International Journal of Scientific Engineering and Technology (ISSN : 2277-1581)
Volume No.2, Issue No.6, pp : 539-544 1 June 2013

Performance Evaluation of Target Tracking Using Various Filters

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Abstract*—Modern radar systems are faced with detection of closely spaced targets with high power ratios between strong and weak reflectors. A Bi-phase code (Barker code) and corresponding decoding filters which are optimal in the sense that they produce no side lobes and they maximize the signal-to-noise ratio (SNR). The theoretical performance of the reiterated filtering technique based on the Linear Minimum Mean Square Error (LMMSE), as implemented in the Adaptive Pulse Compression (APC) scheme, is derived and compared with the matched filter (MF) and Kalman filter. The objective of this work is to analyze the performance of reiterated LMMSE based on APC filter in comparison to MF, Kalman Filter and to optimize the error.

***Key Words*— Adaptive Pulse Compression, Barker code, Kalman Filter, LMMSE , Matched Filter, Reflectors, SNR.**

I. INTRODUCTION

In surveillance and monitor systems that require to determine the number as well as the dynamics targets- Multi target tracking (MTT) is important. The matched filter is the most common receiver structure used for target detection in Radar systems. The Matched Filter is only matched to the transmitted signal, not the received signal as in [7]. Employing Minimum Mean-Square Error (MMSE) estimation to adaptively estimate the filter that matches the return signal denoted as Adaptive Pulse Compression as in [2]. Kalman Filter is an adaptive least square error filter that provides an efficient computational recursive solution for estimating a signal in presence of Gaussian noises as in [3].

The search is made by investigating all possible binary phase codes with a given length. After selecting the code, the first step is to find a filter which produces no side lobes as explained in [1]. This is possible for all codes with no zeros in the frequency domain, and it turns out that most codes satisfy this requirement.

The ideal sequence from this point of view is a Barker sequence, but there is overwhelming evidence that no Barker sequence of length greater than 13 exists .In this paper the performance of matched filter and Adaptive pulse compression filter based on LMMSE and Kalman filter are compared for Multi Targets (MT) as in [1] .

II. FILTERING CONCEPT

The filter obtaining the minimum mean square error (MMSE) is based on the Wiener filter. The assumption of a linear model for the received signal (linear estimator) can be applied, leading to an LMMSE technique. Some alternative techniques to the traditional matched filtering belong to the least squares type as in [2].

These last ones aim at minimizing the square error, either as model matching error or output error. LMMSE scheme in a reiterative way on a reducing subset of the same sequence of samples of the received signal, with no fresh samples added as in [4].

III. SIGNAL MODEL

A. *Transmitted Signal model*

Barker codes and alternating codes are examples of binary phase codes as in [1], Figure.1 demonstrates the side lobe-free filtering in the case of the 13-bit Barker code. It shows the 13 bit barker code itself, sampled at a rate of 3samples per bit. Figure.2 shows the continuous form of the 13-bit barker code which is a transmitted signal.

