



Performance of Fast Algorithms of Target Track Estimators in Clutter Environment

by

H. Nofal **, S. Yousef *, A. Hamad * and M. A. Matar *

ABSTRACT

The characteristic parameters of certain fast tracking algorithms were estimated for a single target in [1-4] under assumptions of a clean environment (no clutter returns) and a 100% probability of detection (P_D).

In the present work, we extend our study to more realistic tracking environments. Characteristic properties of both the tapped-delay-line (TDL) fast Kalman [1] and the gradient lattice [2] tracking algorithms are considered in the presence of clutter returns. Presence of clutter returns transform the mono target tracking problems into a multi-target case. This entails some form of data association along with the necessary gating so as to mitigate the associated computational burden. A single target is assumed to be tracked in conditions of clutter that may lower probability P_D .

A nearest-neighbor (NN) approach to the data association problem is adopted and an algorithm has been developed for investigating effects of gate dimensions on the probability of correct decision P_{CD} , as well as investigating the effects of P_D and the clutter density on P_{CD} and consequently on tracking the assumed target with fast Kalman and gradient lattice tracking filter.

This study shows that the probability of losing track increases, and the average track life decreases significantly with increasing clutter density as well as with lowering detection probability. Fast Kalman filter provides, however, a slightly longer track life with lower probability of losing track at 100% P_D as compared to the lattice filter. Moreover, both algorithms, no improvement in tracking properties was gained with higher-order filters ($N > 2$).

* Staff members of Avionics Dept., MTC, Cairo, Egypt.

** Ph.D. Applicant in Avionics Dept., MTC, Cairo, Egypt.

I. INTRODUCTION

Among sources that degrade performance radar tracking filters are clutter and interferences. These sources limit the target detectability as it may be captured by these signals and tracking may become impossible. Clutter, as conglomeration of unwanted radar echoes [5], complicates the recognition of wanted signals. The presence of clutter returns transform the mono target tracking problems into a multi-target case. This entails some form of data association along with the necessary gating so as to reduce the dimensionality of the problem. This association procedure, beyond the required processing burden, may result in either incorrect assignment or complete loss of data with no assignment at all. This yields additional errors that may cause divergence of tracking filters. These effects are investigated in this work. For tracking of a/c, assumed in our study, clutter echoes include reflections from clouds, precipitations, other meteorological phenomena as well as trees, hills and man-made objects as chaffs ..etc. Such echoes are inherently "composite": clutter target in contrast to isolated or "point" clutter ones. This composite clutter echo will be considered only here. This type of extraneous signals is characterized by existence of significant correlation between successive sweeps' radar echoes. It is this correlation that enables to devise important methods for combating clutter effects: such as MTI, pulse doppler radars, matched filtering and sensitivity-time control [5]. Techniques for clutter reduction are not the subject of this work. It is the effect of clutter that succeeds in penetrating the signal processing part of a TWS radar to its data processing or tracking part that is considered here only.

To study this effect we need to have a simulation model for the clutter encompassing its statistical parameters as well as its spectrum. This will be considered in section II. Section III is dedicated to simulation results and their discussions. Obtained conclusions are given in section IV

II. SIMULATION MODEL AND ALGORITHM

In the following we outline procedure used in performance evaluation in presence of clutter (see [10]). This includes:

- a-Generation of radar measurements as well as clutter returns along with the contaminating Gaussian noise in Cartesian coordinate frame.
- b-Making the gating tests, then through computing a statistical distances, an assignment matrix is formed.
- c-Solving the assignment matrix for data-to-tracks association.
- d-Supplying the tracking algorithm with the assigned measurements we update track, to predict the gate center for the next scan and to estimate the dimensions of the one-sigma gate.

Simulation is done under the following assumptions :

1-probability of detection $P_D = 1$.

2-data association is solved as a nearest-neighbor problem.

3-rectangular track gates with size 5-sigma.

4-track loss is signalized if within five consecutive scans correct measurement was not associated to it.

5-measurement errors are taken to be zero-mean, uncorrelated Gaussian processes with standard deviations of 100 m and 1° (17 mrad.) in range and azimuth respectively.

6-scan period $T = 2$ seconds.

7- 25-run Monte-Carlo simulations are made to get a result.

