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# Performance of clutter map with binary integration against Weibull background

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ABSTRACT

In order to improve the detection performance of Nitzberg's clutter map in a more spiky clutter environment, a new clutter map detection scheme which combines binary integration with the classic clutter map is proposed and analyzed. It's shown that the detection performance of the clutter map with binary integration is greatly improved compared to the classic clutter map with a single pulse processing.


## 1. Introduction

Clutter map is designed to detect radar targets in non-homogeneous background, where the performance of the constant false alarm rate (CFAR) algorithms using sliding-window procedure, such as the cell-averaging (CA) [1], the greatest of (GO) [2] and the ordered statistic (OS) [3], etc. may seriously degrade. The classic clutter map [4,5] was first analyzed by Nitzberg et al. It averages the previous returns of each resolution cell in an exponentially decaying manner to obtain an estimate of the background power level $Z$, and scales it with a factor $T$ to set the adaptive detection threshold. The present return of the resolution cell is compared to the resulting threshold $TZ$ to make a decision about the presence or absence of a target. The performance analysis of the classic clutter map in [4,5] was carried out under Gaussian background, and an analysis under Weibull background with an assumption of known shape parameter was presented in [6]. It's shown in [6] that it is difficult for the classic clutter map to detect any targets in a more spiky clutter environment.

When a target enters the clutter map cell and persists during a number of scans, the detection performance of the clutter map will degrade. In order to enhance the robustness of clutter map, hybrid CFAR procedures have been proposed in Refs. [7,8]. They first process the spatial samples from a bunch of range cells grouped in a map cell, and subsequently filter them on a scan-by-scan basis, under an assumption of Gaussian clutter. In [9–11], such hybrid CFAR procedures for non-Gaussian clutter were introduced and analyzed, relying on the relevant properties of the location-scale distribution. In [12], a biparametric clutter map based on location-scale (L-S) distribution was proposed and two devices, the threshold locker and the input limiter to counter self-masking effect, were suggested.

In order to improve the detection performance of clutter map under a non-Gaussian background, we present a new clutter map scheme in which the binary integration [13,14] is incorporated into the classic clutter map processing. This new clutter map scheme is called the clutter map with binary integration. The proposed clutter map structure is described in Section 2, and its mathematical models under Weibull distributed background with a known shape parameter are given in Section 3. Finally, the detection performance of the clutter map with binary integration is analyzed and discussed.

## 2. Description of clutter map with binary integration

The block diagram of the clutter map with binary integration is shown in Fig. 1. It is assumed, at each scan, that a surveillance radar transmits $M$ pulses in a given direction and the frequency agility technique is used in these pulses. The proposed scheme for the clutter map detection also updates the background level estimate on a scan-by-scan basis. For the $n$th scan, the returns $q_i(n)$ ($i = 1, \ldots, M$) of $M$ pulses for each resolution cell is non-coherently integrated, that is,

$$q(n) = \frac{1}{M}\sum_{i=1}^{M} q_i(n) \quad (1)$$

Then the integrated result $q(n)$ is multiplied by a weight coefficient $\alpha$ and added to $(1-\alpha)\hat{p}(n-1)$, obtained from the previous

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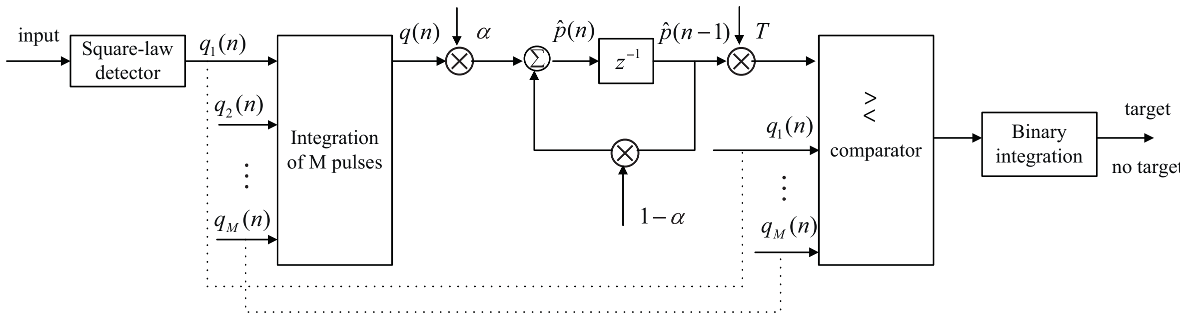


**Fig. 1.** The block diagram of the clutter map with binary integration.

background power level estimate $\hat{p}(n-1)$, to form a new estimate.