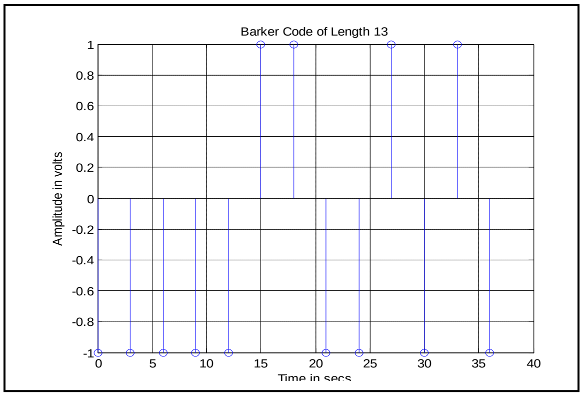

Fig. 1 The 13-bit Barker code sampled at a rate of 3 samples per bit

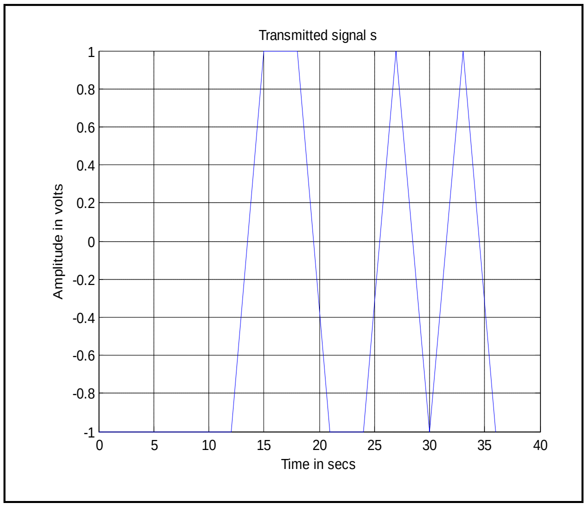

Fig. 2 The transmitted signal- the 13-bit Barker code sampled at a rate of 3 samples per bit shown in continuous form

B. *Received Signal model*

The received signal model is described in terms of its components due to the transmitted signal and noise. The target range profile model assumed here is a random process as in [5]. The noise samples are drawn from such a distribution. When considering N range bins out of the total length L of the processing window, the expression for the received signal is

$$Y^{*}(n) = M^{T}(n)\,\mathbf{s}+b^{*}(n) \qquad \ldots.(1)$$

where the index n indicates the nth range bin, Y*(n) is the received signal vector of N original samples. b*(n) is a vector containing N samples. $M^{T}(n)$ is the matrix used to operate the discrete convolution between the target range profile x and the transmitted signal **s**. **s** is the Barker code-13 as transmitted signal.

It is a square matrix of dimension N, the superscript T indicates the transpose operation, just as H the hermitian operation. The matrix is written as,

$$M(n)=\begin{bmatrix} x(n)\ldots\ldots\ldots\ldots\ldots x(n+N-1) \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ x(n-N+1)\ldots\ldots\ldots\ldots\ldots x(n) \end{bmatrix}$$

The convolution of a target range profile M(n) and the transmitted signal **s** is denoted as i, and the Additive White Gaussian Noise b*(n) is added at the received signal Y*(n) as expressed in equation (1) is shown in the Figure.3,

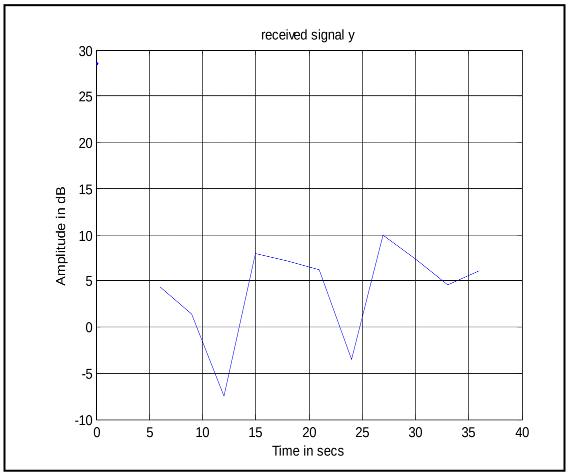

Fig.3 Received signal

IV. PERFORMANCE EVALUATION OF THE FILTERS

While evaluating the performance of any filtering scheme, it is important to quantitatively compare its performance with the one of the MF as in [3]. In the following, derivations are done to achieve such comparison in a set of target range profile scenarios, i.e., single target, two targets as in [5].

A. *Single Target*

A single target is in range bin n, x(n) drawn from a random distribution, b* (n) consists of AWGN with probability density function complex Gaussian $b_N(0,S^2_b)$; The two hypotheses for absence and presence of a single target can be written as,

$$H_0 : Y^{*}_{H_0}(n) = b^{*}(n)$$
$$H_1 : Y^{*}_{H_1}(n) = SX(n) + b^{*}(n) \qquad \ldots\ldots(2)$$

The received signal as in equation (2) is applied to the matched filter. The output of the matched filter is the convolution between the received signal y*(n) and the impulse response of the matched filter h(u) in Fig.4,