Performance Parameters [7-10]:

a-Probability of correct decision P_{CD} , given by :

$$P_{CD} = P_D \cdot P_{CC/D} + (1 - P_D) P_{NC}$$

with P_D the probability of target detection.

$P_{CC/D}$ the probability of correct correlation given that a true target detection occurs.

P_{NC} the probability of no correlation, given that target is not detected. This is given by probability of no clutter (or extraneous) returns within the gate zone.

b-Mean time of track life estimated as the number of tracking scans before terminating track after signalizing its loss.

c-RMS tracking error.

d-Convergence time if convergence occurs.

Clutter Model

a-Clutter spectrum

Typical clutter spectra are the Gaussian and the integrated type, whose parameters are related to the mean and variance of clutter source speed. These spectra are given in the following [5,6] :

$$PSD(f) = \exp(-af^2) \quad \text{Gaussian spectrum}$$

$$PSD(f) = (1 + (f/f_c)^3)^{-1} \quad \text{Integrated spectrum.}$$

with : $f_c = 1.33 \exp(.1356 v)$ with v = wind speed in knots.

$f_c = 1.33 \exp(.0892 v)$ with v = wind speed in m/sec.

$a = .5 (\lambda / 2\sigma_v)^2$; σ_v = standard deviation of v

and λ being the carrier wavelength

Typical values for $f_c = 6.7$ Hz and $a = .012 \text{ sec.}^2$ at $v = 12$ knots. This model for clutter spectrum will be used for evaluating the scan-to-scan temporal correlation for clutter echo signal.

b-Clutter Distribution

Several models as Rayleigh, Weibul and Log-normal distributions are considered in literature [5]. In this work, we are interested in a discrete model accounting for :

- number of clutter returns per scan.
- evolution of this number at next scans
- spatial distribution of the given number of returns and its temporal evolution defined by the above-mentioned spectra.

c-Simulation of Clutter Returns

Simulation of clutter returns with a number considered to be Poisson distributed with density β [8]. The expected number N_c of clutter returns within an area A_o of a one-sigma rectangular gate

is given by : $N_c = \beta \cdot A_o = \beta \cdot (2\sigma_x)(2\sigma_y)$

where σ_x and σ_y are the residual standard deviations in the X and Y coordinates, respectively.

The number N_c is used as the parameter defining the clutter density and is accounted for by C_D in the text. Thus no clutter returns fall within the one-sigma gate occurs with probability $p(0)$, while at least one clutter return will fall within this gate with probability $p(N_c \geq 1)$; given by :

$$p(0) = e^{-N_c} \quad \text{and} \quad p(N_c \geq 1) = 1 - e^{-N_c}$$

As to locations of clutter returns within a square area A, the corresponding number $(A N_c / A_o)$ is uniformly distributed over this square area assumed to be centered at the predicted location of the correct measurement. Then, for every scan, clutter position is determined from the initial position and the considered clutter correlation function.

For simulations purposes ; the hypothetical area A is taken $100 A_o$. Since $A \gg A_o$, actual number of validated clutter returns and

their locations within the track gate, would simulate what might happen in reality. We have considered also "worst-case" situation where different locations for clutter returns within the square area A were independently (zero correlation) and randomly determined for every radar scan.

III. SIMULATION RESULTS

In this section, we give simulation results concerning tracking performance of tapped-delay-line fast Kalman and gradient lattice tracking algorithms in typical tracking cases for a single target in the presence of clutter returns of different densities under certain detection probabilities assumed. A single target moving in a straight line trajectory in X-direction with a constant speed of 250 m/sec, was assumed to be tracked with a 100% probability of detection in a clutter environment.

Determination of Gate Dimensions and Filter Order

Taking G as the normalized gate length in one dimension (referred to corresponding standard deviation of residual error signal). In case of 2-dimensional measurement with the same G for both dimensions, the gate area equals $(G^2 \cdot A_0)$, with A_0 being the area of the one-sigma gate.

Fig.1. shows the obtained results for gradient lattice and the TDL fast Kalman tracking filters with different orders.

These results show that:

1-The gate has almost the same effect on P_{cd} for both filters.

100% P_{cd} will be provided at $G = 5.5 - 6$ with no clutter.

2-No improvement in P_{cd} is gained for tracking filters having order $N > 2$ at no clutter.

