

Detecting moving targets in multiframe SAR imagery without using any direct backscatter

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Abstract

Detecting moving targets using Synthetic Aperture Radar (SAR) imagery is challenging since target images become highly distorted due to the unknown motion of the target. The distortions include smearing, and displacement, of the target signal across the SAR image. This paper reports an approach to moving target detection which avoids these distortions by operating on the target's shadow. Unlike a target's signal, its shadow is not subject to distortions arising from the target motion, and the shadow appears at the true target location.

Our approach to target detection seeks to make target motion observable by sub-dividing the synthetic aperture, c.f. standard SAR processing. The cross range resolution of the image is therefore sacrificed so as to gain a commensurate increase in the number of SAR images. Moving shadows are then observable in the sequence of images.

We perform detection and tracking jointly, and use methods that integrate both target and background information over the sequence of images. Integration over a number of frames is desirable since it allows detection at lower signal to noise than single frame methods. A new Bayesian track-before-detect scheme is developed that operates directly on the intensity levels in a residue image sequence. The residual images are computed from the measurements and comprise target shadows which stand out from the background. Robust detection and tracking has been demonstrated on real SAR imagery from two systems: a helicopter borne system, and a longer range airborne platform. Extrapolation of the empirical results indicates that shadow detection is viable at tens of kilometre stand-off range.

1. Introduction

Synthetic Aperture Radar (SAR) is a high resolution radar imaging technique that is well suited to producing very accurate detailed imagery of the static ground from stand-off ranges. However, historically SAR imagery has proven to be ineffective against detecting moving targets since the motion of the object introduces a residual phase error that results in the image of the object being blurred, de-focused and displaced [Freeman and Currie 1987]. It is nearly impossible to detect moving targets with such uncorrected imagery. There are various image correction techniques [Barbarossa and Scaglione 1998, Fienup 2001] that have been developed to extract the direct echo of moving targets but they invariably involve some form of iterative process. The computational load scales in proportion to the number of candidate targets and detection robustness becomes a major issue in complex clutter background and dense target situations due to unresolved motion errors.

Interestingly, the shadow of the target is not affected by any of the distortion effects. There is no phase contribution from the target shadow region so it is not de-focused and it appears at

the target's true location. Whilst detection remains difficult within a single SAR image (due in part to the generally low contrast level of target shadows) the use of temporal information offers a solution where the target can be detected by change detection and dynamic integration [Jahangir 2006 & 2007]. When a series of such SAR images are played to a human observer, the shadows of moving targets are visible against a static background. The eye performs intensity change detection using some form of dynamic integration over the image sequence.

In our approach we have sought to mimic the integration of the eye. We perform detection and tracking jointly, and use methods that integrate both target and background information over the sequence of images. Integration over a number of frames is desirable since it allows detection at lower signal to noise than single frame methods.

We integrate *background* information via a sequence of SAR images to construct an estimate of the background (i.e. static) scene content. A sequence of *residue* images are computed as the difference between estimated background and each measured SAR image. Detection is performed on the sequence of residual images whereby the tracker integrates the target information assuming a target dynamic model.

A common approach to target tracking proceeds by performing an explicit detection stage (e.g. thresholding) and the detections being passed as inputs to a tracker filter (e.g. Kalman filter) which provides estimates of the target's state (position, velocity, etc...). A disadvantage of explicit detection by thresholding is the inherent loss of information in such an approach. If the shadow contrast is high the information loss may be of little consequence. For lower contrasts, methods which operate directly on the pixel gray levels are preferred, and such methods are known as track-before-detect.

In this paper we summarise a classical approach to moving shadow detection which proceeds by explicit detection and Kalman filtering in Section 2. Example results are provided from a short range helicopter borne system. A new Bayesian track-before-detect scheme that integrates both target and background information over the sequence of images is described in Section 3. The detection scheme is tested on data from both the short-range helicopter borne system and a longer range airborne system with examples containing weaker shadows.

Section 4 considers the case of how the empirical results can be extrapolated to wider scenarios to appreciate the utility of SAR shadow detection for ground moving target indication (GMTI). It identifies alternative sensor configurations that are likely to achieve the same tracking performance as those observed with real data.