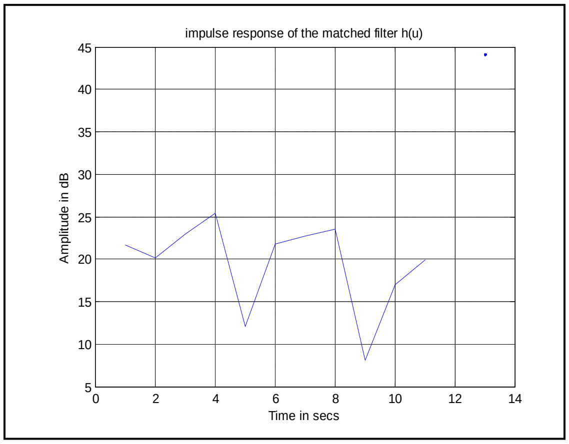

Fig.4 Impulse Response of the Matched filter

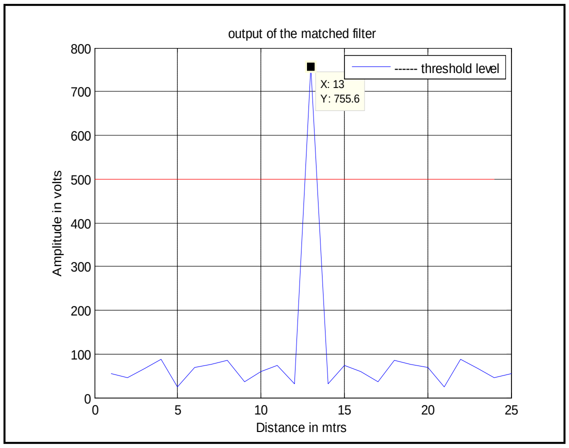

Fig.5 Output of the Matched Filter

Fig.5 explains that the target is detected at a distance of 13m with the main lobe amplitude 755.6 V.

The filter to be applied in the receiver to received sequence as in (3) is generated by the MMSE cost function at the output of the filter as in [6],

$$J(n) = E\left\{\left|x(n) - W^H(n)y^*(n)\right|^2\right\} \quad ..(3)$$

The estimated optimal filter **w**(n) with respect to the criterion in (3),, is a form of the Wiener filter.

In the hypothesis that the target profile samples are uncorrelated and equal to their realization

$$\mathbf{w}(n) = (\mathbf{C}(n)+\mathbf{B}(n))^{-1}E\{\mathbf{M}^T(n)\mathbf{s}\,x^*(n)\} \quad ….(4)$$

with$\mathbf{C}(n) = E\{\mathbf{A}^T(n)\,\mathbf{s}\,\mathbf{s}^H\mathbf{M}^*(n)\} = \sum_{q=-N+1}^{N-1}\rho(n+q)$ $\mathbf{s}_q\mathbf{s}^H_q$, and $\mathbf{s}_q$ contains the elements of **s** shifted by q samples and the remainder zero-filled, i.e., **s**2 = $[0\ 0\ s…….s_{N-3}]^T$ and where $\mathbf{B}(n) = E\{\tilde{\mathbf{b}}(n)\tilde{\mathbf{b}}^H(n)\}$is the covariance matrix of the noise.

The output of the Adaptive Pulse Compression Filter based on LMMSE is shown in Figure.6.

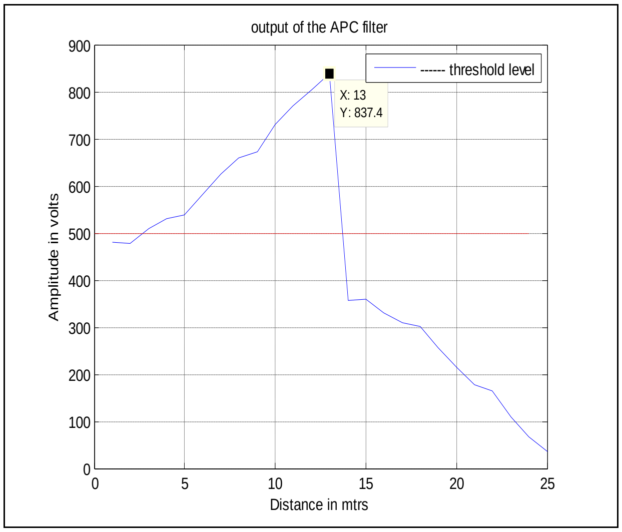

Fig.6 Output of the Adaptive Pulse Compression Filter

Figure.6 expresses the target is detected at a distance of 13 meters with an amplitude 837.4 V.

