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Log-Normal Clutter 환경에서 차량용 UWB 단거리 레이더 수신기의 성능분석

(UWB Automobile Short Range Radar Receivers Performance In a Log-Normal Clutter Background)

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요 약

초광대역 레이더는 높은 분해 능력으로 인해 단거리 차량용 레이더로 주목받고 있다. 차량으로부터 반사된 레이더 신호는 “clutter”라는 원하지 않는 반사 신호를 갖게 되어, 목표물을 검출하는데 어려움을 갖게 된다. 그러므로 목표물에서 반사된 신호로부터 보다 확실하게 검출하기 위하여 레이더 검출기를 개발할 필요가 있다. 본 논문에서는 log-normal clutter 환경에서 다양한 평균과 분산에서 최적인 검출기를 구하였다. 비동기 방식의 검출기로 자승 검출기와 선형 검출기, 로그 검출기 등을 분석하였다. 본 논문에서는 컴퓨터 시뮬레이션을 통해 검출기의 성능을 분석하여, 차량용 레이더로 최적인 검출기를 구하였다.

Abstract

Ultra wideband radars attract considerable attention as a short range automotive radar because of its high range resolution. Radar signal reflected from a target often contains unwanted echoes called as clutter, so the detection of target is difficult due to clutter echoes. Therefore, it is important to investigate the radar detector for better detecting from the reflected signals. In this paper, the optimal detector is obtained for various mean and variance value in log-normal clutter environment. The types of non-coherent detectors used are square law detector, linear detector, and logarithmic detector. The performances of detectors are compared in log normal clutter environment and the suitable detector is determined for automotive short range radar application.

Keywords : UWB Radar, Log-Normal Clutter, Logarithmic Detector, Square law Detector, Linear Detector

Ⅰ. 서 론

High range-resolution radar using ultra wideband (UWB) radio offers many applications to vehicle such as pre-crush warning system, stop and go operation, spot assist, and lane change assist. The European commission approved the decision on allocation of the 24 GHz frequency band for automotive short range radar[1]. The radar system has been identified as a significant technology for the improvement of road safety. Apart from the ability to resolve closely spaced targets in range, it is possible to detect a target more accurately by the high resolution range profile because the radar resolution is smaller than the vehicle size. However, radar echo contains unwanted echoes called clutter, which make it difficult to detect the target even if using the high resolution range profile[2~3]. In the UWB automotive short range radar, the clutter echoes are the echoes from the objects in the road environment.

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In this paper, we use the system bandwidth of 500MHz centered at 24GHz. For 500MHz bandwidth the road clutter resembles log-normal clutter distribution[4]. Here we used different types of non-coherent detectors such as square law detector, linear detector, and logarithmic detector for checking the effect of clutter echoes over the target reflected signals in the radar receiver. The performance of these detectors in automobile environment is compared and a suitable detector that gives optimum performance in log normal clutter environment is found by using computer simulation.

The organization of this paper is as follows. In Section Ⅱ, the system model is described. In Section Ⅲ, the detector models are described. In Section Ⅳ, the simulation results are shown in plots. In Section Ⅴ, the conclusion is given.

Ⅱ. UWB Radar Systems

The block diagram of a UWB radar system as shown in the Fig. 1 is split into two parts, that is, the transmitter and the receiver. First, in the transmitter, the gaussian pulse is generated at each time that the Pulse Repetition Frequency(PRF) generator triggers the pulse generator. The gaussian pulse (T_P) has a sub-nano second duration.

Therefore, we can write the transmitted signal as follows,

$$s(t) = A_T \cdot cos(2\pi f_c t + \phi_0) \cdot p_n(t) \qquad (1)$$

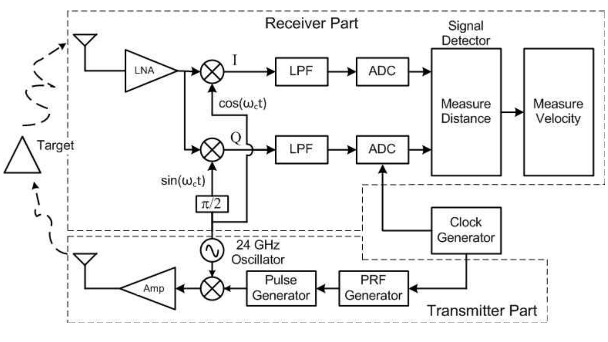


그림 1. UWB 레이더 시스템의 블럭도
Fig. 1. Block diagram of UWB radar system.

