Correspondence

Rank Detector Preprocessor for Glint Reduction in a Tracking Radar

A rank detector [3] is used to detect instantaneous received power fades in a tracking radar. On detection of a fade, censorship of the angular position measurement is implemented in a Kalman tracking filter. It is shown that this technique can typically give a 15% angular tracking improvement on highly dynamic targets.

I. INTRODUCTION

In a tracking radar, the major contributor to angular tracking errors at close range is the glint-induced tracking error [1]. Methods using frequency agility and polarization techniques have been presented [1], but if polarization and frequency diversity are not available, processing techniques must be used to minimize the angular tracking error at close range. The distribution of glint angular errors has been found to follow a Student-*t* distribution with two degrees of freedom [4]. This has the same shape as a Gaussian distribution but exhibits long tails due to data outliers. Due to the non-Gaussian nature of the angular error distribution, robust processing techniques have been suggested [2] to make the angular error distribution more Gaussian.

Kalman filters are employed in tracking radars to provide more accurate state estimates of the position, velocity, and acceleration of the target in the presence of measurement and process noise. At long ranges, measurement noise in the form of thermal noise is dominant. However, at close range the glint angular errors are dominant.

The Kalman filter algorithms are severely compromised when the measurement noise is no longer Gaussian, and particularly so if the measurement noise contains outliers [5]. To solve this problem, robust Kalman filters have been devised [5] as well as robustifying preprocessors creating blocks of robustified averages for the Kalman filter to operate on [2]. Problems associated with these approaches include the computational speed required to process every measurement in the former, and complex iterative processes in the preprocessor of the latter.

A suboptimal data cleaner is proposed using a rank detector [3] to monitor fades in the instantaneous returned power from the target, and to use this

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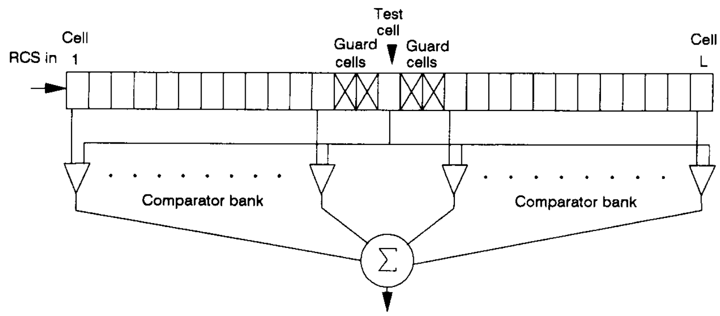

Fig. 1. Block diagram of rank detector.

information to censor angular error measurements in the block averaging process.

A simulation is run where measure angular errors are superimposed on a flypast target trajectory and a Singer [6] Kalman filter is applied to the block averaged data, with and without data censorship. The simulation demonstrates that an improvement in tracking accuracy is possible on maneuvering targets.

II. GLINT DETECTOR

When the target is close, the received power in a tracking radar will always have a large S/N. This power is fed into a rank detector as shown in Fig. 1 and is clocked 1 position on every pulse received.

The rank detector can be described mathematically as follows. If x_i is the instantaneous radar cross section (RCS) magnitude of the ith returned pulse, then the output of the rank detector is described by

$$R_i = \sum_{\substack{k \\ k \neq e}}^{L} C(x_i - x_k)$$

where

$$C(x) = \begin{cases} 1, x > 0 & \text{or} \quad x = 0; \quad i-k \text{ odd} \\ 0, x < 0 & \text{or} \quad x = 0; \quad i-j \text{ even} \end{cases};$$

L is the number of pulses taken into consideration in the operation of the rank detector; and e is a set of values of k which are not included in the summation.

The rank R_i depends on the value of L and the number of guard cells flanking the test cell. A measured radar received power signal is placed into the rank detector with two guard cells and $L = 20$. This results in a rank shown in Fig. 2.