3-For higher clutter densities higher gate dimensions are required and 100% P_{cd} may not be attained.

Hence, gate dimension is minimally $G = 6$ and $N = 2$

Obtained Results :

a-Probability of Correct Decision

Fig.2 shows variations of decision P_{cd} with the clutter density, for different values of P_d for a gradient lattice filter with $N=2$ and a gate of $G=6$. The following remarks can be concluded :

-The probability P_{cd} decreases almost linearly as the clutter density increases. For example, with a 100% detection probability, P_{cd} decreases by 35% as the clutter density increases from 0 to 0.1. The effect of clutter becomes more significant with lower P_d . The corresponding decrease in P_{cd} with 80% detection probability amounts to 55% as clutter density varies from zero to 0.1.

-Probability P_{CD} decreases significantly as P_D goes to lower values in presence of clutter. For example, at a clutter density 0.05, a 10% decrease in P_D (from $P_D=100\%$ to 90%) is associated with a 15% decrease in P_{CD} , while a further 10% decrease in P_D results in 20% decrease in P_{CD} .

Similar results are obtained for tapped-delay-line fast Kalman filter.

b-Average life of a track

This is studied, first through estimating probability of losing the track and then average track life is evaluated at different clutter densities and at different detection probabilities. Fig.3. shows simulations results for gradient lattice and fast Kalman filters with $N=2$ and gate of $G=6$. From these results the following remarks can be concluded :

-The probability of losing track increases and average track life decreases significantly with the increase of clutter density. For example, at 100% detection probability and clutter density 0.02, gradient lattice filter with $N = 2$ and gate $G=6$, loses track after 75 scans with probability 15-20%. The same filter loses track just after 55 scans with probability of 50% at clutter density 0.08.

-Higher probability of losing track at shorter track life are obtained at lower detection probability. For example, at $P_D=80\%$, a target being tracked in a clutter density 0.08, track will be lost just after 30 scans with a probability of 80%.

-It is noticed that the fast Kalman filter provides slightly longer track life with lower probability of losing track at 100% detection probability.

-For both algorithms, no improvement in tracking properties is gained with higher-order filters ($N>2$).

c- RMS Error Performance

Fig.4. shows the RMS error of lattice and fast Kalman filters in the presence of clutter. From these results it may be seen that :

-Increase of the RMS error with the increase of the clutter density and divergence occurs at densities of about 0.05 for the worst-case clutter.

-Larger gate dimensions are required in conditions of high clutter densities.

-As to effects of P_D and clutter density, it is seen that with P_D as low as 75%, both gradient lattice and fast Kalman filters have diverged, even in clean environment. However, fast Kalman filter showed higher susceptibility to diverge at smaller clutter densities.

d-Convergence Time is increased with the increase of clutter densities and convergence may hardly be attained.

IV. CONCLUSIONS

This study comprises the investigation of tracking single target in clutter environment with fast Kalman and gradient lattice filters. The effects of gate dimensions, P_D and clutter density, are investigated in terms of probability of correct association P_{CD} , mean life of track, convergence time and RMS tracking error.

It is seen that the probability of losing track increases, and average track life decreases significantly with increasing clutter density as well as with lowering detection probability. Fast Kalman filter provides, however, a slightly longer track life with lower probability of losing track at 100% P_D as compared to the lattice filter. Moreover, both algorithms, no improvement in tracking properties was gained with higher-order filters ($N > 2$).

References

- [1] H. Nofal et al., "A Fast Kalman Radar Target Track Estimator" URSI Proc., Cairo, Egypt, Feb. 1990.
- [2] H. Nofal et al., "Lattice Algorithms for Target Track Estimation in TWS Radar Systems", URSI Proc., Cairo, Egypt, Feb. 1990.
- [3] S. Yousef et al., "Lattice Algorithms for Maneuvering Target Track Estimation in TWS Radar Systems", URSI Proc., Cairo, Egypt, Feb. 1991.
- [4] M. A. Matar et al., "A Comparative Performance Evaluation for a Set of Target Track Estimators in TWS Radar Systems" Submitted for Publications in ASAT Conf., Cairo, Egypt, May 91.
- [5] M. I. Skolnik, Introduction to Radar Systems, pp. 50-56 and chap. 4 & 12, McGraw-Hill, 1980.
- [6] L. J. Cantafio ed., Space Based Radar Handbook, chap. 11, Artech House, 1989.
- [7] Y. Bar-Shalom and E. Tse, "Tracking In A Cluttered Environment With Probabilistic Data Association", Automatica, vol. 11, pp. 451-460, Sept. 1975.
- [8] S. S. Blackmann, "Multiple-Target Tracking With Radar Applications", Artech House Inc., 1986.
- [9] A. Farina and S. Pardini, "TWS Algorithm in Clutter Environment" IEEE Trans. Aerospace & Elect. S., vol. AES-14, pp. 769-779, sept. 78.
- [10] H. Nofal, "Multi-target Tracking in TWS radars", Ph.D. dissertation, Avionics Dept, MTC, 1990 (to appear)