The Kalman filter is a linear estimator that minimizes the mean squared error as long as the target dynamics are modeled accurately. For a signal $\boldsymbol{x}(n)$ and noisy observation $\boldsymbol{y}(n)$, equations describing the state process model and the observation model in equation (5). The *a priori* and *a posteriori* estimation errors are defined as:

$$\mathbf{e}^-(k)=\boldsymbol{x}(k)-\boldsymbol{x}(k|k-1)$$

$$\mathbf{e}(k)=\boldsymbol{x}(k)-\boldsymbol{x}(k|k) \quad ....(5)$$

Kalman filter estimates a process when the received signal is given as input. The output of the filter is shown in Figure.7.

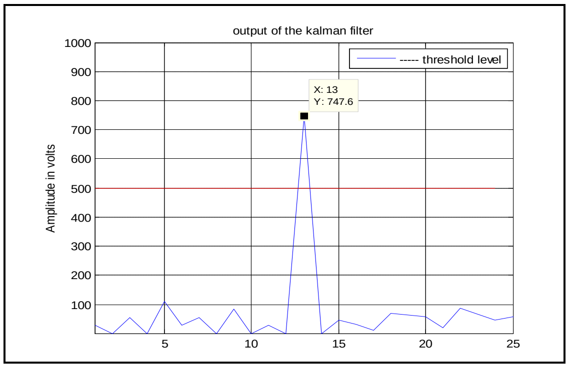

Fig.7 Output of the Kalman Filter

Comparing the three filter outputs, the target is detected at a distance of 13 meters. Fig 5 is the output of MF which has an amplitude 755.6V , Fig.6 is the output of APC Filter which has an amplitude 837.4 V and Kalman filter as in Fig 7 has an amplitude of 747.6 V.

Ideally the target is detected at a distance of 13m with an amplitude of 900 V. Finding the error with reference to the ideal case is shown in Figure.8,

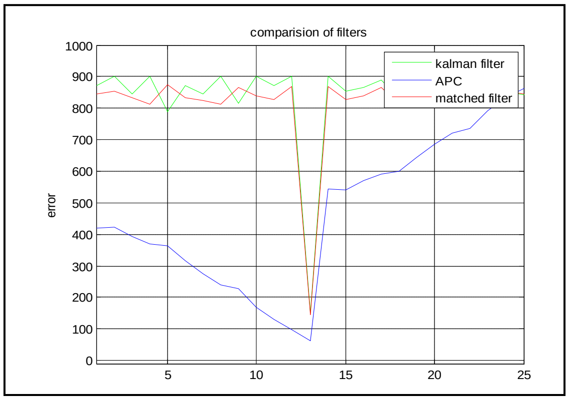

Fig.8 Comparison of error for the three filters

APC Filter based on LMMSE Technique has less error compared to MF and Kalman Filter as shown in Fig.8. Consider now the signal-to-noise ratio (SNR), one defines the SNR at the output of a generic filter **f**, in terms of the ratio of the expected values of the signal echo and the expected value of the noise component, as in [8] is shown as,

$$SNR_{out}(f_{H_1}) = \frac{E\left\{f_H S X^2\right\}}{E\left\{f_H b^{*2}\right\}} \qquad \text{……..(6)}$$

Figure.9 explains that SNR for the APC filter is 53dB which is much more better compared to the other two filters.

