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Change Detection Method for Intensity VHF Wavelength-Resolution SAR Images

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ABSTRACT

This paper presents the proposal of a new change detection method for intensity VHF wavelength-resolution images. High-amplitude pixels are related to the presence of strong scatterers, resulting in high detection probability performance. However, the number of false alarms tends to be high too. To reduce the influence of the strong scatterers that are not related to targets, i.e., present in both surveillance and reference images, in this initial study, difference images are considered. The proposed change detection method is based on a likelihood-ratio test, where the tested hypothesis is the bivariate exponential distribution. The derivation of the proposed likelihood test is presented. Finally, the proposed change detection method is assessed considering data measured with the CARABAS II VHF UWB SAR system. Preliminary results show that the proposed method is efficient in detecting both positive and negative changes.

Keywords: Change detection method, CARABAS II, Intensity images, VHF UWB SAR

1. INTRODUCTION

Intensity images are commonly used on microwave SAR images as in Cha, He, and Huang papers, where intensity images were employed in the change detection for urban areas, ocean surface, and scenarios with low-intensity scatterers in the background\textsuperscript{1−3} However, this type of image is not commonly studied for very-high frequency (VHF) wavelength-resolution SAR images, which are frequently used for change detection methods in foliage penetration (FOPEN) applications. The intensity VHF wavelength-resolution SAR images are the type of image used throughout this paper.

Ultra-wideband (UWB) radars operating in VHF or ultra-high frequency (UHF) frequency bands provides SAR images that are characterized by a resolution in the order of radar signal wavelengths. Due to it, the images generated by these systems are frequently named wavelength-resolution SAR images. Since the wavelengths in the VHF frequency band are in the order of a few meters, the influence in the detection of small scatterers in ground area of interest is mitigate, i.e., scatterers with dimensions significantly smaller than radar signal wavelength. Additionally, large scatterers, i.e., with bigger dimensions than the radar signal wavelength, tend to be stable in time and less influenced by environmental effects, as proved in Smith\textsuperscript{5} Wavelength-resolution SAR images are nearly speckle-free, removing the necessity of using any technique of despeckling, as proved by Machado\textsuperscript{4} This kind of image is frequently used for the detection of concealed targets in regions with high-density vegetation, as seen in Ulander\textsuperscript{6} Therefore, wavelength-resolution SAR images are a good solution for FOPEN applications, especially for the detection of concealed targets using change detection (CD) methods without using clutter reduction techniques, as was widely discussed by Vu, Lundberg, and Ulander\textsuperscript{7−9}

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Change detection methods for wavelength-resolution SAR images are a research topic of interest. Considering this specific kind of image, several change detection methods presenting a high performance in terms of the probability of detection with a lower level of false alarm rate (FAR) have been proposed by Vu, Lundberg, Ulander, Palm and Ramos. Recently, change detection methods considering non-orthodox methodologies have been proposed presenting some performance gains. For instance, the use of machine learning and neural networks were considered in Campos, the use of using small stacks of images was explored in Vu, and one implementation using the Bayes theorem, as in Alves. However, to the best of the author’s knowledge, there are no studies regarding the use of Intensity VHF wavelength-resolution SAR images for change detection methods.

Combining the characteristics of the SAR intensity images with the advantages of wavelength resolution SAR images, this paper presents a new change detection method and some preliminary results.

Combining the characteristics of the SAR intensity images with the advantages of wavelength resolution SAR images, this paper presents a new change detection method and some preliminary results. The method consists in the use of the Bivariate Exponential distribution on a likelihood-ratio test (LRT) considering intensity VHF wavelength-resolution SAR images as input. This method is initially assessed considering the data set obtained by UWB VHF SAR CARABAS II system. Experimental results are presented and discussions regarding its performance in terms of the probability of detection and false alarm occurrence are provided.

The contributions of this paper are the following:

- Derivation of a likelihood-ratio test for a new change detection method;
- Evaluation of the method considering some samples of the available image data set;
- Three results cases are discussed, considering three different types of images used as input.

The following sections are organized as follows. Section 2 presents the database considered in this paper. Section 3 derivation of a likelihood-ratio test for a change detection method, which is also described in this section. Section 4 presents the simulation results and some discussions. Finally, Section 5 presents some concluding remarks.

## 2. DATA DESCRIPTION

The SAR images used in this paper were obtained using the UWB VHF SAR CARABAS II system. The data set is provided by FOI and has been published by Air Force Research Laboratory (AFRL). This data set is composed of 24 incoherent wavelength-resolution SAR images.

The images were obtained from flight campaigns covering the same ground area of 2 km × 3 km forming a 6 km² images with a pixel size of 1 m × 1 m. These flight campaigns were held in the northern Sweden in 2002. The ground area is formed basically by forestry areas but containing some human-made structures, lakes, and fields.