Section 5 summaries recent work where moving targets are detected by detection of the disturbance of the ground due to a vehicle's motion, e.g. a trail of compressed grass. A sequence of coherent change detection (CCD) images reveals the areas of grass surface that have been depressed by the vehicle tyres. Targets are detected through locating this expanding CCD trail in the grass surface which is independent of the target's direct backscatter. Finally, Section 6 concludes with some of the key advantages of SAR-based GMTI in providing an enhanced situational awareness.

2. Shadow detection through pre-screening

Figure 1a illustrates a block-diagram for shadow based detection. Shadow pre-screening is performed on clutter residue images. The static background is estimated using temporal averaging of the aligned input spotlight SAR images. The residue images are then obtained by dividing this background estimate with the measured SAR image (ratio image). Standard Kalman filtering is applied to the output of the pre-screener thresholding to obtain valid tracks.

The algorithm was applied to spotlight SAR images from a helicopter borne SAR system where the stand-off range was less than 1km. A total of sixteen images were processed and the

output for one of these is shown in Figure 1b. The shadows from the moving targets appear quite bright in the ratio image along with those of the trees. The reason for the latter is that the tree shadows also create a change as the shadows rotate with the changing aspect angle of the spotlight SAR images. The final image on the right in Figure 1b shows the raw pre-screener plot detections (red dot and green line) and the tracker output (blue cross) overlaid on the original SAR image. The pre-screener, that applies an initial thresholding followed by clustering and discrimination, has been reasonably successful at suppressing false alarms, for examples those from the static tree shadows. The tracker has a much simpler task and in this example the moving targets have been detected and correctly located on the cinder track. Note this process has only used the shadow information and is therefore entirely independent of the target Radar Cross Section (RCS).

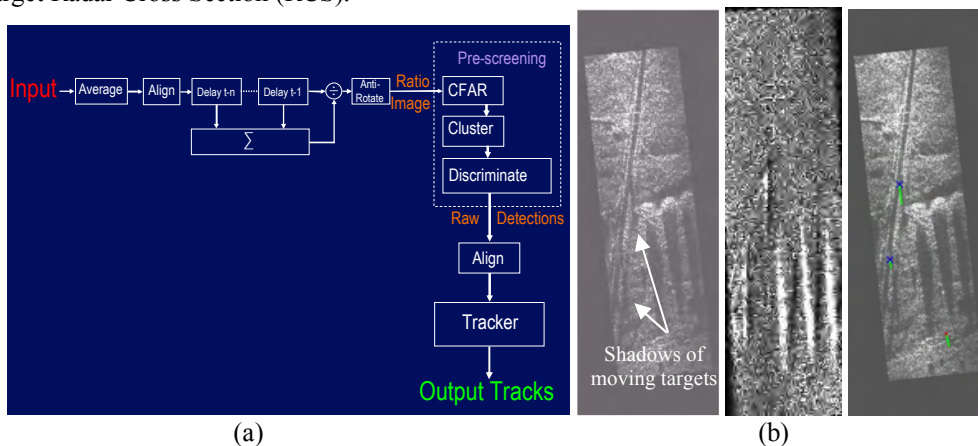


FIGURE 1. (a) Schematic flow diagram of the SAR shadow detection algorithm (b) Example imagery illustrating the various stages of algorithm, (left) original SAR image containing moving targets, (centre) clutter residue image, (right) tracker output overlaid on the original SAR image: pre-screener detections marked as green lines with red dots and tracker output shown as blue crosses.

3. A track-before-detect technique for shadow detection

This section reports a new efficient Bayesian track-before-detect technique that operates directly on the pixel intensity levels in the residue images without any thresholding. It detects departures from the clutter distribution of the residue images due to target motion. Here residual images are computed by inference of a resolution enhanced, and noise reduced, estimate of the background scene content. The resolution enhanced scene content is used to *predict* a counterpart measurement for comparison with each *received* SAR image. The difference between the *predicted* and *received* measurements define the residual. Changes relative to the static background appear as outliers in the residual. We used the Temporal Resolution Enhancement (TRE) framework [Rollason & Watson 2009] to produce the residual images. TRE differs from Temporal Averaging (section 2) in that the sensor point spread function, and noise level are modelled.

