across sensors [5]. The off-the-

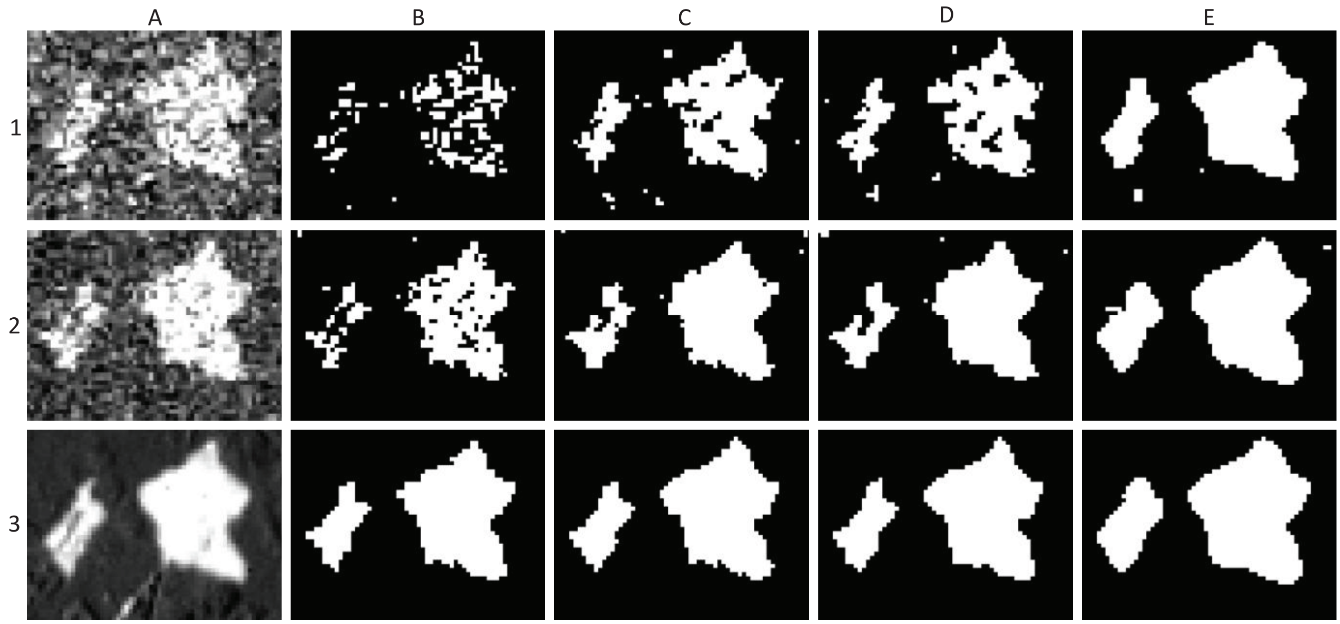

Fig. 1 Results from a sub region (1200 m × 900 m) of the area subject to change detection. Column A shows 1) HH ratio image (unfiltered and histogram matched), 2) HV ratio image and 3) SPOT-4 HRV-IR red band reflectance difference image for reference (clear-cuts appear bright). Columns B-E show results from iterative histogram matching and LN-GKIT thresholding using 1) HH images and 2) HV images. In 3) HH and HV information have been combined through Markovian Data Fusion (MDF). For columns B-E the images were pre-filtered using B) no filter, C) 7 × 7 Improved Sigma (MMSE) filter, D) 3 × 3 truncated flexible adaptive filter and E) a 5 × 5 truncated mean filter.

shelf histogram matching using look up tables often found in software was discarded because it does more of a contrast stretch than actual distribution matching. Instead, a piecewise cubic Hermite interpolating polynomial-fit [6] on the cumulative sum of the normalized histogram is performed for both the reference and target image to closely mimic their cumulative distribution functions (cdfs). The pixel values of the target image is then first run through its cdf polynomial and then through the inverse cdf of the reference image. In addition to producing a close histogram match the polynomials will come to practical use as explained below.

For increased accuracy and also to be able to cope with large percentage of change in areas an iterative normalization and thresholding procedure is proposed. After a first polynomial-fit histogram match an image ratio is taken and an initial change map is produced using the thresholding algorithm (GKIT). Now, “change” pixels should not have been taken into account when performing the initial histogram match. Therefore, the procedure is iteratively repeated using only “no change” areas for the polynomial approximations of the reference and target image cdfs. The remaining pixels in the target image are then run through the first (target) cdf and second (reference) inverse cdf. The convergence of a similarity measure of the “no change” pixels is used as stopping condition. For this study, the median pixel Symmetric Image Ratio (SIR) proposed in [5] taken among “no change” pixels was used (no proof of convergence). Empirically this has been shown to work for areas subject to at least moderate change. Notice that two thresholds are produced in each run (inverse ratio is used for the second) corresponding to both positive and negative changes.

The detection algorithm was applied to PALSAR (FBD34, 16 looks, 20 m pixels, γ_0-backscatter) images acquired during late summer of 2007 and 2008. A red band reflectance difference image from a SPOT-4 HRV-IR image pair, acquired at similar dates as the PALSAR images, was chosen for visual reference, since there is an apparent increase in red band reflectance after clear-cutting in Swedish boreal forest [7].

For unfiltered images both the quality of the histogram matching and the probability of finding a threshold are low due to speckle. For this reason various filters were tested for performance. In Fig. 1, a close-up of the results from using B) no filter, C) a 7 × 7 Improved Sigma (MMSE) filter ($\xi = 0.9$ and disabled point target preservation) [8], D) a 3 × 3 truncated version of the flexible adaptive filter proposed in [9] ($a = 0.6$, $b = 0.9$, ignoring 4 pixels when computing the mean and standard deviation) and E) a 5 × 5 truncated mean filter (ignoring 12 pixels) can be seen. As a next step Markovian Data Fusion (MDF) was applied to exploit the combined information from the HH and HV polarized data (10-norm and a 5 × 5 window for probabilities were used) [3]. There is an obvious tradeoff between proper fine detail delineation and reduction of false detections. Even if the 5 × 5 truncated mean filter over-smoothens when compared to the others, it clearly shows that the HH polarized data also carry useful information for the change detection. The LN-GKIT algorithm was able to threshold the unfiltered ratio image in this test. However, this is not always the case, and more stable thresholding and histogram matching is attained with some level of filtering. And although the MDF alone could produce a satisfactory change map, the adaptive filters provided stability along with reduction of some horizontal and vertical pre-processing artifacts, present in A1, A2, and the whole of column B in Fig. 1.

To assess the prospect of using L-band satellite SAR data for large area forest change detection, a set of computationally efficient techniques have been combined and applied to ALOS PALSAR data over Swedish boreal forest. The approach shows promising results when it comes to both detection and delineation of clear-cuts. However, there is a trade-off between the two, depending on the amount of filtering applied. Irrespective of which filtering technique tested, the Markovian Data Fusion (MDF) method exploiting the information from two polarization channels improved the result. Less pre-filtering is required and also preferred for the MDF as it alone account for spatial information to overcome speckle. If only one polarization channel is available the end result relies more heavily on pre- or post filtering. Whilst HV polarized data shows satisfying detection and delineation results when used solo, HH data requires heavier smoothing to achieve similar detection results. This reduces the possibility to detect small area changes and achieve fine detail delineation using only HH data.

As a conclusion L-band satellite SAR imaging seems well suited for large area monitoring of clear-cuts in Swedish boreal forest, at least during favorable conditions. For this purpose the computationally cheap histogram based methods used in this study along with multi-channel SAR data fusion are pertinent choices.

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