Synthetic Aperture Radar: Principles and Applications of AI in Automatic Target Recognition

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Abstract. This paper addresses the problem of detection, imaging and automatic target recognition of moving targets using synthetic aperture radar. The challenge in processing moving targets is addressed with special emphasis on the blind angle ambiguity and on the maximum unambiguous moving target velocity. It is shown that both ambiguities can be solved by including information about the antenna radiation pattern. This information is crucial to obtain focused images of moving targets in order to perform automatic target recognition. Some methodologies using artificial intelligence tools to perform automatic target recognition are presented.

1 Introduction

Ground surveillance radar is a useful tool for remote sensing. Airborne and spaceborne radar sensors are able to quickly cover large areas of the ground and to produce high quality radar maps, in all weather, day and night [1]. Synthetic aperture radar (SAR) was introduced in the 1950s as a mean to obtain high resolution radar images.

The so-called stripmap SAR acquisition geometry, illustrated in Fig. 1, is widely used. This acquisition geometry provides data along a terrain strip parallel to the flight direction (azimuth direction). The radar travels at constant velocity in the azimuth direction and transmits wideband microwave pulses at regular intervals. The corresponding echoes are recorded. Many pulses are transmitted during the so called integration time, i.e., the time the platform takes to travel the footprint cross-range length.

High resolution in range is obtained using traditional pulse compression techniques and is independent of the antenna size. High resolution in the azimuth direction is obtained via synthesizing a long array, by taking advantage of the platform movement.
If a moving target signature is processed as if originated by a static target, the resulting SAR image shows it defocused and/or at wrong positions, depending of the motion direction. This problem is illustrated in Fig. 2. The figure shows the result of focusing, with static ground parameters, a target area where a moving vehicle (a BTR-60) is present. As expected, only the ground becomes focused. The moving vehicle appears misplaced, blurred and defocused.

If correctly processed it should appear focused on the road at coordinates \((x,y)=(90,124)\) m. To obtain focused and correctly positioned images of moving objects it is necessary to know the moving target velocity vector. Fig. 3 shows the moving vehicle focused and repositioned after estimation of its trajectory parameters.

Notice that due to fact that a single SAR sensor is used and because, in this particular situation, the moving target spectra (although 6 times folded) is completely superpositioned on that from the clutter, the defocused image of the BTR-60 cannot be removed from the image. This is one of the limitations of the single SAR sensor based techniques that are addressed in the presentation.
The SAR community is presently researching, among others, the detection, imaging, and recognition of moving targets, for surveillance purposes. Many applications aim at determining the position and the velocity of certain targets. The purpose may be, for example, to detect ships in the sea [2, 3] or to find traffic jams [4]. Other civil applications include oil pollution monitoring and surface currents measurement. Some military applications are also oriented towards detecting and recognizing moving targets [5]. The purpose may be to intercept targets threatening facilities or resources. In other scenarios the purpose may be to keep the moving objects safely apart from each other as they navigate, thus requiring accurate detection, high resolution imaging, and precise kinematics estimation.

The classical solution to the problem of simultaneously imaging, repositioning and full trajectory estimation of moving targets requires, usually, two or more sensors. The reduction of the number of sensors is a crucial issue in spaceborne missions, since it reduces the payload, and, therefore, the mission costs. The presentation will also address, although briefly, the design of processing schemes aiming at imaging, repositioning, and full trajectory estimation of moving targets in SAR, using a single sensor and a posteriori recognition using artificial intelligence (AI) based methods.
2 Presentation outline

2.1 Synthetic Aperture Radar Principles

The presentation starts with an introduction to the stripmap SAR acquisition geometry and presents an imaging scheme belonging to a class of algorithms often referred to as wavenumber domain (ω-k) processors (or as wavefront reconstruction algorithm in Soumekh's terminology [1]) to produce focused images using the recorded echoes from a given illuminated target area. Other popular SAR imaging algorithms are also mentioned. The limitations in processing moving targets using a single SAR sensor are then addressed and the ill-posedness nature of the problem (termed blind angle ambiguity or azimuth position uncertainty problem) is brought to focus. The state-of-the-art in moving target detection, trajectory estimation, and imaging is then surveyed. The described methodologies are classified into two
classes: The single SAR based sensor, and the array SAR based sensor. Advantages and disadvantages of each one are referred to.

The blind angle ambiguity problem is then addressed. This ambiguity refers to the fact that the position and velocity of a moving target cannot be inferred from its phase history using data from a single sensor. It is shown that the blind angle ambiguity can be solved by including information about the antenna radiation pattern. Shape analysis of the antenna radiation pattern is conducted and the findings illustrated experimentally.

2.2 Moving Target Detection, Trajectory Estimation and Focusing

A recently published procedure to image and to estimate the velocity vector and the coordinates of multiple moving targets, using data from a single SAR sensor is then presented [2]. It exploits the structure of the amplitude and of the phase modulations of the returned echo from a moving target. The technique is developed in the spatial domain and extracts the data along a curve determined by the moving target trajectory parameters. Experimental results will be provided.

2.1 Automatic Target Recognition

The last topic of the presentation addresses the problem of automatic target recognition (ATR). This step of the processing aims at the classification of specific targets in natural environments.

Typically the systems that perform ATR are divided into two blocks. One that brings into focus a region of interest; followed by one that acts as a classifier [6]. The brute-force approach needed to classify each pixel is prohibitive from the computational point of view. Instead, the first block selects the areas that have high probability of containing targets and is designated by prescreener. Therefore, only a small part of the overall data is used for ATR.

The most popular prescreener types used in SAR are based in the constant false alarm (CFAR) detectors. This consists, typically, in performing a test based on the pixel intensity versus the local neighborhood. Although this method is the simplest, it does not provide the best results. A modified technique, which uses multilayer perceptron network, is then presented.

Many artificial intelligence techniques have been tried for classification such as those based on genetic programming and neural networks. However, due to the noisy characteristics of the radar images, see Fig. 4, the most successful classifiers are based on Neural Networks.

The presentation is concluded by providing current trends and suggestions of future research directions in moving target imaging, trajectory estimation and ATR using SAR data.
Fig. 4. Optical image of a BTR-60 (left) and the corresponding image in X-Band (right).

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References