An Analysis of the Shadow Feature Technique in Radar Detection

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Good target detection can be achieved by using Shadow Feature algorithms, particularly in heavy clutter environments. This letter analyses the performance enhancement of a Shadow Feature algorithm applied to a Maximum-likelihood CFAR (ML-CFAR) detector. Results show that detection performance is significantly improved.

I. INTRODUCTION

The concept of making use of the target shadow feature for detection has been discussed in [1],[2] & [3]. As shown in fig. 1, the shadow feature results when a portion of the ground is obscured by the target as seen from the radar; there will be no clutter returns for a number of range bins behind the target. Thus, by detecting these abrupt changes in clutter returns, a more reliable detection of the target can be obtained.

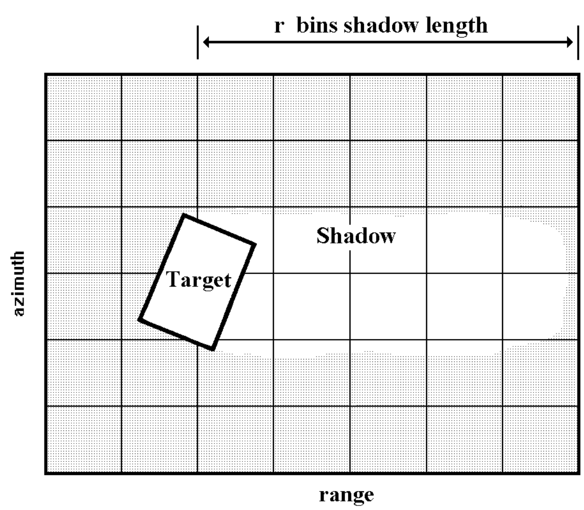

Fig. 1 Shadow Effect

Section II. of this paper contains an analysis of the Shadow Feature Technique, together with the method of implementation. Section III. describes the results of the implementation. Section IV. concludes the paper.

II. ANALYSIS OF THE SHADOW FEATURE ALGORITHM

The performance analysis of this algorithm is based on the Conditional Probability concept and on the assumption that there is only one target in the detection domain. Fig. 2 shows the block diagram of the detector processor [3]. We examine the hypothesis of a target in the test bin, i.e. the i^{th} bin, as shown in the block diagram, see fig. 2.

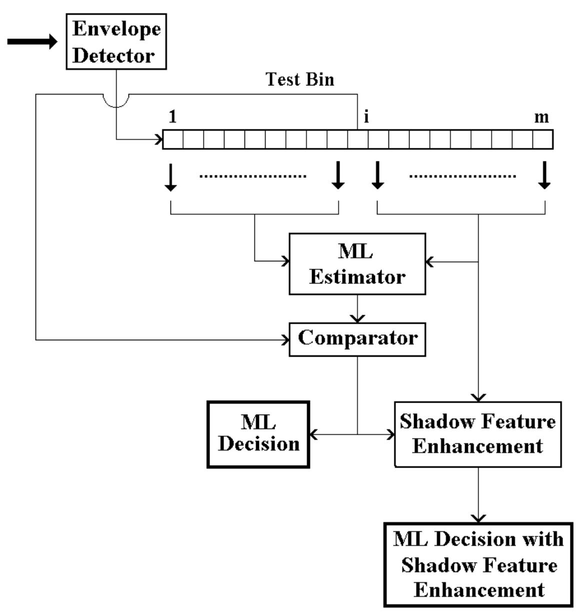

Fig. 2 ML-CFAR Processor with Shadow Feature Enhancement

Let $P_{d,t}^{\,i}(x)$ be the probability of successful target detection in the i^{th} bin using a threshold value of x, and $P_{fa}^{\,i}(x)$ be the corresponding probability of false alarm. $P_{d,c}^{\,i}(x)$ is the probability of detection when the bin constitutes clutter-only signal returns, and $P_{d,s}^{\,i}(x)$ is the probability of shadow detection when the bin constitutes neither target nor clutter returns.

The shadow length can be estimated from the elevation / azimuth angles of the radar, the ground profile, and the expected target height. For a shadow length of r bins, the overall probability of a target detection, $P_d(x)$, is equal to the probability of successful target detection in the test bin and shadow detection in the subsequent r bins:

$$P_d(x) = P_{d,t}^{\,i}(x) * \prod_{n=i+1}^{i+r} P_{d,s}^{\,n}(x) \qquad (1)$$

The overall probability of false alarm, $P_{fa}(x)$, is equal to the probability of false alarm in the test bin plus the probability of not detecting clutter signals for the subsequent bins:

$$P_{fa}(x) = P_{fa}^{\,i}(x) * \prod_{n=i+1}^{i+r} \left(1 - P_{d,c}^{\,n}(x)\right) \qquad (2)$$

By using eqns. (1) & (2), the performance of the Shadow Feature algorithm in terms of the P_d and P_{fa} can be obtained as a function of $P_{d,c}$, $P_{d,s}$ and the threshold value, x. $P_{d,c}$ can be expressed as a function of the clutter characteristics in terms of the clutter cross-section statistical distribution curve [5]. $P_{d,s}$ can be expressed as a function of the noise characteristics.