where the gaussian pulse train, $p_n(t)$, is

$$p_n(t) = \sum_{n=-\infty}^{+\infty} p(t - n.T_{PRI}). \qquad (2)$$

The parameters employed in this UWB radar system are described as follows; A_T is the amplitude of single transmit pulse, ϕ_0 is the phase of the transmit signal, f_c is the carrier frequency, and T_{PRI} is the pulse repetition time.

Since the range resolution of the UWB radar system is much less than the extent of the target, the echo signal is the summation of the time-spaced echoes from the individual scattering centers that constitute the target[5]. Therefore, in this paper, we can assume that the target has L independent reflecting cells. And the target model is written as

$$h(t) = \sum_{l=0}^{L-1} \alpha_l \cdot \delta(t - \tau_l) \qquad (3)$$

where the number of scatters L, the amplitude of the scatters α_l and the time delays of the scatters τ_l are all unknown. The baseband complex received signal reflected from the target is given by

$$\bar{r}(t) = A_T \sum_{n=-\infty}^{+\infty} \sum_{l=0}^{L-1} \alpha_l e^{j\theta_l} p(t - nT_{PRI} - \tau_l) + c(t) \qquad (4)$$

where $c(t)$ is the reflected clutter signal from the unwanted object.

Ⅲ. Non-Coherent Detectors

First, in the receiver, the signal detector of the UWB radar must determine that a signal of interest is present or absent. Then, the UWB radar processes it for range determination.

In this paper, we use the non-coherent detectors of type square law detector, linear detector, and logarithmic detector. The detector consists of coherent range gate's memory, non-coherent range gate's memory, coherent integrator, and non-coherent integrator. The coherent and non-coherent range gate's memory size (M) is less than maximum range and indicates the total number of target range to be tested. These range gates are used as buffer to integrate the values coherently and non-coherently. Therefore, at every T_{PRI}, we use the samples as much as the range gate's memory size(M).

At every T_p, the in-phase(I) and quadrature-phase(Q) sampled values are used as the input of the detector. The switch-I is shifted at every sampling time T_p and the samples at each range gate are coherently integrated. It takes $N_c \cdot T_{PRI}$ time to coherently integrate and dump for all range gates. The parameter N_c indicates the coherent integration length. If the round trip delay(τ) from target is equal to the time position of i-th range gate ($i \cdot T_p$), then the target range can be expressed as $i \cdot T_p/2 = i \cdot \Delta R$. And then the range resolution is given by following formula; $\Delta R = c \cdot T_p/2$. In order to find whether the target is present or not, the output of the coherent integrator can be distinguished between the two hypotheses,

$$H_1 : \overline{X}_i(m) = \frac{A_T \alpha}{N_c} \sum_{n=mN_c}^{(m+1)N_c-1} e^{j\theta_l} p(t - nT_{PRI} - \tau_l) + c(n) \quad (5)$$

$$H_0 : \overline{X}_i(m) = \frac{1}{N_c} \sum_{n=mN_c}^{(m+1)N_c-1} c(n) \quad (6)$$

where m indicates the m-th coherent integration and H_1 is for $\tau = i \cdot T_p$ and H_0 is for $\tau \neq i \cdot T_p$. Also, we assume that the sampling rate of the ADC is equal to the pulse width. The baseband received signal is sampled at peak point of $p(t)$. Then the values of the coherent integration for each range gate $(\overline{X}_i(m), i = 1, 2, .., M)$ are stored in the coherent range gate's memory.