For organization purposes, the 24 images were divided according to four different target deployments (missions) and six different flight scenarios (passes). Each image has 25 targets, which are terrestrial vehicles, and was formed by small, medium, and large vehicles. The images from the data set are already calibrated and geocoded. For the sake of simplicity, it is considered the same image classification as the one used in the FOI challenge paper. Finally, more information regarding the evaluated data set can be found in Lundberg and Ulander papers.

## 3. CHANGE DETECTION ANALYSIS

The proposed change detection for intensity SAR images is based on a hypothesis test to determine if a target is present or absent in a specific pixel position. The hypothesis test can be expressed as

\[ H_0 : z = q \quad \text{(no target)}, \]

(1)
where $H_0$ is the hypothesis that the evaluated pixel is background-related, and $H_1$ is the hypothesis that the evaluated pixel is target-related (change), $s$ is related to the target, and $q = c + n$, in which $c$ is related to the clutter and $n$ to the noise. The approach commonly used to address this topic is the use of likelihood-ratio tests.

### 3.1 Likelihood-ratio Test

As previously mentioned, the proposed target detection method for VHF UWB SAR intensity images is based on a Likelihood-ratio Test using the bivariate exponential distribution. The selection of the exponential distribution was based on the nature of SAR images and knowing that the SAR intensity images are frequently modeled using the exponential distribution, as seen in Oliver.\(^{16}\) The probability density function (PDF) of the bivariate exponential distribution, from Nadarajah can be written as\(^{17}\)

$$f(x, y) = \frac{\mu_1 \mu_2}{1 - \rho} \exp \left[ - \frac{\mu_1 x + \mu_2 y}{1 - \rho} \right] I_0 \left[ \frac{2\sqrt{\rho \mu_1 \mu_2 xy}}{1 - \rho} \right],$$

where $\mu_1$ and $\mu_2$ are defined as the inverse of the expectations of $X$ and $Y$, respectively, $\rho$ is defined as the correlation coefficient between $X$ and $Y$, and $I_0$ is defined as the modified Bessel function of the first kind of order zero.

The proposed likelihood test uses as input two SAR images, named as surveillance image, i.e., the image which is expected to contain targets, and the reference image, i.e., an image where no targets are considered, and can be written as

$$\Lambda(z) = \frac{P(z|H_1)}{P(z|H_0)},$$

where both $P(z|H_1)$ and $P(z|H_0)$ statistics are modeled using the bivariate exponential distribution, $z = (x, y)$, and $x$ and $y$ are the pixel intensity in evaluated position, respectively, in the reference and surveillance images. $P(z|H_1)$ represents the hypothesis where a target is observed in (2), and can be expressed by

$$P(z|H_1) = \frac{\mu_1 \mu_2}{1 - \rho} \exp \left[ - \frac{\mu_1 (x - S_x)^2 + \mu_2 (y - S_y)^2}{1 - \rho} \right] I_0 \left[ \frac{2\sqrt{\rho \mu_1 \mu_2 (x - S_x)^2(y - S_y)^2}}{1 - \rho} \right].$$

Otherwise, $P(z|H_0)$ represents the hypothesis where no targets are observed in (1), and can be expressed by

$$P(z|H_0) = \frac{\mu_1 \mu_2}{1 - \rho} \exp \left[ - \frac{\mu_1 x^2 + \mu_2 y^2}{1 - \rho} \right] I_0 \left[ \frac{2\sqrt{\rho \mu_1 \mu_2 x^2 y^2}}{1 - \rho} \right].$$

Thus, the likelihood test (4) can be written as

$$\Lambda(z) = \frac{\mu_1 \mu_2}{1 - \rho} \exp \left[ - \frac{\mu_1 (x - S_x)^2 + \mu_2 (y - S_y)^2}{1 - \rho} \right] I_0 \left[ \frac{2\sqrt{\rho \mu_1 \mu_2 (x - S_x)^2(y - S_y)^2}}{1 - \rho} \right] \times \frac{\mu_1 \mu_2}{1 - \rho} \exp \left[ - \frac{\mu_1 x^2 + \mu_2 y^2}{1 - \rho} \right] I_0 \left[ \frac{2\sqrt{\rho \mu_1 \mu_2 x^2 y^2}}{1 - \rho} \right],$$

By considering that $S_x = 0$, i.e., no targets (positive changes) are present in the reference image and under simple mathematical simplifications, the likelihood test $\Lambda(z)$ can be written as

$$\Lambda(z) = \exp \left[ \frac{\mu_2 S_y (2y - S_y)}{1 - \rho} \right] I_0 \left[ \frac{2\sqrt{\rho \mu_1 \mu_2 x^2 (y - S_y)^2}}{1 - \rho} \right].$$

It is important to highlight that it is possible to detect negative changes by assuming different values of $S_y$ or by evaluating $S_x$ instead of $S_y$. However, considering the characteristics of the selected data set, in this paper’s evaluation we focus on the detection of positive changes ($S_x = 0$). Additionally, for the sake of simplicity, $S_y$ was substituted by $s$ throughout the rest of this paper.
3.1.1 Change Detection Method

The change detection method proposed in this paper is performed in two basics steps. First, the previously described Likelihood-ratio test is performed. Then, an optional step related to morphological operations is performed. Finally, a binary image is generated as the output of the processing chain, which is named detection image. A basic diagram block for the proposed change detection method is presented in Figure 1.