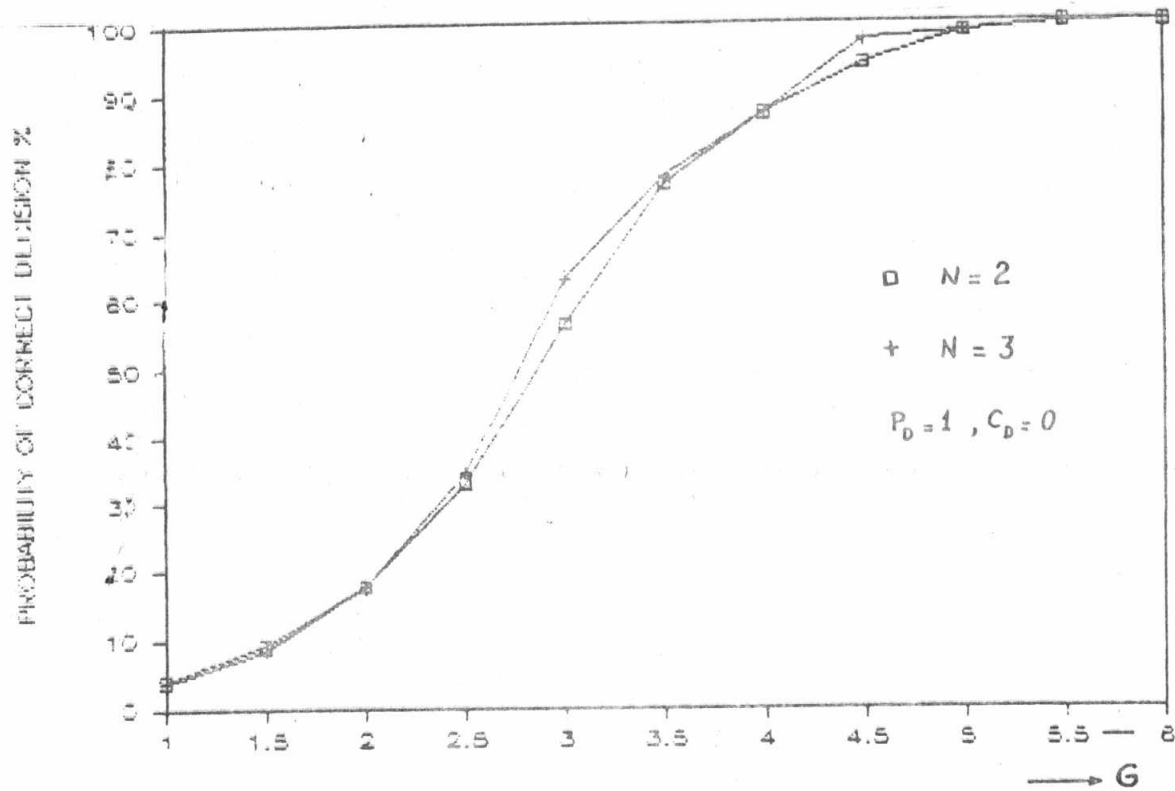


Fig. 1. EFFECT OF GATE SIZE ON P_{CD}

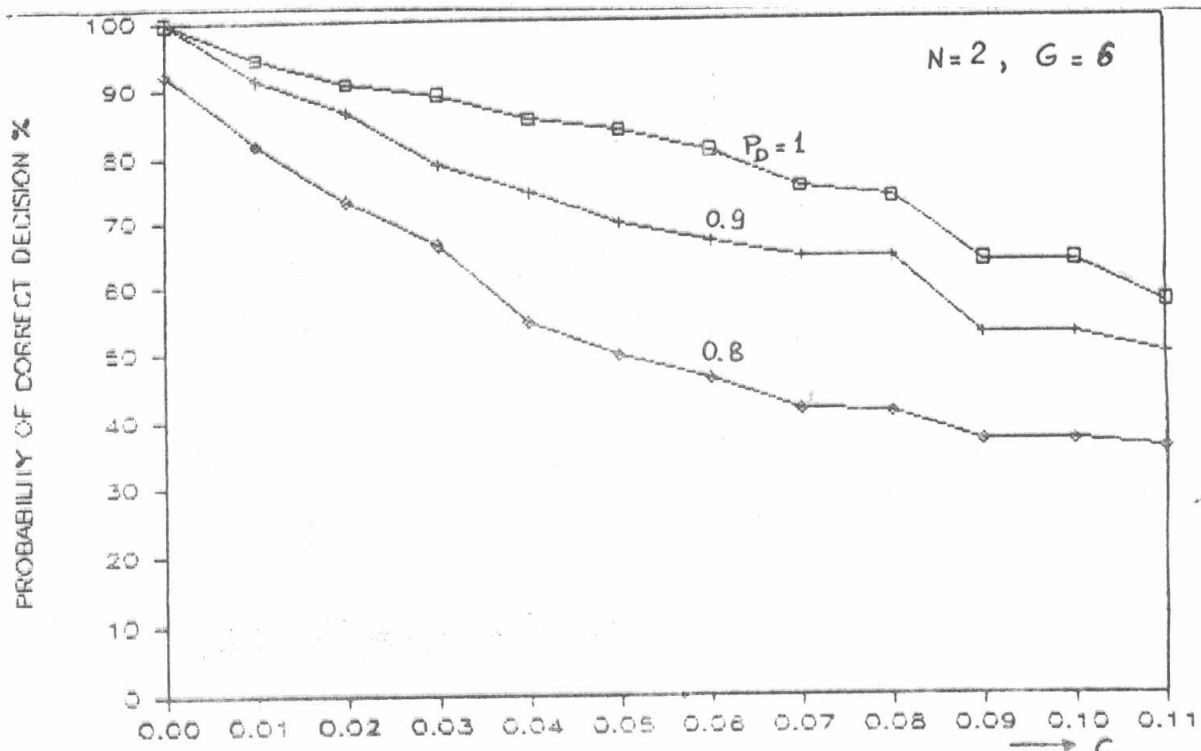