1. Square law detector

The value received from the coherent integration is squared and operated at every $N_c \cdot T_{PRI}$. In square law detector, the squared range gate values are combined (both I and Q branch values are summed) as shown in the Fig. 3(a). The i-th range gate's output after squaring, $Y_i(m)$, can be represented as

$$Y_i(m) = ((X_i^I(m))^2 + (X_i^Q(m))^2) \quad (7)$$

2. Linear detector

In the case of linear detector as shown in the Fig. 3(b), the value received from the coherent integration is squared and operated at every $N_c \cdot T_{PRI}$. The squared range gate samples are combined and then square root is taken. The i-th range gate's output of the linear detector, $Y_i(m)$, can be represented as

$$Y_i(m) = \sqrt{((X_i^I(m))^2 + (X_i^Q(m))^2)} \quad (8)$$

3. Logarithmic detector

In the case of logarithmic detector as shown in the Fig. 3(c), the value received from the coherent integration is squared and combined at every $N_c \cdot T_{PRI}$. And then the square root is taken before natural logarithm is applied. The i-th range gate's output of the logarithmic detector, $Y_i(m)$, can be represented as

$$Y_i(m) = \ln\left(\sqrt{((X_i^I(m))^2 + (X_i^Q(m))^2)}\right) \quad (9)$$

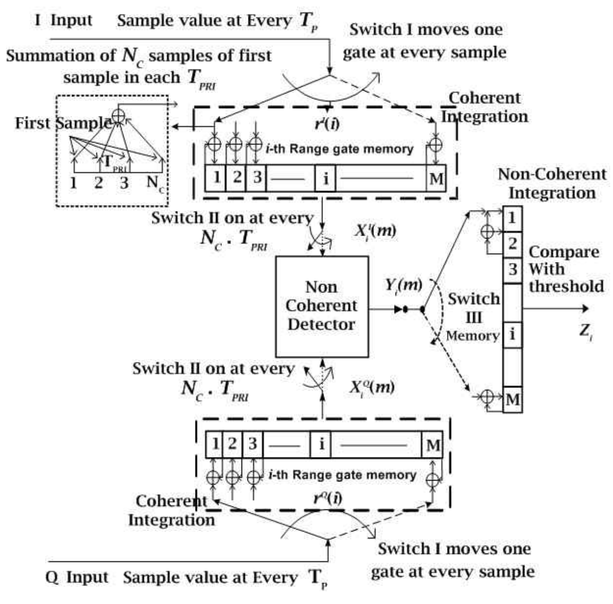


그림 2. UWB 레이더 수신기의 블럭도
Fig. 2. Block Diagram of the receiver with detector.

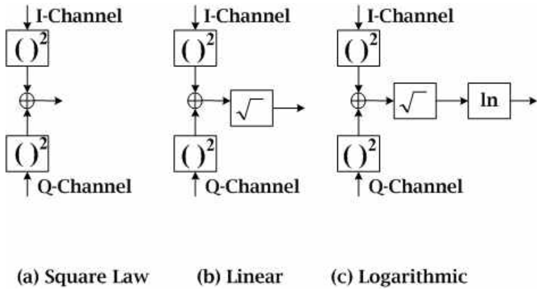


그림 3. 비동기 검출기의 블럭도
Fig. 3. Block Diagram of Non-coherent detectors.

When the power is stored in the i-th non-coherent range gate's memory at every $N_c \cdot T_{PRI}$, then the output of the non-coherent integration can be written as

$$Z_i = \frac{1}{M} \sum_{m=1}^{M} Y_i(m) \tag{10}$$

where $Y_i(m)$ is the power at $m \cdot N_c \cdot T_{PRI}$ of the i-th range gate.

The total number of the non-coherent integration is N_n. It means that the detector takes $N_n \cdot N_c \cdot T_{PRI}$ time duration to determine the output.

Ⅳ. Computer Simulation Results

In this paper, we assume that each clutter is independent and un-correlated. The parameters that we used in the simulation are as follows; the coherent integration number, N_c, is 200 and the non-coherent integration number, N_n, is 100. The tabulated mean and variance values as shown in Table 1 are taken from the reference paper[4] where the empirical data for the 24 GHz UWB automotive short range radar clutters is obtained by using the experimental setup in the University of Kitakyushu at different clutter environment[4]. These values are used in the simulation for checking the performance of the detectors in log-normal clutter environment.