$$\hat{p}(n) = (1-\alpha)\hat{p}(n-1) + \alpha q(n) \tag{2}$$

Obviously, the mathematical model (2) is a one-order auto-regressive (AR) filter which exponentially smoothes the previous returns of each resolution cell. Here $\alpha$ controls the decaying rate. The present background estimate $\hat{p}(n)$ is multiplied by a threshold parameter $T$ to obtain the detection threshold for the next scan. The threshold parameter $T$ is determined by the required false alarm rate. However, the present return $q_i(n)$ of $M$ pulses is compared to the threshold value $T\hat{p}(n-1)$ obtained by the previous estimate $\hat{p}(n-1)$, instead of $T\hat{p}(n)$ produced by the present estimate $\hat{p}(n)$, in order to avoid an overestimate of the actual background power caused by the useful targets echoes. For each return $q_i(n)$ $(i=1,\ldots,M)$ of $M$ pulses, a decision is made according to the following:

$$q_i(n) \underset{H_0}{\overset{H_1}{\gtrless}} T\hat{p}(n-1) \tag{3}$$

If the present return $q_i(n)$ is greater than the threshold $T\hat{p}(n-1)$, a successful detection for the $i$th pulse is made. Finally, binary integration is applied to the results of preliminary decision on $M$ pulses. That is, if at least $K$ out of $M$ detections occurs, the presence of a target is declared. If the decision of no target is made, $q(n)$ is used to update the background estimate. Otherwise, $q(n)$ is not used to update the background estimate.

## 3. Mathematical model of clutter map with binary integration

It is assumed that returns of each pulse for a resolution cell are independent from cell to cell and from pulse to pulse, and identically distributed according to Weibull distribution. The probability density function (PDF) and the cumulative distribution function (CDF) of the square-law detected outputs $q_i(n)$ $(i=1,\ldots,M)$ are [6], respectively

$$f(t) = \rho^{-c/2}\frac{c}{2}t^{(c/2)-1}\exp\left[-\left(\frac{t}{\rho}\right)^{c/2}\right]; \quad t \geq 0 \tag{4}$$

and

$$F(t) = 1-\exp\left[-\left(\frac{t}{\rho}\right)^{c/2}\right]; \quad t \geq 0 \tag{5}$$

where $\rho$ and $c$ represent the scale and shape parameters of Weibull distribution, respectively. However, there is not an analytical expression for the PDF of the non-coherent integration $q(n)$ of returns $q_i(n)$ $(i=1,\ldots,M)$, except for $c=2.0$. For $c=2.0$, corresponding to a Gaussian background, the PDF of $q(n)$ is given by

$$f(t) = \left(\frac{M}{\rho}\right)^M \frac{1}{(M-1)!}t^{(M-1)}\exp\left(-\frac{M}{\rho}t\right); \quad t \geq 0 \tag{6}$$

Then the moment generation function (MGF) is shown as

$$\Phi_{q(n)}(s) = \frac{1}{(1+(\rho/M)s)^M} \tag{7}$$

The response $\hat{p}(n)$ of the linear time-invariant (LTI) system of Eq. (2) with an input of $q(n)$ can be expressed as [6]

$$\hat{p}(n) = \sum_{j=0}^{n}\alpha(1-\alpha)^j q(n-j) \tag{8}$$

Under hypothesis $H_1$ and at $c=2.0$, it's assumed that a Swerling II target enters a resolution cell of the clutter map. In this case, the PDF of $q_i(n)$ $(i=1,\ldots,M)$ is given by

$$f(t) = \frac{1}{\rho(1+\lambda)}\exp\left[-\frac{t}{\rho(1+\lambda)}\right]; \quad t \geq 0 \tag{9}$$

where $\lambda$ is the average signal to clutter power ratio (*SCR*). The detection probability for each pulse $q_i(n)$ $(i=1,\ldots,M)$ is determined by

$$\begin{aligned} P_{d1} &= Pr[q_i(n) > T\hat{p}(n-1)|H_1] \\ &= E_{\hat{p}(n-1)}\{Pr[q_i(n) > T\hat{p}(n-1)|\hat{p}(n-1), H_1]\} \\ &= E_{\hat{p}(n-1)}\left\{\exp\left[-\frac{T\hat{p}(n-1)}{\rho(1+\lambda)}\right]\right\} \\ &= \Phi_{\hat{p}(n-1)}(s)\big|_{s=T/(\rho(1+\lambda))} \end{aligned} \tag{10}$$

where $\Phi_{\hat{p}(n-1)}(s)$ is the MGF of previous estimate $\hat{p}(n-1)$. Since the MGF of a linear combination of statistically independent variables is equal to the product of their individual MGFs, the MGF of $\hat{p}(n-1)$ is expressed as

$$\Phi_{\hat{p}(n-1)}(s) = \prod_{j=0}^{n-1}\frac{1}{[1+\alpha(1-\alpha)^j(\rho/M)s]^M} \tag{11}$$

Applying of binary integration to the results of preliminary decision on returns $q_i(n)$ $(i=1, \ldots, M)$, the total detection probability about the presence of target in a resolution cell is given by

$$P_d = \sum_{i=K}^{M}\binom{M}{i}(P_{d1})^i(1-P_{d1})^{M-i} \tag{12}$$

Let $\lambda=0$ in (10), the probability of false alarm for each pulse $P_{fa1}$ can be obtained, and we have

$$P_{fa1} = \Phi_{\hat{p}(n-1)}(s)|_{s=T/\rho} \tag{13}$$