For the ML-CFAR detector and a Rayleigh target model in a Weibull clutter [3], the performance enhancement may be determined as follows: the probability of false alarm in the i^{th} bin, $P_{fa}^{i}(x)$ is

$$P_{fa}^{\;i}(x) \;=\; \left(1+\frac{x^2}{m}\right)^{-m}$$

and the probability of detection in a target constituted bin, $P_{d,t}^{i}(x)$, is

$$P_{d,t}^{\;i}(x) \;=\; \left(1+\frac{x^2}{m\,(1+SCR)}\right)^{-m}$$

where m is the number of bins considered in the ML-CFAR detector, and SCR is the signal to clutter voltage ratio. The probability of detection in a clutter-only bin, $P_{d,c}^{i}(x)$, is

$$P_{d,c}^{\;i}(x) \;=\; \left(1+\frac{x^2}{m}\right)^{-m}$$

For the shadow bins, in which only noise exists, the probability of shadow detection, $P_{d,s}^{i}(x)$, is:

$$P_{ds}^{\;i}(x) \;=\; 1-\left(\text{Probability of Noise Detection}\right)$$

III. RESULTS AND DISCUSSIONS

Results for the Shadow Feature algorithm enhancement are calculated at different SCR levels. It is assumed that the signal and clutter are much larger than the noise amplitude. Figures 3a to 3b compare the performance of the Maximum-likelihood CFAR detector with the Shadow Feature enhancement. The Shadow Feature algorithm provides better detection capability than the ML-CFAR only, limiting the P_{fa} to relatively low values. It can be considered that in the detector processor the original threshold of the ML-CFAR only is lower in order to improve the overall P_d with a corresponding increase in P_{fa}. However, the Shadow Feature algorithm compensates for this increase in P_{fa}, resulting in a better overall detection capability. Figures 3a and 3b also reveal this, i.e. the Shadow Feature algorithm will have P_{fa} no greater than 0.02.

For small P_{fa}, such as 10^{-5} to 10^{-6}, the overall P_d for the Shadow Feature algorithm still exceeds that for the ML detector only, even for small estimated shadow length. However, this improvement diminishes as the false alarm rate tends to zero.

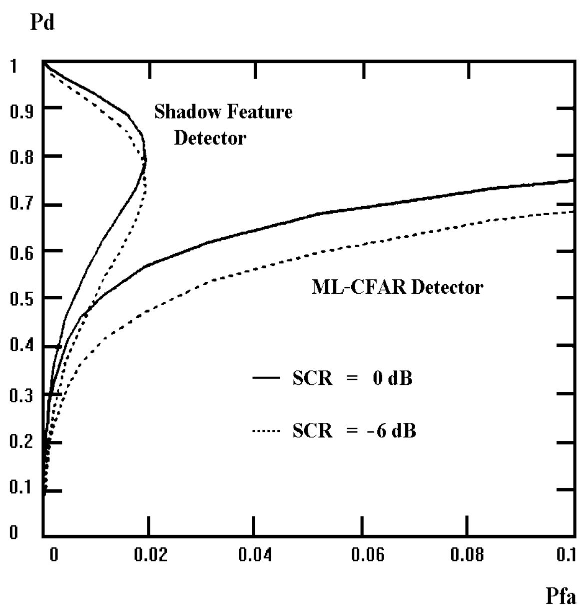

Fig. 3a Detection performance for m=5, r=2

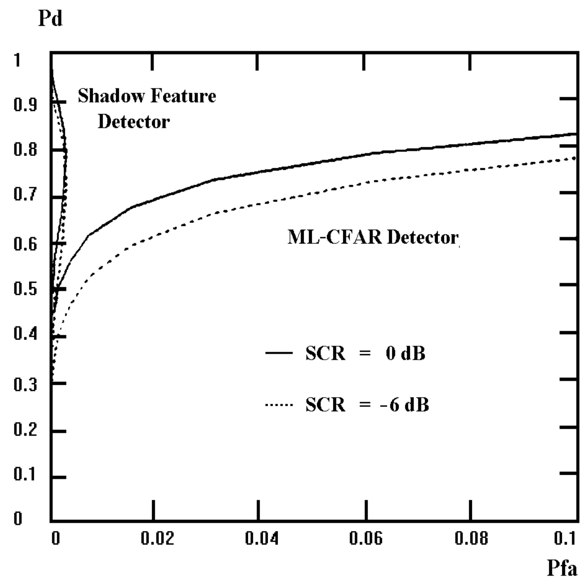

Fig. 3b Detection performance for m = 7,r = 3

IV. CONCLUSION

A performance analysis of the Shadow Feature algorithm is described in this letter together with detailed analytical results. These show that the algorithm is readily applicable to radar systems and is effective even in low signal to clutter environments below 0 dB.

V. REFERENCES

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