As observed in Figure 1, the first block is a likelihood test that uses as input one surveillance image and one reference image, which are intensity images obtained by using the operation $|.|^2$ in each pixel position of the original amplitude images. The proposed test (8) performs a thresholding operation that consists of assigning 1 when $\Lambda(z) \geq Th$ and assigning 0 when $\Lambda(z) < Th$, resulting in a binary image. Additionally, for the evaluated data set, the statistics were obtained considering a window of $100 \times 100$ pixels with a step of 10 pixels, in a similar way as Lundberg.\textsuperscript{8}

The second step is optional, which consists of morphological operations. These operations are selected according to the methods’ application specificity. For the application considered in this paper, similar morphological operations like the ones used in Alves and Vu.\textsuperscript{14,18} Additionally, the same structuring elements were applied. These operations are one erosion followed by dilatations, which mitigate the detection of changes related to isolated pixels and the multiple detections of the same targets.

4. EXPERIMENTAL RESULTS

The experimental tests were performed considering the proposed change detection method and using some images provided in the CARABAS-II dataset. For this initial study, the parameters used in the evaluation, e.g., “s” and thresholds were selected empirically.

The experimental results evaluations can be divided into three major cases. The first case considers the experimental setup presented in Section 3. Additionally, some discussion regarding the detection of elongated structures and the mismatch related to the clutter-plus-noise statistical model and the data are provided. To avoid the detection of the elongated structures, for the second case, the evaluation considers the proposed method in Section 3 using difference intensity images as input. It is important to highlight that this use of other images from the data set tends to result in other target-like pixels in the surveillance image. Finally, the third evaluation consists of using a ground prediction method present by Palm to obtain the difference image without including target-like pixels in the surveillance image.\textsuperscript{10}

4.1 Case I

For the first evaluation of the proposed method, Figure 2 presents an example of the binary output image, considering the use of empirically selected parameters. For this evaluation, the intensity constant was empirically set as $s = 0.6$ and using a threshold $Th = 10^4$. Figure 2(a) presents the binary output image when it is considered the inputs $M2P5$ (mission 2 - pass 5) as the surveillance image and $M4P5$ as the reference image. Similarly, Figure 2(b) presents the binary output image when it is considered the inputs $M3P2$ as the surveillance image and $M5P2$ as the reference image. The selection of these image pairs was made to present a case with the absence of elongated structures and a case with the presence of this pattern.

From the results observed in Figure 2, it is possible to identify that the proposed change detection method tends to achieve high detection probability, i.e., all the 25 targets are identified in both images, which are inside the red highlighted areas. However, as can be observed in Figure 2(b), the method detected an unwanted
Experimental results considering Case I, where red highlighted areas represent the target areas. (a) Shows the output image when it is considered the inputs $M_2P_5$ as the surveillance image and $M_4P_5$ as the reference image. (b) Shows output image when it is considered the inputs $M_3P_2$ as the surveillance image and $M_5P_2$ as the reference image. The blue highlighted is related to the detection of an elongated structure related to the background, generating several false alarms.

The occurrence of these false alarms and the detection of the elongated structure can be justified by the selection of the background statistics for the wavelength-resolution SAR intensity images. Even knowing that the exponential distribution yields a good fit for the background statistics for scenarios with the absence of strong scatterers in this kind of image, this distribution tends not to yield a good fit for scenarios where strong scatterers are present. The images from the data set contain different structures besides the targets, e.g., rods, fences, and other human-made structures, which tend to result in a heterogeneous background.

To better visualize this mismatch for such scenarios, as the one observed in the elongated structures, Figure 3 presents the histogram considering and $100 \times 100$ window, where this structure is present and the theoretical exponential distribution fitted for the same data. Thus, it is suitable to state that the proposed change detection method is not able to properly manage images with a heterogeneous background justifying additional studies regarding the background statistics. Another possibility is to include other processing steps before the likelihood-ratio test to remove this kind of structure. One example of this scenario is discussed in Case II.

