Interferometric Analysis of Raw Data for Radio Frequency Interference Detection in ALOS-2

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Abstract

In this paper, we propose a novel radio frequency interference (RFI) detection method for multi-receiver SAR systems. The approach is based on the differences between scattered radar echoes and direct signal of RFI, and further assumed that RFI signals have more similarity than echoes in a multi-receiver SAR system. Based on this idea, we developed an interferometric analysis method for separating RFI polluted bands from the SAR raw data. Experimental results show an effectiveness of the proposed method by reducing the noise level in the sea area by up to 3dB.

1 Introduction

Radio frequency interference (RFI) is a continuous problem for both radiometry and synthetic aperture radar (SAR) [1]. Especially for L-band SAR, it shares the bandwidth with, for example, global navigation satellite systems (GNSS), telecommunication and aircraft surveillance radars. RFI detection in SAR has been mainly approached by spectrum-based methods, which detect abnormally strong signals in the radio frequency domain. We generally expect that RFI sources transmit their signal continuously in a relatively narrow bandwidth (e.g., GNSS or telecommunication) or instantly in a wide bandwidth (e.g., surveillance). In other words, RFI is statistically distinguishable when we analyse the radar echo in the time-frequency domain. One drawback of this approach is that it becomes undistinguishable when the RFI signal has the same or weaker power than radar echo, a narrower bandwidth and/or a shorter duration.
Some of the latest SAR systems carry multiple receivers in order to increase their swath by exploiting the discrete phase center (DPC) approach, digital beam forming (DBF) and / or perform along track interferometry (ATI). The principle purpose of placing multiple receivers is to distinguish slight differences of the scattered echo in those receivers so that we can extract the targets' information further. From the point of view of RFI detection, those receivers can be used for advanced detection methods.
In this paper, we propose an interferometric approach to detect RFI-polluted bands. SAR antennas receive slightly different radar echoes each other because of their displaced phase center. On the other hand, RFI signals are recorded with the same phase pattern for all receivers. That is, RFI signals are more coherent between the receivers.
Based on this idea, we made an interferogram between two received channels in the frequency domain of raw data to identify high coherent bands. Experimental results using ALOS-2 data showed that the proposed method can detect RFI polluted bands for every echo line and improve the SNR with a 3 dB improvement when compared to conventional spectrum-based approaches.

2 Interferometric coherence of raw frequency images

In the rest of this article, we describe the methodology particularized to the case when the number of receivers is 2 which is the most basic situation and corresponds to the configuration of ALOS-2. Needless to say, the theory can be easily extended to 3 or more receivers.
If a signal *g(t)* is received by two antennas namely Rx1 and Rx2, the time difference *D* between the antennas is a function of the incidence angle θ as follows.

$$D = \frac{L \sin\theta}{c} \tag{1}$$

where *c* is the speed of light and *L* is the distance between Rx1 and Rx2. That is, $Rx1(t) = g(t)$ and $Rx2(t) = g(t-D)$.
In RFI free case, the received signals are the summation of the scattered radar echo and thus, Rx1(t) and Rx2(t) have relatively low correlation, since it is assumed that the system pulse repetition frequency is not sufficiently high to allow SAR data correlation between the channels. When one signal dominates the others, the correlation increases.
RFI is an example of such a dominating signal. Therefore, if we can estimate θ (or *D*) and *g(t)*, it is easy to subtract RFI. Several Direction of Arrival (DoA) estimation methods have been proposed. The difficulty in those methods is that most RFI in spaceborne SAR comes from the same direction as that of the scattered echoes [2].
On the other hand, if we can measure the correlation of the arrived signals between Rx1 and Rx2 directly, it becomes easier to detect RFI.
Here, we describe an interferometric analysis in the frequency domain of raw data as follows. For L-band SAR,

most RFI sources are GNSS and telecommunication systems, which use narrower band than SAR does. On the other hand, those RFI sources transmit their signal continuously. Such a feature makes it difficult to calculate the correlation in the time domain (i.e., Rx1(t) and Rx2(t)). As they have narrower bandwidth, it is reasonable to detect them in the frequency domain (Rx1(f) and Rx2(f)) by searching the higher correlation band than the other bands.
As shown in (2), the Fourier transformation for the time shifting is a shift in the phase.

