SAR : multi-temporal pile

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Abstract: Synthetic Aperture Radar images can be acquired in a long time frame, allowing to compute interferences if the acquisition trajectories of the aircraft or satellite are identical between each acquisition. Those interferences helps in understanding changes in environments : biomass evolution along seasons, greenhouse emissions in urban zones, buildings and structure demolition or construction and even vehicule position.

Keywords: SAR, multi-temporal pile.
OCIS codes: (000.0000) General.

References and links

1. "Introduction à l'imagerie SAR", N. Trouvé, IOGS **SAR** (2024).

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1. Introduction

The goal here is to compute the displacement speed of a vehicule located over La Seine in Paris between two acquisition dates. For that we will make the important hypothesis that the acquisition was made in "Stripmap" mode. First, we computes minimal resolution in this context, then compute the acquisition on-ground dimensions, bandwidth and antenna size to conclude if the assume mode was correct. Second, we will change the dynamic of the acquired images in order to enhance the contrast of details. We will then compare two pictures with different acquisition dates, and applying a threshold will help in distinguishing changes between the two. Finally we will use a lowpass filter the filtering out the speckle noise, and ultimately compute the speed of a moving object.

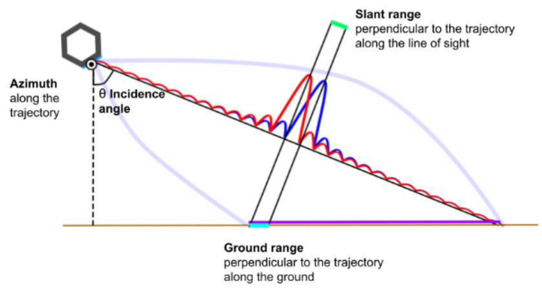


Fig. 1: Geometry of SAR imaging

The file `Ville1.npz` contains:

1. A matrix (`parametre_image`) of size $N_r \times N_c \times 4$, which represents a temporally aligned stack of 4 images acquired by the TerraSAR-X satellite (X-band, wavelength of 3.1 cm, parameter `l_onde`).
2. The acquisition dates, provided as a character string in the format `YYYYMMDD` (parameter `vec_date`).
3. The baselines between the 2nd, 3rd, and 4th acquisitions relative to the first, which is considered the reference (parameter `vec_baseline`).
4. The satellite's flight altitude, which is 514 km (parameter `H`).
5. The incidence angle in degrees (parameter `theta`).
6. The pixel size in meters:
   - In slant range (parameter `taille_pixel_slantrange`), corresponding to the image columns.
   - In azimuth (parameter `taille_pixel_azimut`), corresponding to the image rows.

2. Acquisition mode : stripmap or spotlight ?

Minimal resolution in stripmap mode

We have from [1] the following expressions, that allows to compute the azimuthal minimal resolution δ_{Az}, with c the speed of light, r the distance to the target, f_0 the frequency of the radar wave, T_{obs} the integrating time and V_{air} the velocity of the radar carrier. W_x is the on-ground azimuth swath dimension in the x direction, L_x the antenna width, λ the relative wavelength, ψ_x the azimuthal aperture angle.

$$\delta_{Az} = \frac{c.r}{2.f_0.T_{obs}.|V_{air}|} \tag{1}$$

$$\begin{aligned} T_{obs,max} &= \frac{W_x}{|V_{air}|} \\ \delta_{Az} &= \frac{c.r}{2.f_0.W_x} \\ \psi_x &= \lambda/L_x \\ W_x &= r\psi_x = r\lambda/L_x \end{aligned}$$

so

$$\delta_{Az} = \frac{L_x}{2} \tag{2}$$

The `Ville1.npz` file contains necessary data to first compute the azimuthal pixel size to then derive the antenna size and compare it to the true dimensions given by the Airbus datasheet. Then can be computed the resolution, using the bandwidth of the radar emitter.

```
['image', 'l_onde', 'theta', 'H', 'vec_baseline', 'taille_slant_range', '
vec_date', 'taille_pixel_azimut']
```