The track-before-detect technique uses images to represent probability surfaces, and performs both the prediction and update operations as convolutions. Convolution is attractive because it is computationally efficient and can exploit parallel architectures such as a Graphics Processing Unit. An algorithm for inference of position and velocity of point targets was detailed in [Strens & Gregory 2003]. For detection of shadows with unknown contrast and size, a new algorithm has been formulated so as to infer the unknown intensity and size. Also,

an appearance model [Rollason & Salmond 2001] has been included to provide an estimated probability that a target is being tracked.

The algorithm was tested on the short-range helicopter data described in the previous section. Figure 2 (left) is the residue image using TRE that has succeeded in suppressing the static scene. The tracker has managed to track both targets as can be seen from Figure 2 (right) although now there are some spurious tracks due to shadows from the trees.

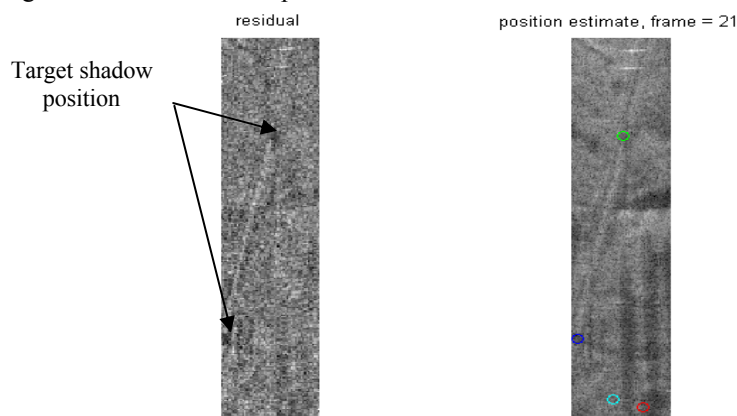


FIGURE 2. (left) A revised residue image for the SAR image from the helicopter system (right) track-before-detect output showing estimated target position superimposed on the last SAR image in the sequence

The shadow track-before-detect technique has also been successfully demonstrated for longer stand-off ranges as illustrated by Figure 3 using QinetiQ PodSAR imagery [Jahangir & Coe *et al.* 2008]. In this example two small civilian 4x4 vehicles were travelling off-road parallel to a track at 15 mph at 12km range. Two faint shadows of the vehicle can be just made out from the SAR image on the left. The clutter residue image in the centre only preserves the moving shadow signal. Finally, the tracker output in the image on the right shows both targets have been detected and tracked. The targets have only 50m separation but the tracker is able to maintain good tracks for both vehicles over the entire 30 secs observation sequence.

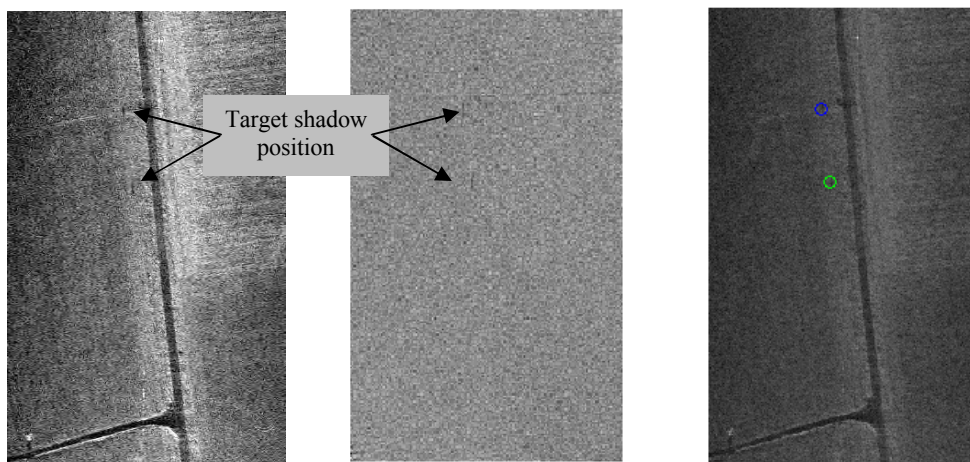


FIGURE 3. (left) Original PodSAR image (centre) Clutter residue image (right) track-before-detect output: estimated target position superimposed on the SAR image.