Fig. 2. EFFECT OF CLUTTER DENSITY ON P_{CD}

AV-7 503

FOURTH ASAT CONFERENCE
14-16 May 1991, CAIRO

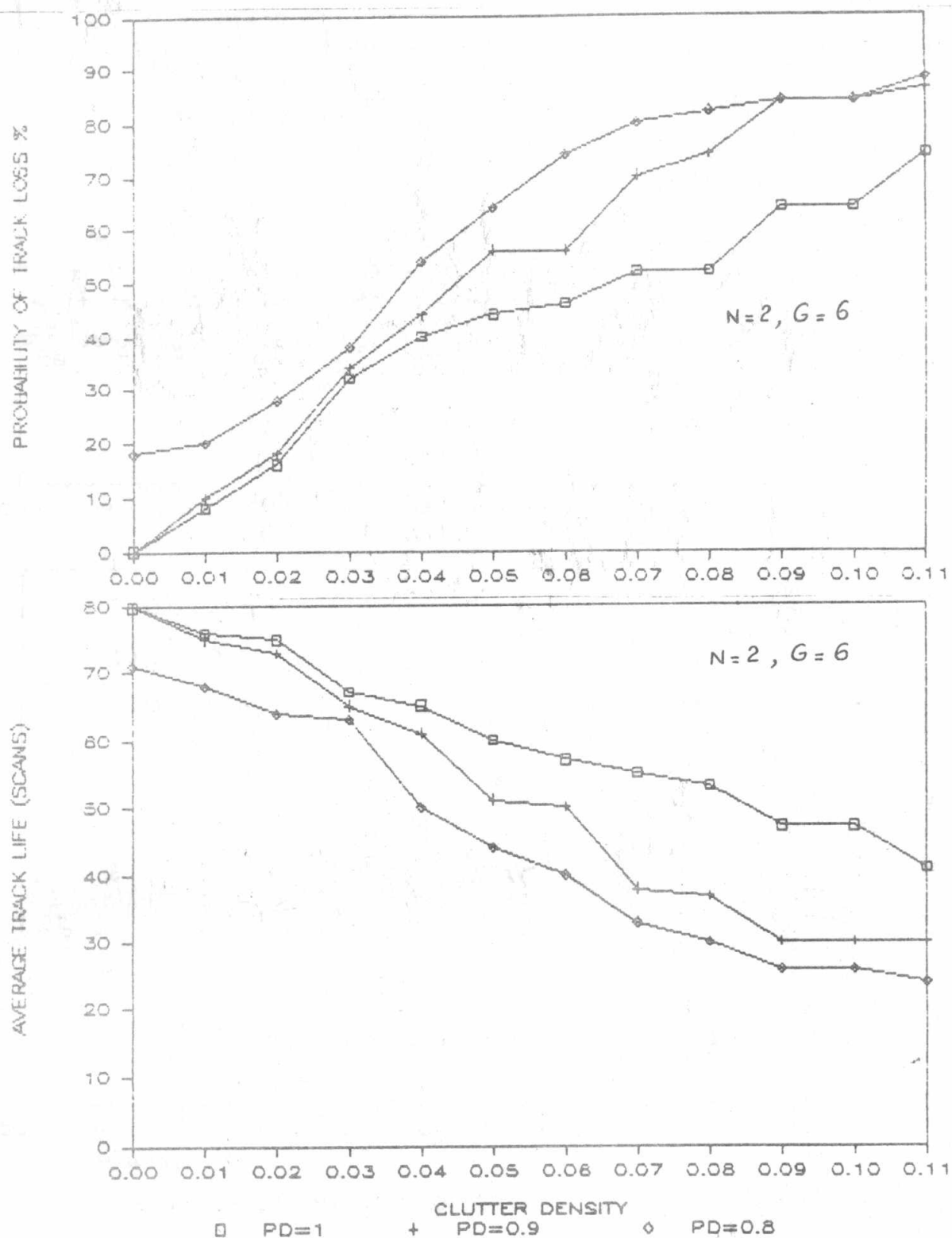


Fig. 3. EFFECT OF CLUTTER ON AVERAGE LIFE OF TRACK