$$g(t-D) \xrightarrow{FT} G(f)exp(-j2\pi Df) \quad (2)$$

It means that the phase difference is proportional to the frequency and the property of the RFI signal *G(f)* is common to all receivers. Therefore, if we calculate the phase gradient of the interferogram of Rx1(f) and Rx2(f), RFI-polluted band becomes constant (3).

$$I(f) = \left(R_{x1}(f)R_{x2}^{*}(f)\right) \quad (3)$$

where * is complex-conjugate. In other words, highly polluted bands have a constant phase slope in (3). It can be detected by calculating the interferometric coherence in (3). Interferometric coherence $\Gamma(f)$ is calculated as (4).

$$\Gamma(f) = \frac{|\sum I(f)|}{\sqrt{\sum |R_{x1}|^2 \sum |R_{x2}|^2}} \quad (4)$$

where the bracket is absolute and Σ represents summation of the sampled signals. If an identical signal is received by two receivers, $\Gamma(f)$ becomes 1. If multiple signals arrive from multiple directions, $\Gamma(f)$ becomes smaller. In RFI-polluted case, $\Gamma(f)$ can be maximized by estimating *D*.
The merit of this method is its accuracy and simplicity. As it does not require temporal window, it can detect RFI pulse-by-pulse. It only requires a specific frequency window to calculate the correlation coefficient. In this manner, it is possible to calculate the correlation $\Gamma(f)$ and find RFI-polluted bands for every pulse.

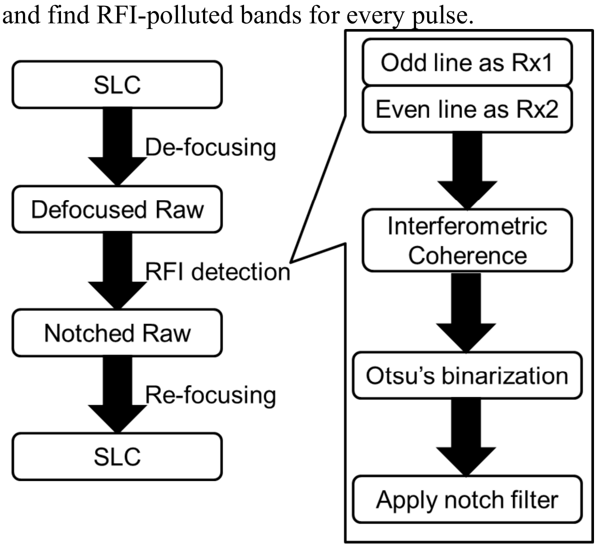

Figure 1 Flowchart of the proposed method for ALOS-2.

The processing flow is shown in Fig. 1, particularized to the ALOS-2 case. As ALOS-2 raw data is undisclosed, we firstly de-focused the single-look-complex (SLC) data. In the raw data, the signals of Rx1 and Rx2 are reconstructed into one raw, whereby the parameters for the reconstruction are unknown. Therefore, we assumed that the neighbouring lines represent two receivers. Here, we processed odd and even lines as Rx1 and Rx2, respectively. If the parameters are known, the method can be applied to recovered Rx1 and Rx2. Finally, we applied Otsu's binarization method [3] to apply the notch filter based on the interferometric coherence.

3 Experimental results

We used ALOS-2 PALSAR-2, 3m-resolution, HH polarized data in Tokyo bay, Japan. The observation date is Nov. 9, 2015.
Fig. 2 shows the recovered raw image and its frequency image. In the raw amplitude image, the contribution of RFI is not significant, because most of the RFIs are narrowband and spread over the raw image. We can see some bands are cut by the ALOS-2 operational SAR processor, though some minor but strong narrowband signals remain.