Listing 1: Importing `Ville1.npz` data

Antenna size and acquisition mode

To compute the pixel size, it is only necessary to compute the projection of the slant range onto the ground (see Fig. 1). Then, multiplying by the image dimensions in x and y directions gives the directional on-ground swath.

```
On-ground pixel pitch is 0.799 m.
The 4 images are contained within an array of shape (2002, 2001, 4).
The on-ground dimensions of the EM beam is 1599.598 m (slant) by 1723.959
m (azimuth).
```

Listing 2: Computed pixel pitch and Swaths

The resolution is different in distance and in azimuth since that, for the distance, the image results from the correlation between the chirps received and emitted, and in azimuth it is the synthetic radar method that is employed. Resolution in distance is given by : $\delta_r = c/2B$. The slant resolution is then compared with the provided balue in order to extrapolate this proportional factor to the azimuthal resolution from pixel size.

```
The slant resolution is 0.5 m which is compared to the given slant pixel
size 0.455 m.
The ratio between the resolution in distance and the parameter pixel_size
 (slant) is R = 0.91 P.
So the azimuthal resolution is R_a = 0.784 m.
Then, the size of the antenna can be computed, taking this resolution as
the best one : L = 1.568 m.
```

Listing 3: Slant and Azimuthal resolution

Because the informations provided by Airbus are 4,78 m in distance (azimuthal) and 0,7 m in distance, and since we computed an antenna azimuthal size of 1,6 m, the hypothesis needs to be rejected. The acquisition was made in spotlight mode.

3. Multi-temporal pile : computing speed of moving object

The original images have a wild dynamic. This means that the minimum and maximum received intensities are so different that the received intensities close to the average are not visible directly (Fig. 2).

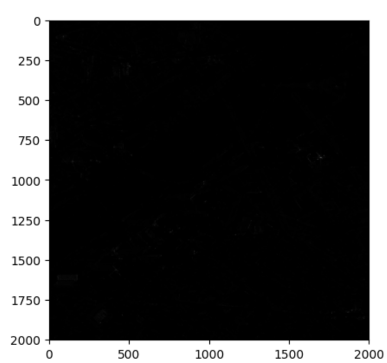
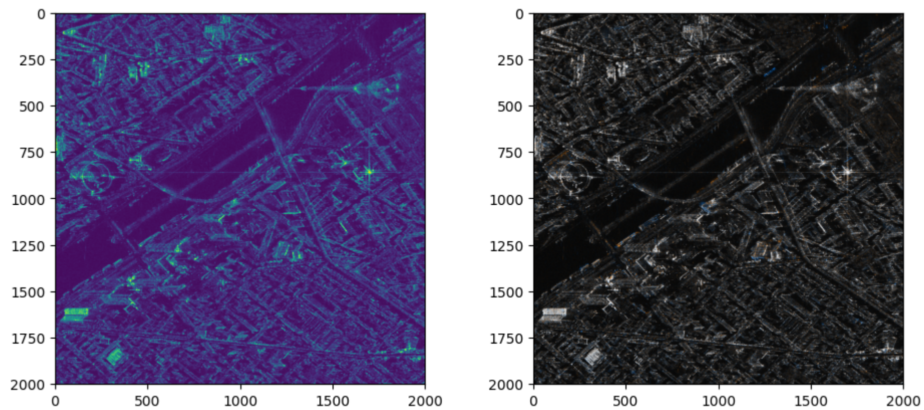


Fig. 2: Original image

The threshSAR function computes the normalized image between the minimal value of the image set as zero and a maximal value computed as the mean plus a times the standard deviation of the modified image, with a a user defined parameter, and finally multiply it by a constant.

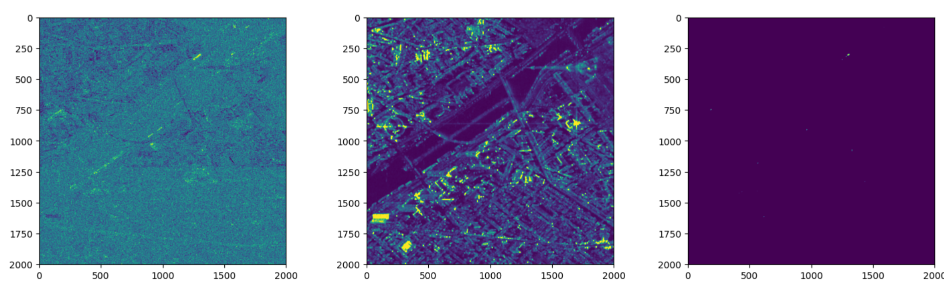
This formula is more versatile and very simple to understand. Typical values of σ will range from 0 to 3, above which only a few outliers will be saturated. This method allows to adapt the range of highlighted dynamic range to each image.