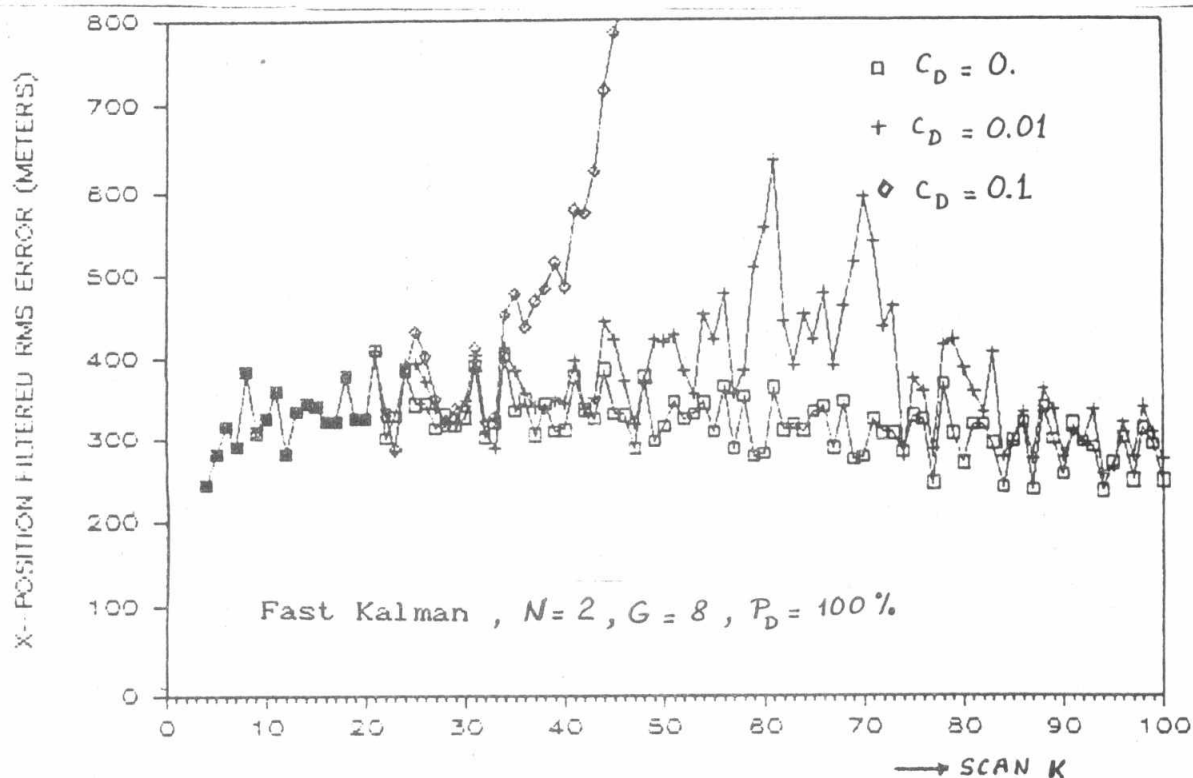
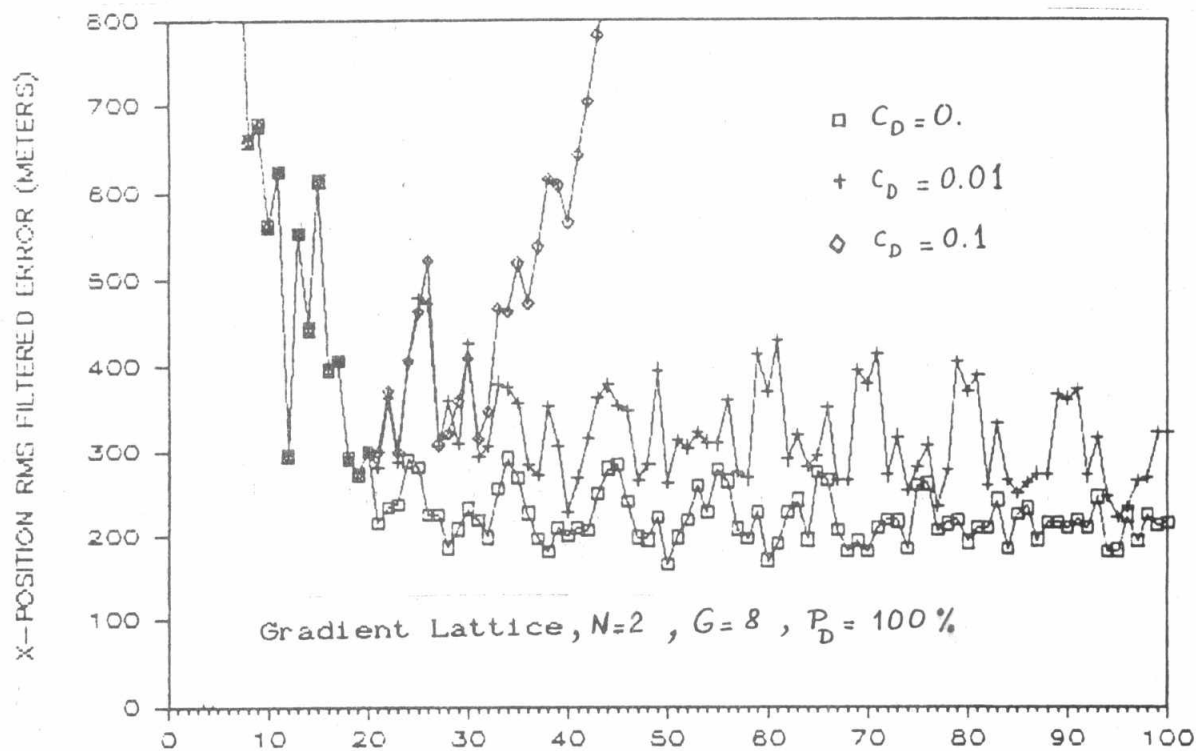


Fig. 4. EFFECT OF CLUTTER ON RMS TRACKING ERROR