4.2 Case II

Case II consists of the use of a new type of input image. The use of difference intensity images has been considered to address the Case I observed issue regarding the elongated structures. The surveillance and reference input images are generated using three images by performing a simple subtraction operation considering a common...
image, i.e., the surveillance image is formed by the subtraction $Image_1 - Image_3$, and the reference image is formed by the subtraction $Image_2 - Image_3$.

The binary output images for the proposed method for Case II are presented in Figure 4. For this evaluation, it was selected the intensity constant $s = 0.225$ and threshold $Th = 30$. Figure 4(a) considers as the surveillance and reference images, respectively, the difference of the $M2P5$ and $M4P5$ and the difference of the $M3P5$ and $M4P5$. Similarly, Figure 4(b) considers as the surveillance and reference images, respectively, the difference of the $M3P2$ and $M5P2$ and the difference of the $M4P2$ and $M5P2$. In both images, the targets area is highlighted in red, and the targets area, which is included by the common image, is highlighted in green.

From the results observed in Figure 4(a), the proposed method was capable of detecting all the 25 targets with two false alarms. Additionally, from the results observed in Figure 4(b), the method addressed the issue related to the elongated structures. However, some miss-detections were observed. The issue related to these miss-detections is mainly related to the selection of the parameters “$s$” and the threshold. Also, it is possible to observe the targets from the common image in both Figure 4(a) and 4(b), which are mainly explained by the inclusion of strong scatterers in both surveillance and reference image, resulting in a scenario where the bivariate exponential distribution does not yield a good fit. To properly address this issue, pre-processing techniques are required to remove these targets, such as the example presented in Case III.

### 4.3 Case III

Case III consists of the use of a common image without targets for obtaining the difference input images. These common images without targets were obtained by using a ground-prediction technique proposed by Palm. The method consists of obtaining a background image by performing simple operations in stacks of images considering the same flight geometry. Thus, for the evaluation in Case III, the input images are formed by the original images subtracted by a common background image obtained by the ground prediction method proposed by Palm.

The binary output images for the proposed method for Case III are presented in Figure 5. For this evaluation, it was selected the same algorithm parameters as in the Case II. Figure 5(a) considers as the surveillance and
Figure 4. Experimental results considering Case II, where red and green highlighted areas represent the target areas from Image1 and Image3, respectively. (a) Shows the output image when it is considered the inputs \((M2P5 - MAP5)\) as surveillance image and \((M3P5 - MAP5)\) as reference image. (b) Shows output image when it is considered the inputs \((M3P2 - M5P2)\) as surveillance image and \((M4P2 - M5P2)\) as reference image. In both images, the targets area is highlighted in red, and the targets area, which is included by the common image, is highlighted in green.

reference images, respectively, the difference of the \(M2P5\) and \(GP5\) (ground prediction for Pass 5) and the difference of the \(M3P5\) and \(GP5\). Similarly, Figure 5(b) considers as the surveillance and reference images, respectively, the difference of the \(M3P2\) and \(GP2\) and the difference of the \(M4P2\) and \(GP2\).

From the results observed in Figure 5(a), the proposed method was capable of detecting all the 25 targets with only one false alarm. Additionally, from Figure 5(b), the method was capable of detecting all the 25 targets with only two false alarms. Also, by the use of the ground prediction method, the issue related to the inclusion of targets observed in Case II was properly addressed. Thus, from the observed results in Cases I, II, and III, it is possible to observe that the proposed change detection method has promising results, especially regarding the detection probability for Intensity VHF wavelength-resolution SAR images.

5. CONCLUSION

The paper presents an initial study of one new change detection method for intensity VHF wavelength-resolution SAR images using a bivariate exponential distribution. The method was evaluated using images from the CARABAS II data set, under the consideration of three different cases regarding the input images. For all evaluated scenarios, the proposed scheme presented promising results, especially regarding its detection capacity. However, some scenarios presented some issues regarding the false alarm occurrences and the detection of elongated structures. Under the consideration of the mentioned issues and the promising results observed, new studies are currently being made. These studies are i) The numerical evaluation in terms of receiver operating characteristic curves of the proposed method for all the 24 images; ii) A study regarding the selection of the
Figure 5. Experimental results considering Case III using the proposed method with a ground-prediction technique, where red highlighted areas represent the target areas. (a) Shows the output image when it is considered the inputs \((M2P5 - GP5)\) as surveillance image and \((M3P5 - GP5)\) as reference image. (b) Shows the output image when it is considered the inputs \((M3P2 - GP2)\) as surveillance image and \((M4P2 - GP2)\) as reference image. \(GP2\) and \(GP5\) represents the images formed by the ground-prediction technique referent to Pass 2 and Pass 5, respectively.

algorithm parameters; iii) The study of other candidate distributions for modeling the background in intensity VHF wavelength-resolution SAR images.

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