4. Projected performance for SAR shadow based GMTI

Although performance is ultimately driven by the clutter-to-shadow-signal (CSSR) ratio, a key parameter affecting tracking is the relative shadow blurring. As targets move, their shadows are blurred leading to a loss in CSSR. However, for a given target and clutter background the blurring and therefore the effective CSSR will be identical as long as the total displacement of the target during the SAR aperture time is preserved. Based on this consideration of a fixed target displacement, it is possible to extrapolate and infer tracking performance given the empirical results obtained with real SAR imagery.

Figure 4 plots scenarios that equate to the same target displacement (and thus tracking performance) as the PodSAR example with the two targets at 12km travelling at 15mph. The plot on the left is for a fixed target speed and it shows that detection range increases for faster platforms and those operating at higher frequency. The underlying assumption here is that SAR clutter contrast is fixed irrespective of platform type or ground range. Likewise the plot on the right shows that for a fixed range, the same target displacement (and therefore tracking performance) is achieved with the alternative platforms for target speeds 2 to 3 times faster than the PodSAR example. These results are indicative of the likely tracking performance and suggest that the technique is feasible for a significantly wider range of operating conditions.

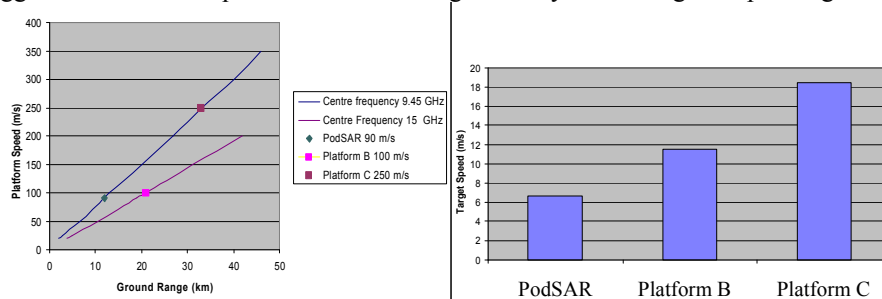


FIGURE 4. (left) platform speed versus ground range at a given target speed of 15mph (right) target speed for varying platform speed at a given ground range of 12km

5. GMTI using continuous Coherent Change Detection (CCD)

Detection of moving targets without the use of target direct echo has also been shown to be possible with a series of CCD images [Jahangir & Kealey *et al.* 2008]. The information used in this case is the vehicle ground trail. A pair of SAR images of the same scene when combined coherently forms a CCD image that is sensitive to small phase changes in the scene. Vehicle trails over grass show up very clearly in the CCD image since the shift in the grass blades produces enough of a phase change to register in the CCD image. Jahangir & Kealey *et al.* 2008 showed that if a series of CCD images are generated then the ground trail of a moving target can be observed growing lengthwise in the CCD sequence. This growing vehicle trail can thus be detected as an outlier against a static CCD background.

The principle of the CCD based GMTI technique is demonstrated with the aid of the images shown in Figure 4. The top image is a SAR image from one of two repeat passes. The next two images are CCD images formed using different pairing of the SAR images from the same two repeat passes. The bottom image is the non-coherent change image formed through combining the two CCD images. This reveals new changes, highlighting the portion of the trail that the target has travelled since the first CCD image. For a series of such CCD images, techniques similar to those described in Section 3 and 4 can be applied to detect and track a moving target from its expanding ground trail.