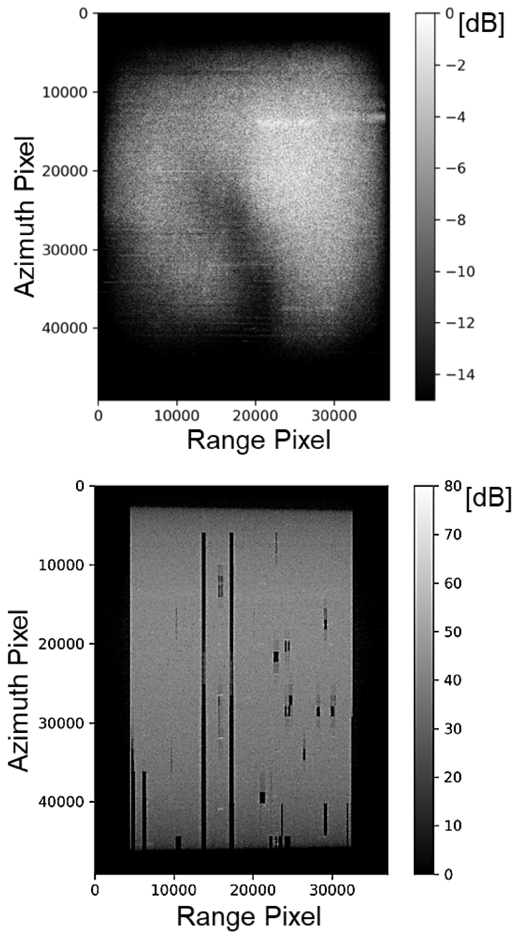

Figure 2 Top: De-focused raw and Right: its frequency spectrum (in dB).

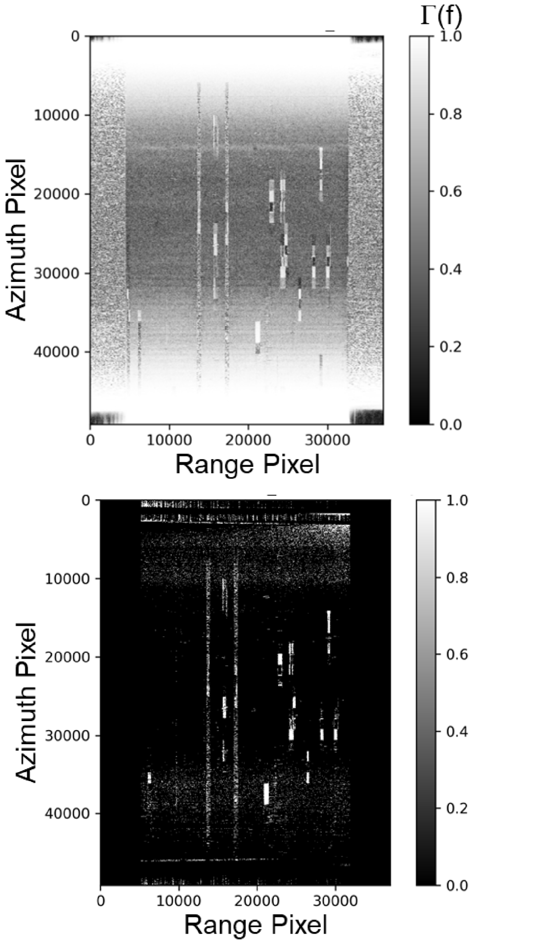

Figure 3 Top: Interferometric coherence of Rx1 and Rx2 and, Bottom: Detected RFI polluted band.

Figure 3 presents the detection result. We can see that top and bottom part of the scene have high coherence. This is because the recovered raw doesn't contain enough radar echo in those regions as the half of the impulse response function was removed during SAR processing. Note that a zero-padding in time domain was applied in order to avoid folding when decompressing the data. By exploiting Otsu's binarization method, the highly coherent regions in those areas are mostly rejected, but remaining narrowband RFI signals in the middle are notched.

Finally, we obtained the notched raw image as shown in Fig. 4. The raw amplitude image seems identical to that in Fig. 2. However; narrowband RFI signals are mostly removed in the spectrum domain.