Log Normal Clutter Power Calculation:

$$Mean = e^{\mu + \sigma^2/2} \tag{11}$$

표 1. 로그 노말 클러터 환경에서 다양한 평균값과 분산값을 갖는 클러터 파라메터
Table 1. Clutter parameters of Mean and Variance Values in the log-normal clutter Environment.

μ	σ	Clutter Power
5.2	0.8	118KW
4.7	0.7	32KW
5.1	0.6	55KW
3.8	0.8	7KW

$$Variance = (e^{\sigma^2} - 1)(e^{2\mu + \sigma^2}) \tag{12}$$

$$Clutter\,Power = e^{2(\mu + \sigma^2)} \tag{13}$$

The clutter power is the function of mean and variance value of the distribution. As the mean and variance value decreases, the clutter power decreases. Consequently, the performance of the detector increases.

In the Fig. 4, the performance of the logarithmic detector is simulated for different clutter power values in log-normal clutter environment. The logarithmic detector gives better performance when the clutter power is small. So, the performance of the logarithmic detector is increased when the clutter power reduces to 32KW.

In the Fig. 5, the performance of the non-coherent signal detectors (logarithmic detector, linear detector and square law detector) is obtained for various log-normal clutter environment by using the compter simulation. The logarithmic detector gives better performance than linear detector and square law detector because the coherent integration values are square rooted and taking natural logarithm. Resultantly, the clutter power values of the logarithmic detector reduces to 5% of the linear detector clutter power value and 50% of the square law detector value. Therefore, the signal to clutter ratio of the logarithmic detector is increased, thus the detection probability is more optimum than other two detectors.

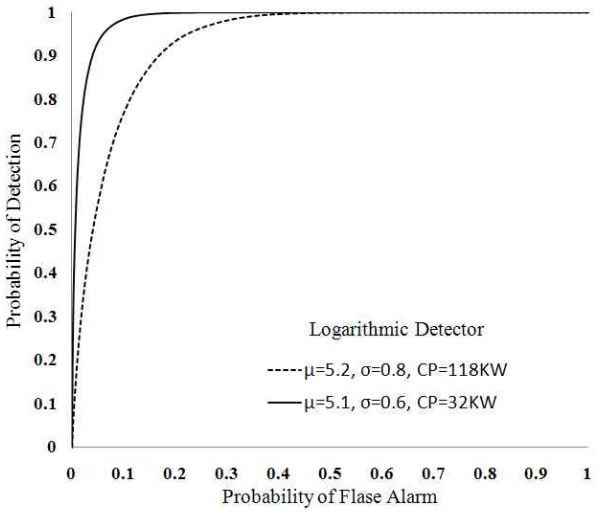
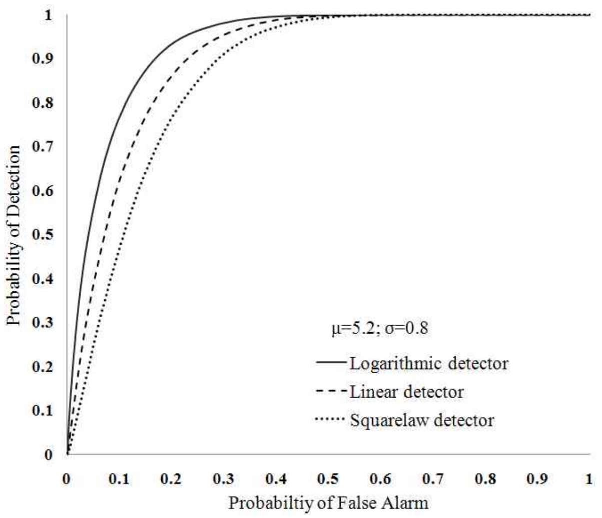
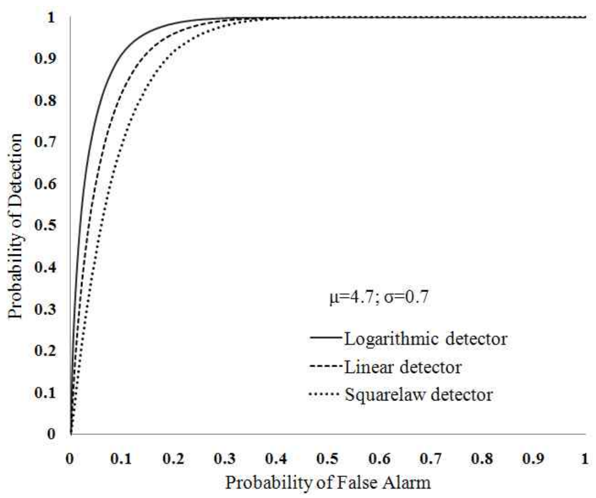


