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# ROAD DETECTION IN A FOREST USING SENTINEL-1 AND FBR TIME-SERIES SPECKLE FILTERING

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## ABSTRACT

Temporal and spatial information is exploited in order to improve road detection performance in a forested area. Speckle is filtered using an FBR-based SAR time-series speckle filter, thus preserving temporal information. The additional spatial information is provided by the ascending and descending directions of acquisition of the satellite. Instead of a detection being made if the pixel value is lower than the threshold, we require the threshold to be met for every date in the time-series, and from both directions at once. This corresponds to both a temporal and spatial (generally East-West) stability requirements, and tends to reduce false positives as forest is not a stable environment. The technique was applied on a Sentinel-1 dataset over an area in northern Belize.

**Index Terms**— Road detection, SAR, time-series, Sentinel-1

## 1. INTRODUCTION

Road detection using individual SAR images has been possible for at least 20 years [1, 2]. It generally follows the same process: speckle filtering, intensity thresholding and curvilinear features extraction. In this paper, we have explored the benefits of adding two other image points of view (time and direction) to the thresholding and applying it to the detection of dirt paths in forests.

## 2. METHOD

In this article, we focus on the first two components of classical SAR road detection, namely speckle filtering and intensity thresholding.

Speckle filtering is a necessary first step in road detection, as speckle (both high-valued and low-valued) can lead to misdetections (generally false negatives and false positives, respectively). What we propose here, in order to preserve both spatial resolution and temporal information, is to use an FBR-based time-series speckle filter [3] instead of either a spatial or temporal speckle filter. This technique relies on the temporal coefficient of variation to filter out change and speckle from

a SAR time-series. Temporal interpolation is then used to replace the filtered values. The spatial resolution is preserved as the processing is applied pixel-by-pixel. The temporal information is preserved as pixels are only modified if affected by change or speckle. Typically, only 40% of the values in the time-series are filtered. Even then, the intensity value they are replaced with is obtained through temporal interpolation between the neighbouring stable values, i.e. the intensity is now an estimation of what it would have been without the change or the speckle. By doing this, we have now added time as a new mean of discrimination between road and non-road. More precisely, a road or path is more temporally stable than the neighbouring forest. To exploit this, the intensity thresholding should now be applied to the whole time-series, and a detection made if, for every date, the threshold is not exceeded.

Another information source readily available on most SAR sensors is the direction of acquisition. Exploiting different acquisition directions to improve road detection performance has already been done in [4]. Here, we make sure that the thresholding condition is true for all directions. We reach the same conclusion than Tupin et al.: the added information reduces false alarm probability (namely here, the linear shadows are eliminated).

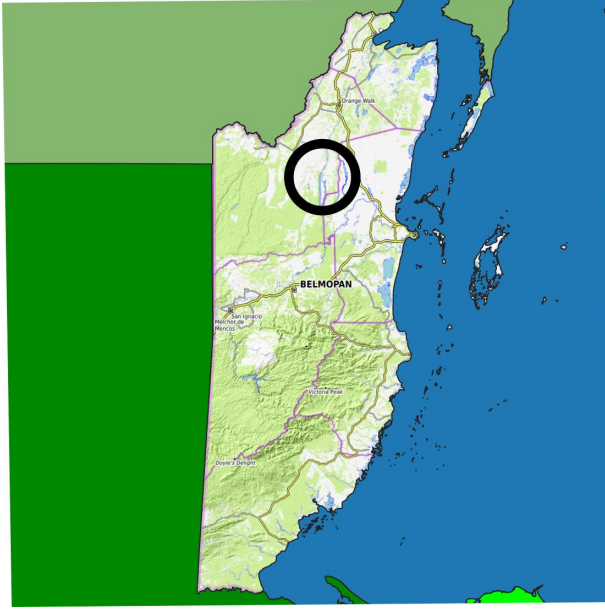
Finally, a pixel is detected if it matches all these criteria:

- intensity lower than the threshold (classical method)
- from all directions
- and for every date in the time-series

This is equivalent to requiring a certain level of temporal stability and isotropy along the illumination directions. A forest canopy should fit neither of these conditions, as it is temporally fluctuating (wind, seasonality, ...) and not perfectly flat (i.e. not isotropic).

For example, some satellite data comes from two directions: *ascending* and *descending*. In this case, isotropy is required along the East-West direction.

It is not possible to discriminate between non-forest areas and paths using only the SAR intensity, for the simple reason that a bare soil or grassy path is a non-forest area. We



**Fig. 1.** Map of Belize. The area of interest is circled in black. Basemap from [6]. Shapefiles from [7, 8].

therefore have masked non-forest areas (Fig.3) using ESA’s WorldCover 2020 land cover product [5]. However, the next step in the road detection process from the literature (*curvilinear structure extraction*) might make this part unnecessary.