Numerically, the RFI-free bands have an interferometric coherence $\Gamma(f)$ up to 0.5 while 0.8 for the polluted bands. Fig. 5 shows the cut out of the averaged spectrum between 22510 th to 25540 th lines. The graph shows the averaged spectrum of every 10 echoes. Some strong (up to 10 dB) peaks can be seen. However, most of those peaks are not higher than 3-6 dB and thus, difficult to detect with spectrum-based method. However, once we calculate $\Gamma(f)$, those peaks show significantly high values in terms of coherence.

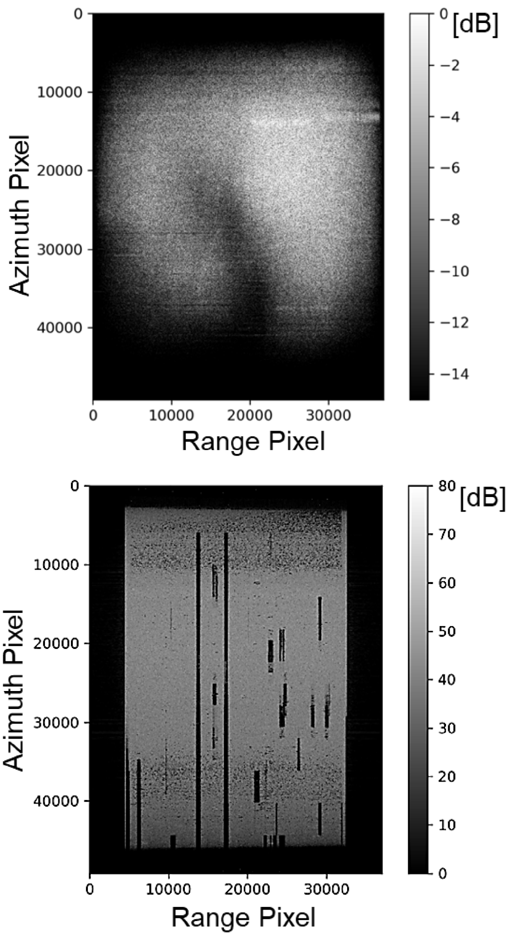

Figure 4 Top: RFI suppressed raw and Bottom: its spectrum (in dB).

Finally, we compare the amplitude of SLC as shown in Fig. 6. By comparing the amplitude in the ocean region, we found that the amplitude of ocean region dropped from -13.2 dB to -16.5 dB.

4 Conclusion

In this paper, we have presented a novel RFI mitigation method for multi-channel SAR systems, which is based on the exploitation of the interferometric coherence between adjacent channels. The proposed method enables line-by-line RFI detection by searching the identical signals in multiple receivers. Experimental results show the effectiveness of the proposed method, in spite of the fact that the results have not been obtained by directly applying the method to the original multi-channel raw data. Instead, an azimuth decompression was necessary to retrieve the reconstructed raw data. Future work will focus on the application of the proposed approach to the original multi-channel SAR raw data.

5 Literature

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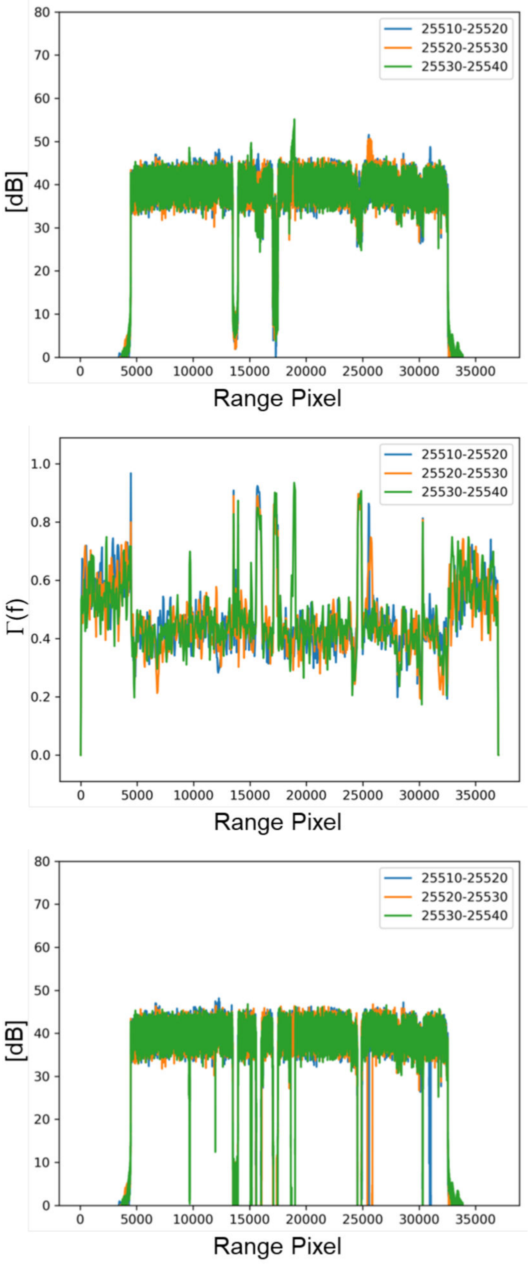