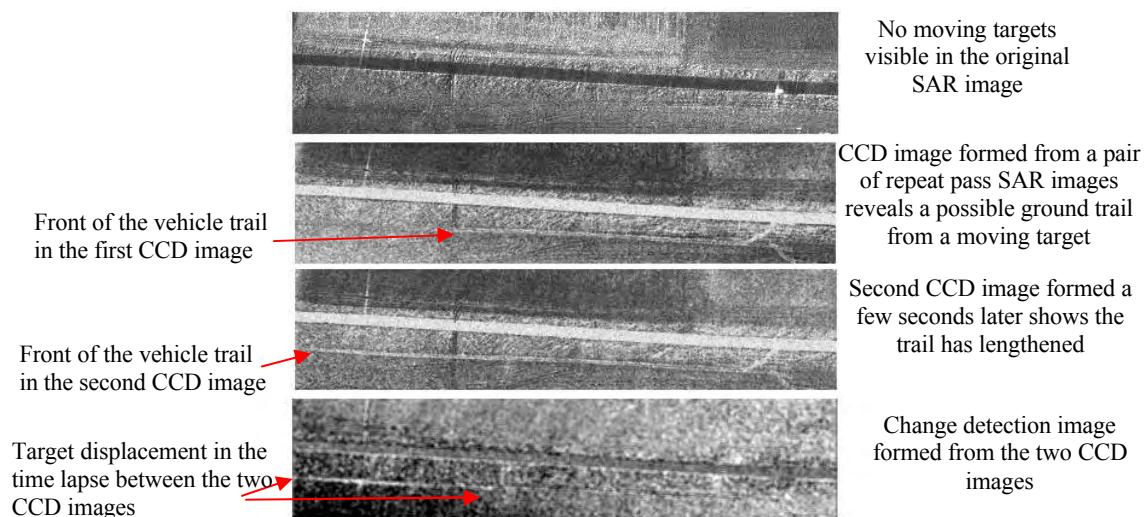


FIGURE 4. Sequence of images demonstrating the phenomenon of detecting moving targets from the ground trail observed in multiple CCD images

6. Conclusion

Exploiting the scene dynamics in multiframe SAR image sequence provides an innovative approach to detecting moving targets. We have shown that target shadows can be detected as outliers against a static clutter scene. A new track-before-detect technique was developed that integrates both target and background information, and offers significant potential for detection at longer ranges. With CCD image sequences it is the dynamics of the ground trail that enables moving targets to be detected. Key advantages of these SAR-based GMTI solutions are good location accuracy which is independent of range, no Doppler ambiguities and very low detectable velocity. Detection is limited by the clutter characteristics and further analysis is required to establish the performance bounds in relation to the clutter

REFERENCES

- BARBAROSSA, S. & SCAGLIONE, A. 1998. Autofocusing of SAR images based on the product of high-order ambiguity function, *IEE Proc. Radar Sonar Navigation*, **145**, 269-73
- FIENUP, J. R. 2001. Detecting Moving Targets in SAR Imagery by Focusing, *IEEE Trans. AES.*, **37**, No. 3, 794-809
- FREEMAN, A. & CURRIE, A. 1987. Synthetic Aperture Radar (SAR) Images of Moving Targets, *GEC J. Res.*, **5**, No. 2, 106-115
- JAHANGIR, M. 2006. System and Method for Processing Synthetic Aperture Imagery, *UK Patent Application No. 0606489.3*, 31 March 2006
- JAHANGIR, M. 2007. Moving target detection for Synthetic Aperture Radar via shadow detection, *IET Conf. On Radar Systems (Radar 2007)*, Edinburgh, UK, 16-18 October 2007
- JAHANGIR M., COE D., BLAKE A. P., KEALEY P. G. & MOATE C. P. 2008. PodSAR: A versatile real-time SAR GMTI surveillance and targeting system, *IEEE RadarCon 2008*, Italy, 27-29 May 2008
- JAHANGIR M., KEALEY P. G., MOATE C. P. & HILL R. D. 2008. System and Method for Processing Radar Imagery, *UK Patent Application No. 0823034.4*, 18 December 2008
- ROLLASON M. P. & SALMOND D. 2001. A particle filter for track-before-detect of a target with unknown amplitude, *IEE Colloquium on Target Tracking: Algorithms and Applications*, October 2001
- ROLLASON M. P. & WATSON G. H. 2009. Temporal resolution enhancement from motion - application to airborne imagery, EMRS DTC conference, Edinburgh, July 2009
- STRENS M. & GREGORY I. 2003. Tracking in cluttered images, *Image & Vision Comp.*, **21**, 891-911