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# TEMPORAL STACK SPECKLE AND TARGET FILTERING FOR ENVIRONMENTAL APPLICATIONS

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## ABSTRACT

SAR images are affected by speckle noise and the presence of ephemeral targets. We propose a method to filter both from individual images in a temporal stack through the use of a modified Frozen Background Reference (FBR) algorithm. We tested this on a 30-image stack of Sentinel-1 data over a region with different environments and a fair appearing on a few images.

**Index Terms**— SAR, Sentinel-1, time-series, speckle filtering, FBR.

## 1. INTRODUCTION

Some satellites with Synthetic Aperture Radar (SAR) offer the possibility of building time series of SAR images. They thus provide us with an additional dimension to extract information from. This is useful for a wide range of applications such as disaster analysis/prevention [1], agriculture monitoring [2, 3], environmental monitoring (deforestation [4], glacier [5], etc.)

It is well known that a typical issue with SAR is speckle. It is generally filtered within a single image using various techniques. Conversely, several filters have been developed along the time dimension (with or without the space dimension), like the multi-temporal filter of Quegan [6]. Another example is the Lê et al. filter [7], which builds a change matrix (using the coefficient of variation), then replaces the stable points by their average.

We propose using the time dimension to filter a SAR time series by adapting a work [8] previously developed by some of the authors for change detection in a time series. The basic idea of the latter was to create a reference scene without any target. This was done pixel by pixel by using the temporal Coefficient of Variation (CV) to detect and reject temporary changes.

Here, we focus on environmental applications. The idea is to use the CV to detect short and intense variations (whether due to speckle or targets) and remove them. The time series is then reconstructed through interpolation. A great advantage is that it should preserve any seasonal variations.

## 2. PRINCIPLES

The method consists of first using a modified Frozen Background Reference (FBR) algorithm on a temporal stack of SAR images to detect temporally anomalous pixel values and second, replacing said values in the individual images with one respecting certain conditions.

### 2.1. Classical Frozen Background Reference algorithm

Our objective is to remove speckle and ephemeral targets using the temporal diversity of a stack of SAR images instead of spatial filtering. That way, it is possible to avoid the loss of spatial resolution that comes from its use. Colin Koeniguer and Nicolas state that the temporal CV possesses interesting properties that should enable us to separate speckle and ephemeral targets from permanent scatterers and the scene's background [9]. The Frozen Background Reference algorithm [8] made use of these properties. In its original application, it creates a SAR image devoid of ephemeral targets from a provided temporal stack. To do this, and for each spatial pixel, it iteratively removes the value furthest away from the average intensity of said pixel's temporal profile as long as its coefficient of variation is higher than the theoretical CV of speckle  $\gamma$ , defined by:

$$\gamma = \sqrt{\frac{\Gamma(L)\Gamma(L+1)}{\Gamma(L+1/2)^2} - 1}$$

where  $\Gamma$  is the *gamma* function, and  $L$  is the Equivalent Number of Looks (ENL).

Because the mean of the temporal profile is recomputed at each iteration, removing a high-intensity value could lead to a feedback loop causing the script to converge toward the low-intensity values. Some modifications are then required to correct this behavior.

### 2.2. Modified FBR algorithm

A possible solution would be not to recompute the mean (i.e., always use the first temporal average as the reference when looking for the value to remove). This would sometimes cause the opposite effect: the algorithm would converge

toward the high-intensity values, as shown in Fig. 1 (Interpolated Data (locked)).

A compromise is finding a criterion to trigger the recomputing of the mean. Because the feedback loops are caused by extreme values which separate initial and final average intensities, we decided to use the ratio of the reference mean and the current mean. If they are separated by a certain percentage (i.e., when an extremum caused the reference mean to be inaccurate), we use the current mean as the new reference. This leads to a better selection of valid pixels, as shown in Fig. 1 (Interpolated Data (criterion)).

### 2.3. Pixel replacement strategies

While the FBR was initially used to produce a unique image free of ephemeral targets from a SAR stack, we instead want to filter each individual input image. Therefore we must find new values for the removed pixels.

One solution is to use the temporal mean of the valid temporal values. This is relatively simple to implement and might be enough for some applications or for spatial pixels where the temporal profile is supposedly random. Likewise, a random value selected in the range of valid pixels could preserve the randomness of the profile, as long as the distribution parameters are correctly determined.

When invalid pixels are spread spatially, it is also possible to use the interpolation of their neighbors to replace them.