(a) threshSAR (b) imCompareSameDynamicMax

Fig. 3: Comparing images with enhanced identical dynamics

To compare the two images, the function imCompareSameDynamicMax is used, which code describe that the image of reference, im1 here, will be displayed in blue, when the compared image, im2 here, will be displayed in red (or orange). The green channel of the image is composed of the mean im1+im2 / 2, which completes a second channel (the green one) for both images.



(a) dividing pixels to pixels (b) boxcarFilter (c) threshold

Fig. 4: Pixel to pixel comparison and filtering of Speckle noise

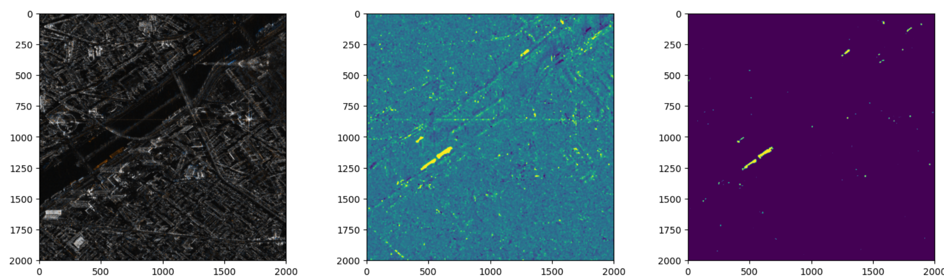
Because of the speckle, images are very noisy (Fig; 5a). To remove this noise, the boxcarFilter function of the provided package is employed. The size of the convolution kernel, ie the window, defines how far the filter will search in the surrounding pixels to compute the mean. Usually, we select a odd number so that the indow is centered on the focused pixel. The larger the window, the larger the focused pixel is spread on the image (Fig. 5b). Finally, one can apply a threshold to the image in order to keep only changing values above or under a givven value, 10 here on Fig. 5c.

This method can be employed with two given images, here one from February, 11th, 2009 and one from April, 22nd, 2009. Looking at pixels (320,1250) for the February picture, and

(450,1550) for the picture taken in April it seems that a vehicule, that may be a boat has moved. The images are very distant on a temporal basis, howver the speed can still be computed. Converting the on-image traveled distance dn from pixels to meters $dn.pa$, the target-carrier distance r and the speed of the carrier V_s, according to the following formula :

$$v = \frac{dn * pa * V_s}{r} \tag{3}$$

The traveled distance (in pixels) needs to be the one projected against the carrier trajectory. The Eiffel tower layover reveals the trajectory of the satellite, which is orthogonal to the layover. Here, the trajectory is vertical. We then have to compute the projection over the vertical (azimuth) of the displacement of the two selected changes, one on each image 20090211 and 20090422.



(a) Comparison with identical dynamic (b) Filtered pixel to pixel comparison (c) Threshed pixel to pixel comparison

Fig. 5: Image 20090211 and image 20090422 pixel to pixel comparison

We thus obtain a traveling speed of 4,8 $\mathrm{km.h^{-1}}$ which is relevant for a boat. However the time frame are two far to be consistently used in the speed computation here.

```
The speed of the observed vehicule was 4.781 km/h, heading from the
southern riverside to the northern between 2009 02 11 and 2009 04 22.
```

Listing 4: Outputs

4. Conclusion

The ultimate goal of this study was to compare time-distant SAR images and compute traveling speed of moving objects. First the acquisition mode was retrieved, using the minimal on-ground resolution and antenna size, then the comparison between SAR images was done using enhancement of dynamics and filtering. Retrieving the trajectory of the carrier allowed to compute the moving speed of an object associated to a boat on the river La Seine.

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