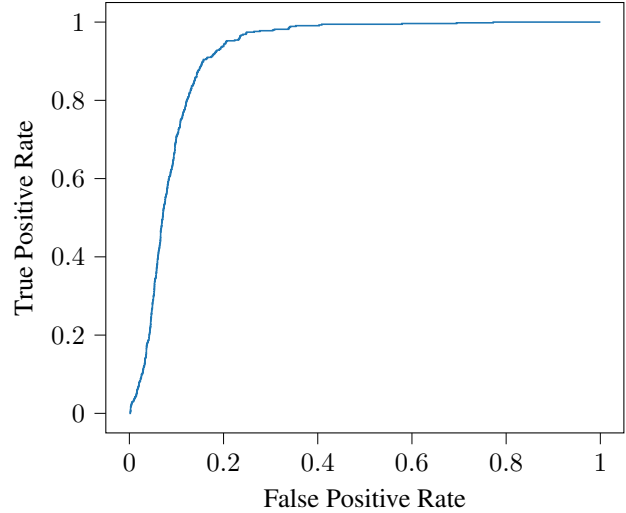
### 3. RESULTS

Our area of interest is a small forest on the Eastern shore of the New River Lake, opposite the town of Indian Church in Belize (Fig.3a). It contains three straight segments of roads in the center of the area and a more curved path along the top of the image. A river crosses the northern parts of the AoI, from East to West.

We use Sentinel-1 SAR time-series going from March 2019 to November 2021. Optical imagery [9] was used to confirm the presence of the paths over the whole timeframe.

We obtain pretty good results using a threshold of -7.5 dB, as shown in Fig.3b. As a reminder, we apply this threshold for both directions and for every date. Both the straight and curvy paths are correctly detected, along with the river. No false negatives occur, all the non-detections are as expected. Some of the false positives come from errors in the ground-truth mask. Some refining on that end might be required.

More importantly, most of the false positives are due to deforestation. The land cover product covers 2020, i.e. roughly the middle of our SAR time-series. It is likely that deforestation occurred between the end of 2020 and the end of the time-series in late 2021. This is further supported by the location of these false alarms: along the edges of the land cover mask, or linking separate patches of non-forest.



**Fig. 2.** ROC Curve using our dataset and ground-truth mask. The AUC score is 0.911.

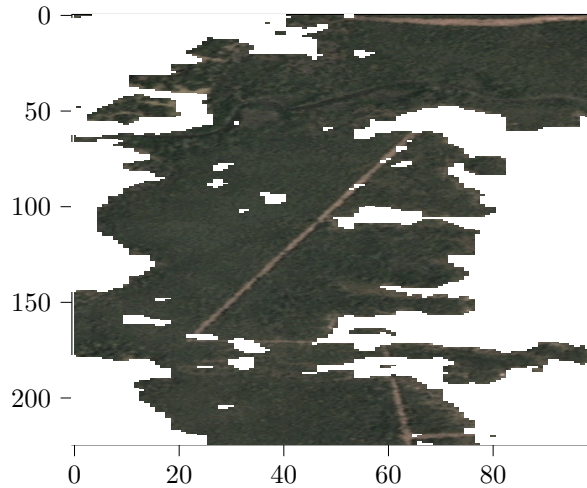
Correcting this would require either using a more up-to-date land cover product or trimming the end of the dataset.

The river is classified as forest in the land cover. It is probably possible to discriminate between it and the paths, as the river’s intensity is expected to be lower. A second threshold might be enough. In the meantime, the river in this dataset has been added to the ground-truth mask.

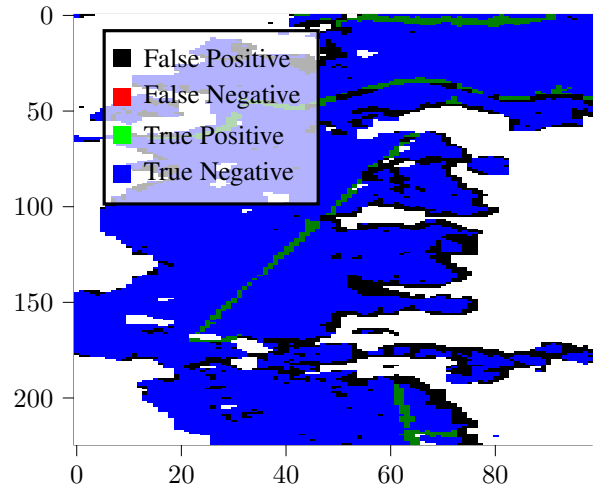
A ROC curve (Fig.2) was generated using our dataset and ground-truth mask. Our technique’s good performance is confirmed by an AUC score of 0.911.

### 4. REFERENCES

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(a) Optical image [9]



(b) Labelled output image

**Fig. 3.** Optical image and labelled output image for the area of interest. The threshold used is  $-7.5$  dB. The landcover mask [5] is represented by the white areas.

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