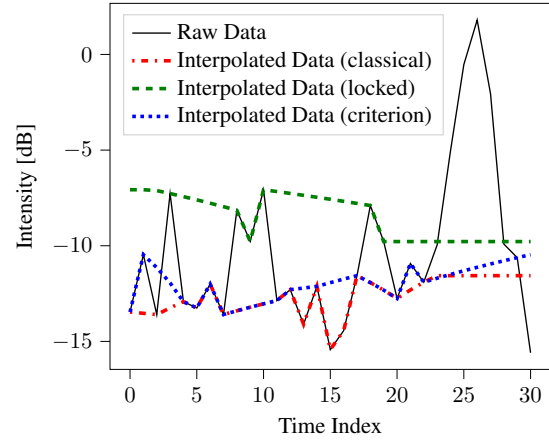
When the temporal profile is supposed to follow a pattern, or when no hypotheses are made, invalid pixels can be interpolated temporally instead. This is what was done in this article: we used linear interpolation to generate our figures, dates outside the range of valid indices were extrapolated, and their values were clipped between the maximum and minimum correct values.

## 3. TEMPORAL STACK FILTERING OVER PARIS, FRANCE

In this section, we will compare raw SAR images with the outputs from a (spatial) Lee filter [10], a (spatio-temporal) Quegan filter [6], and our method. SAR temporal means and optical images are also provided for reference.

The *Bois de Boulogne* is one of two large Parisian parks. It is located in the 16<sup>e</sup> *arrondissement*, on the city's western side. We have decided to focus on a particular part of it centered around the *Pelouse de la Muette* (Fig. 2a). This clearing splits parts of the forest and links the *Lac Inférieur* (left of the image) with the city (right). The *Pelouse* is known for periodically hosting a fair (Fig. 2b). The Parisian *Périphérique* (large road encircling Paris) is also present in this area. It passes through tunnels in two sections: a long one next to the *Pelouse* and a smaller one further south. The latter is particularly noticeable on the SAR temporal mean (Fig. 2c) as trees are visible instead of the expected low backscatter. We

Temporal profile for a pixel of interest (Ascending, VV, dB)



**Fig. 1:** Temporal profile for a pixel on the *Pelouse de la Muette*. *Classical* is the output of the original FBR algorithm (i.e., the reference mean is recomputed at every iteration). *Locked* is the output of the modified algorithm when only the initial mean is used. *Criterion* is the output when the mean is recomputed only when the ratio criterion is fulfilled. Linear interpolation with clipped extrapolation was used to replace temporally anomalous values.

can also notice that the clearing itself cannot be easily distinguished from the forest.

The raw image (Fig. 3a) is as expected: contiguous black areas for the water, high-intensity areas for the buildings (lower right corner), and medium intensity for the forest. The roads and the *Pelouse* can be detected as a drop in backscattering between the two parts of the forest and between the forest and the city.

The Lee-filtered image (Fig. 3b) still shows all of this but is quite blurry.

The Quegan filter (Fig. 3c) provides a better result than Lee in terms of spatial resolution/blurriness, but the temporal averaging lessens the image's temporal individuality.

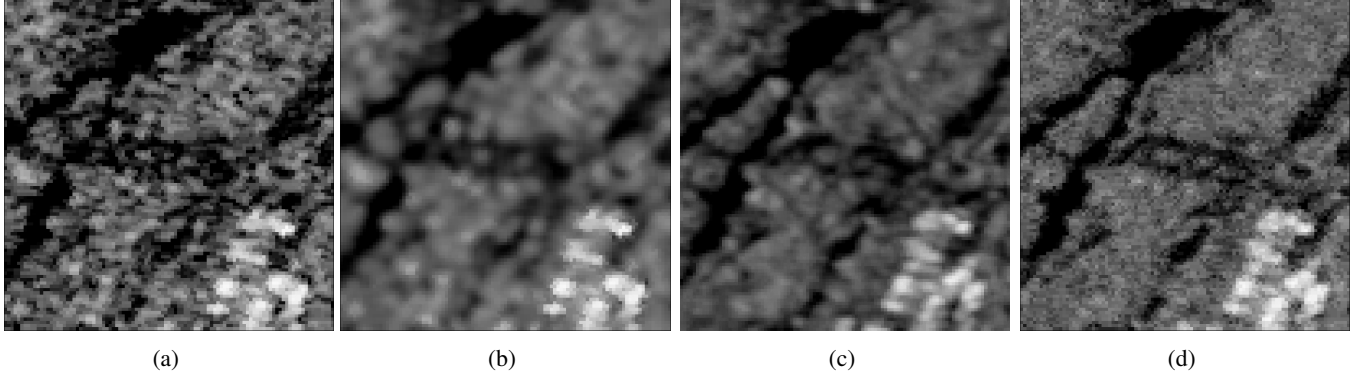
Our technique (Fig. 3d) removes the speckle without reducing the spatial resolution. Therefore the shapes of most targets fit well with their counterpart in the temporal mean. Furthermore, only temporally aberrant values are modified: the image is partly unchanged (table 1).