Figure 5 Cut out for averaged spectrum in 25510 – 25540 lines. Top: RFI contaminated spectrum, Middle: Plot of *Γ(f)* and, Bottom: Notched spectrum (in dB).

6 Acknowledgement

The ALOS-2 original data are copyrighted by the Japan Aerospace Exploration Agency (JAXA) and provided under JAXA 6th ALOS Research Announcement PI No. 3044.

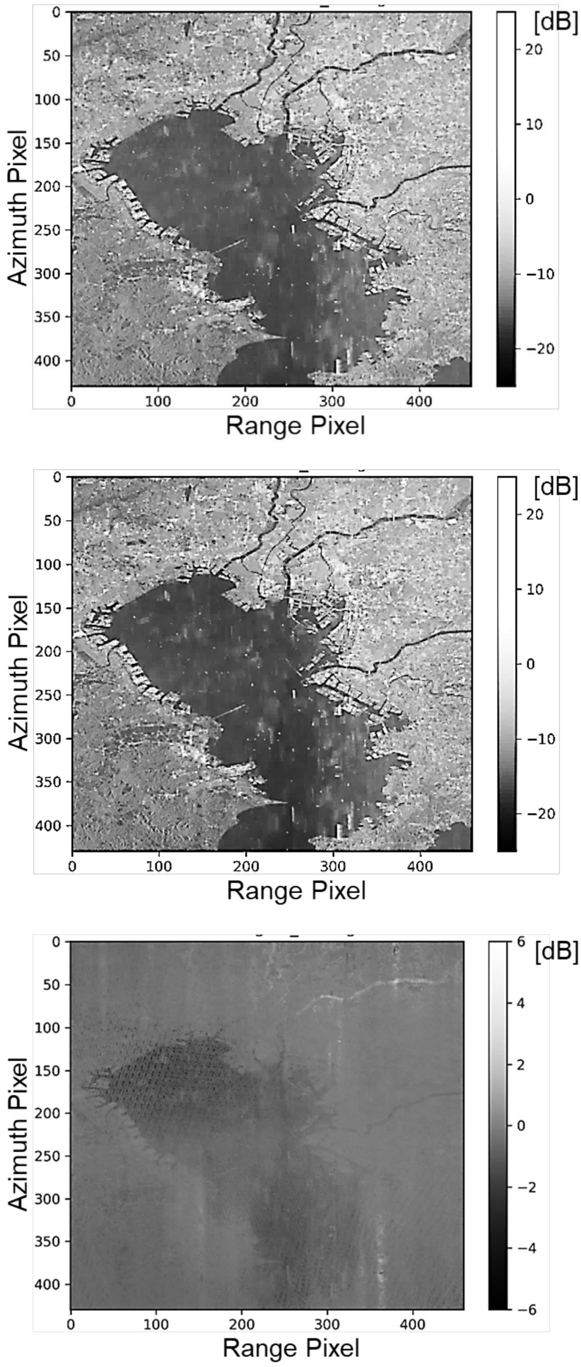

Figure 6 Difference in SLC: Top: RFI contaminated, Middle: RFI removed and Bottom: Difference (in dB)