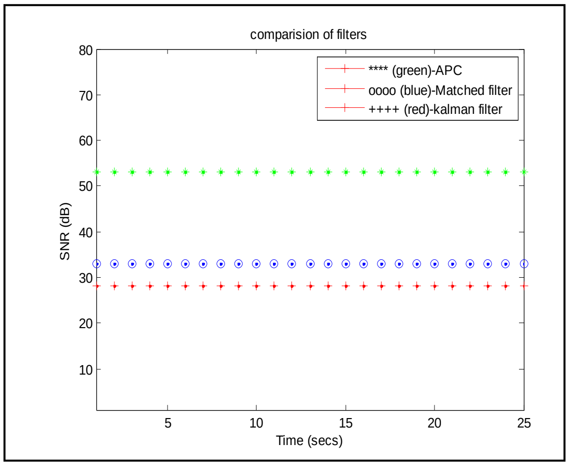

Fig.9 SNR of the three filters

B. *Two Targets*

As in the previous section, the signal model is shown. The only modification being that in the two-target case is all elements of **x** are zero except the two as in [4]. Assume that the second target is located at D cells apart from the first target. The two targets are x(n) and x(n-D), indicated as x and x_D for convenience. The no-target, single-target, and two-targets hypotheses can be formulated as:

$$\begin{aligned} H_0 &: Y^*_{H_0}(n) = b^*(n) \\ H_0 &: Y^*_{H_0}(n) = SX(n) + b^*(n) \qquad \text{……(7)} \\ H_0 &= Y^*_{H_1}(n) = M^T(n)S + b^*(n) \end{aligned}$$

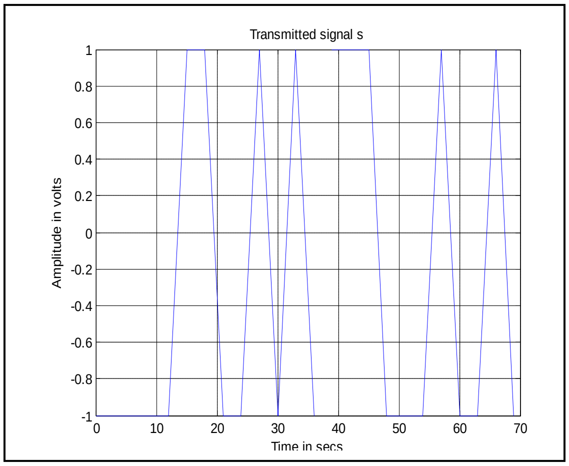

Fig.10 Barker sequences transmitted in continues form

Barker sequences shown in Fig.10 are transmitted in continuous form which is sampled at a rate of 3 samples per bit. In the two-target case the estimated target profile at iteration m can be then written as

$$X^*(m) = w^{(m)H} SX + w^{(m)HS_D X} \quad \text{....(8)}$$

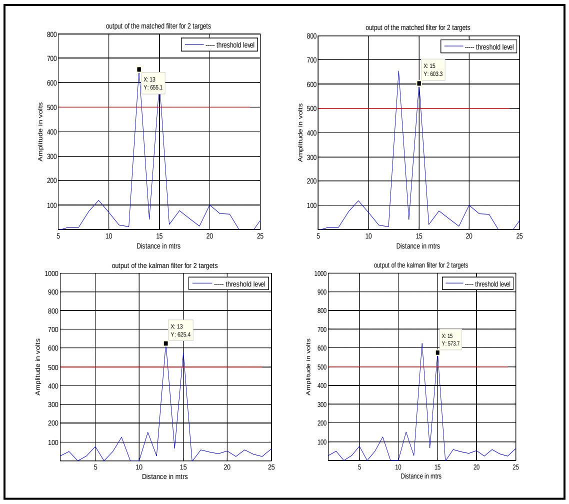

Fig.11 (a)Two target Case-Output of MF representing the 1st target
(b) Two target Case-Output of MF representing the 2nd target
(c) Two target Case-Output of KF representing the 1st target
(d) Two target Case-Output of KF representing the 2nd target

From the above simulations Fig.11 (a) is output of MF detecting the 1st target at a distance of 13m with an amplitude 655.1V (b) represents the 2nd target detected at 15m with an amplitude 603.3V (c) is the output of Kalman Filter detecting the 1st target at a distance of 13m with an amplitude 625.4V (d) represents the 2nd target detected at 15m with an amplitude 573.7V.