One notable exception is the *Pelouse*: the temporal mean (Fig. 2c) has a considerably higher intensity because it incorporates the very high backscatter of the fair that is present on a couple of dates within the stack (Fig. 4a for example). Our method is not affected by this and therefore produces a faithful correction of the raw image.

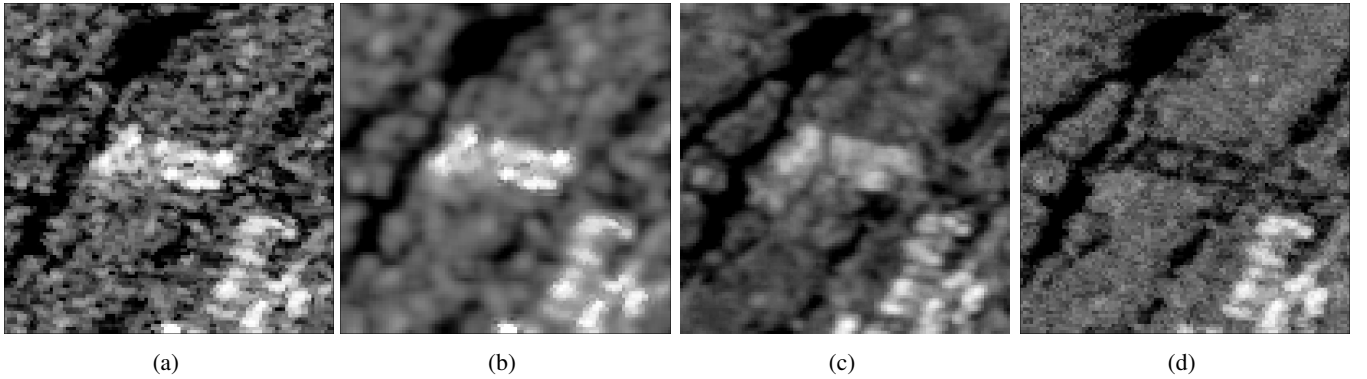
In fact, as the fair is considered an anomaly by the FBR algorithm, and its corresponding pixels are marked for replacement, we are able to remove it from images where it should be present (Fig. 4d).



**Fig. 2:** Parts of the *Bois de Boulogne*: (a) annotated optical image without the fair (2020/04/24, © Planet Labs PBC [11]), (b) optical image with the fair (2020/09/13, © Planet Labs PBC [11]), (c) temporal mean of SAR images (Ascending VV, 30 dates).



**Fig. 3:** Sentinel-1 SAR image of *Bois de Boulogne* taken on 2020/04/22 (Ascending VV, no fair): (a) raw image, (b) filtered using Lee filter (5x5), (c) filtered using Quegan filter with a Lee filter (5x5), (d) filtered using our technique.



**Fig. 4:** Sentinel-1 SAR image of *Bois de Boulogne* taken on 2020/09/13 (Ascending VV, fair): (a) raw image, (b) filtered using Lee filter (5x5), (c) filtered using Quegan filter with a Lee filter (5x5), (d) filtered using our technique.

Lee (Fig. 4b) and Quegan (Fig.4c) filters cannot do this and produce a blurry image.

Some statistics of the difference between raw and pro-

cessed images (in dB) of the area of interest are provided in table 1. They were computed for both satellite directions (*ascending* and *descending*) and for every FBR version **after re-**

[dB]	Mean	Std	5 <sup>th</sup> %ile	95 <sup>th</sup> %ile	% of zeros
Asc v0	3.54	1.55	1.38	6.32	60.8
Des v0	3.65	1.74	1.38	6.77	60.8
Asc v1	3.41	1.70	1.16	6.48	57.2
Des v1	3.45	1.83	1.15	6.73	57.2
Asc v2	3.29	1.57	1.17	6.11	59.3
Des v2	3.39	1.75	1.15	6.54	58.9
Quegan	1.40	1.23	0.10	3.75	0.00

**Table 1:** Statistics of the differences of backscatter (in dB) between the raw images and the filtered ones **after removal of zeros** over the *Pelouse de la Muette*, for both satellite directions and every FBR version (v0, v1, and v2 meaning *classical*, *locked* and *criterion*, respectively). Left to right: the mean, the standard deviation, the 5<sup>th</sup> and 95<sup>th</sup> percentiles, and the percentage of 0 dB values.

**moval of zeros.** The table therefore describes the statistics of the modified pixels. Our method leaves roughly half the pixels untouched (last column). However, it probably depends on the temporal behavior of the scene. Statistics for Quegan (last line) were also provided: it modifies every pixel, but not as strongly (mean difference more than halved and lower standard deviation).

#### 4. CONCLUSIONS

Through the use of a modified FBR algorithm, we succeeded in removing ephemeral targets and reducing speckle from individual images within a SAR temporal stack without loss of spatial resolution. The effects over the temporal axis still have to be studied.

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