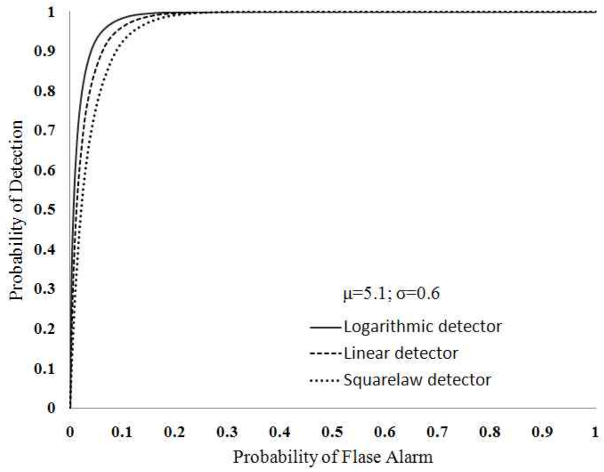
그림 4. 다양한 클러터 전력에 따른 로그 검출기의 성능
Fig. 4. Performance of the logarithmic detector at different clutter power(CP) values.



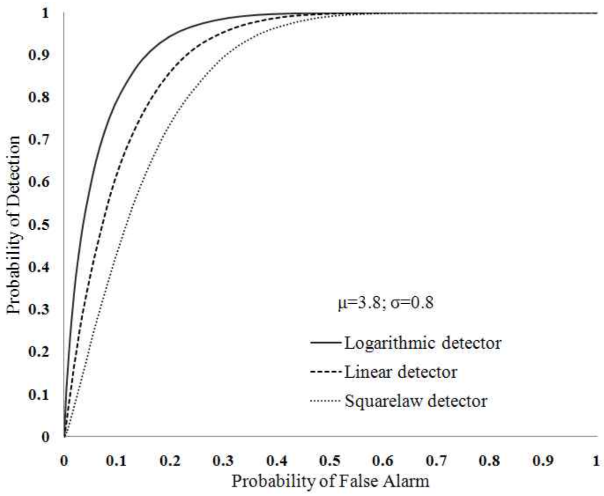
(a) μ=5.2 and σ=0.8



(b) μ=4.7 and σ=0.7



(c) μ=5.1 and σ=0.6



(d) μ=3.8 and σ=0.8

그림 5. 다양한 평균(μ)과 분산(σ)에서 비동기 검출기의 성능
Fig. 5. Performance of the non-coherent detectors for various μ and σ.

V. Conclusion

In the UWB automotive short range radar, the clutter echoes are the reflected signals from the unwanted objects in the road environment. For 500MHz bandwidth, the road clutter resembles log-normal clutter distribution. Considering log normal clutter environment, the different types of non-coherent detectors such as square law detector, linear detector, and logarithmic detector are discussed. By using the computer simulation, the performance of the non-coherent detectors is analyzed for different sets of mean and variance value in the log-normal clutter environment.

In all the cases, the performance of the logarithmic detector is superior to the linear detector and square law detector because the coherent integration values are square rooted and taking natural logarithm. Resultantly, the clutter power values of the logarithmic detector reduces to 5% of the linear detector clutter power value and 50% of the square law detector value. Therefore, the signal to clutter ratio of the logarithmic detector is increased. We can conclude that if the clutter power value decreases, then the signal to clutter ratio is increased. So, the detection probability is increased. Therefore, the logarithmic detector can be considered as the optimal detector for the automotive short range radars in log-normal clutter environment.

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