Received signal when applied to the Adaptive Pulse Compression Filter based on LMMSE, the output of the filter is as shown in Figure.12,

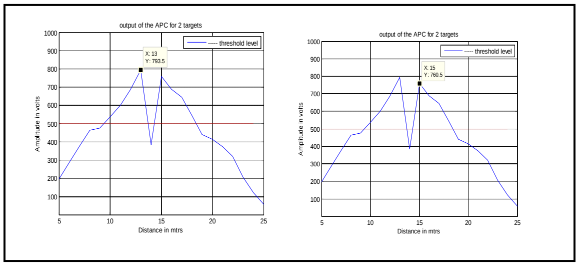

Fig 12 (a)Two target Case-Output of APC representing 1st target
(b) Two target Case-Output of APC representing 2nd target

The 1st target is detected at a distance of 13m with an amplitude of 793.5V and 2nd target detected at a distance of 15m with an amplitude of 760.5V. Comparing the three filter output's for two target case. APC Filter based on LMMSE generates the accurate output compared to the other two filters.

Considering the error to determine the performance of the three filters.

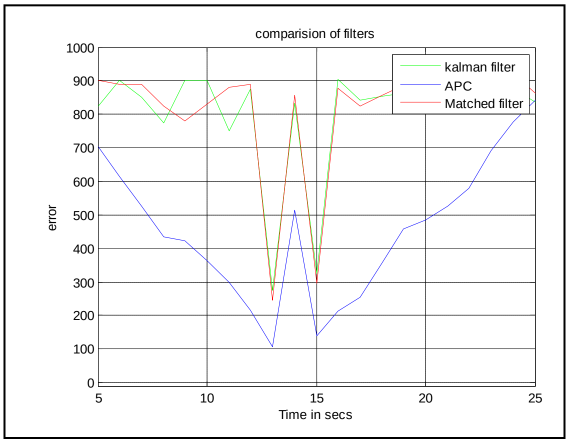

Fig.13 Comparison of error for the three filters-two target case

From the Fig.13, the APC Filter has less error which shows a value less than 700V is best compared to other two filters.

Consider now the signal-to-noise ratio (SNR) as explained in equation (6)

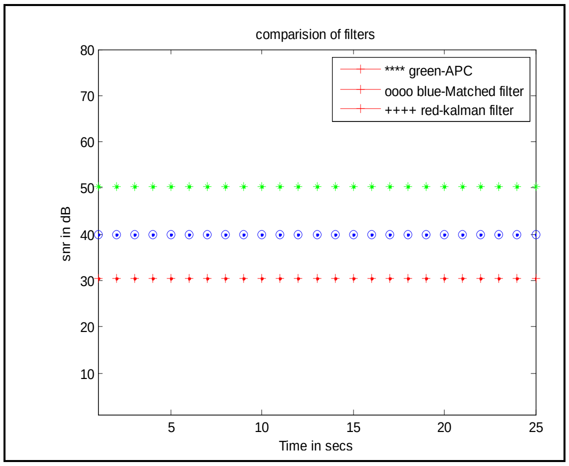

Fig.14 SNR of the three filters-for two targets case

Figure.14 explains that SNR for the APC filter is 50dB which is much more better compared to the other two filters.

V. ANALYSIS

In the previous sections, the theoretical and practical performance of the filtering schemes has been derived and compared for the single-target case and two-target case and plots of the outputs are shown, respectively, of the MF and the LMMSE filter using APC initialization for various parameters and Kalman Filter. Simulations have been obtained for coded signals that represents APC Filter based on LMMSE is better compared to MF and Kalman Filter.

VI. CONCLUSIONS

It has been shown that matched filtering achieves the optimal radar performance for a point target against a Gaussian noise background. This is due to the property of MF of maximizing the output SNR In this paper the performance of the LMMSE-based filtering technique designated APC is considered. The analysis of the performance of reiterated LMMSE-base of the APC filter in comparison to matched filter and Kalman Filter done. Analytical performance derivations are also given for the single target, two-target case and thus it can be extended to the multiple-target case.

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