It has been experimentally shown by Wallin and Aas [7], that where a received power level fades as at sample 17, there is a great chance of a glint spike occurring as can be seen in Fig. 3. The sample number 17 corresponds to a low rank R_{17} which in this case is 0. It can also be clearly seen how the rank R_i is not sensitive to the slow fluctuations in received power as can be seen from sample 30 to sample 50 in Fig. 2.

The rank for the example shown in Fig. 2 can only have rank values distributed from 0 to 15. Due to the limited number of rank values possible, the glint spike censorship is done when a rank of 0 is obtained. The performance of the detector is modified by adjusting the length L and the number of guard cells. It is assumed that the test cell will remain centrally located.

III. SIMULATED PREPROCESSOR PERFORMANCE

A simulation was made up using various values of L and a number of guard cells on two glint/received power data sets. The first data set has slow fluctuations with a correlation time between received power fades of approximately 12 samples. This corresponds to a low angular rate and/or a radar operating at a low frequency. This data was simulated from spatial scatterers represented by Woolcock [8]. The second data set was measured, and has fast fluctuations with an estimated correlation time between received power fades of two samples. This corresponds to a high angular rate and/or a radar operating at a high frequency. This data set was measured on a millimeter wave tracking radar, and is seen in Fig. 2 and Fig. 3.

The glint data was superimposed on the elevation of a flypast target to simulate the measurement noise. The relative increase in measurement noise as the target range becomes less is also included into the elevation measurement data sequence. The instantaneous received power is assumed not to have any range bias due to sensitivity time control (STC) circuitry in the radar.

The received power measurement data sequence is passed through the glint detector. When the rank R_i becomes zero, the corresponding elevation measurement is not included in an elevation block data set. After 32 pulses, the block is averaged and the block standard deviation is found and passed on to the Kalman filter.

An optimized one-dimensional Singer Kalman filter [6] is applied to the averaged measurement data using the block variance to determine the measurement noise R_k.

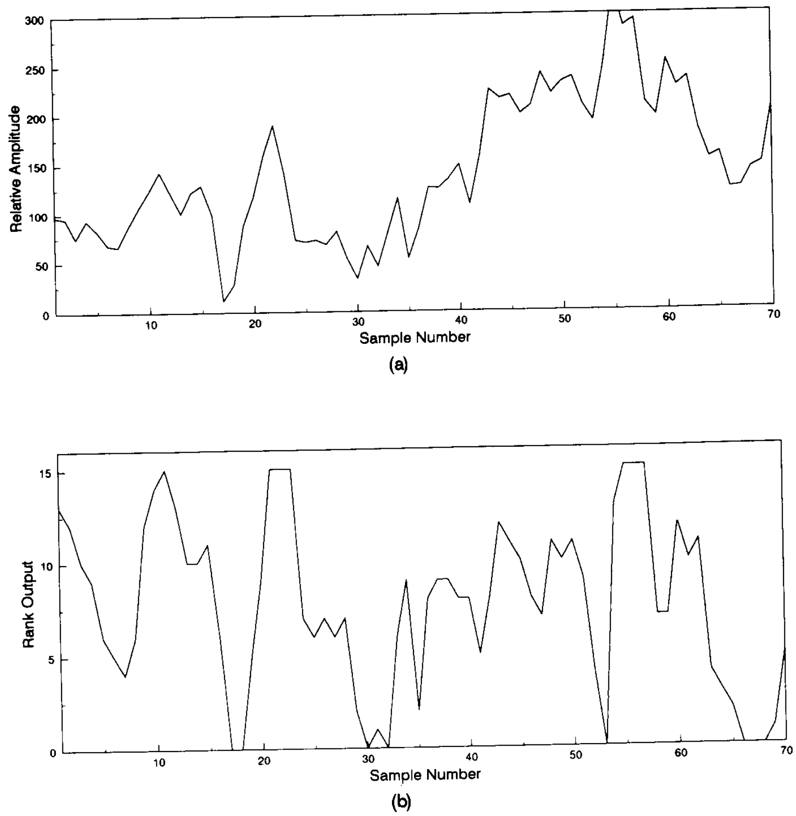

Fig. 2. (a) Test cell value at cell 11 and (b) R_i.

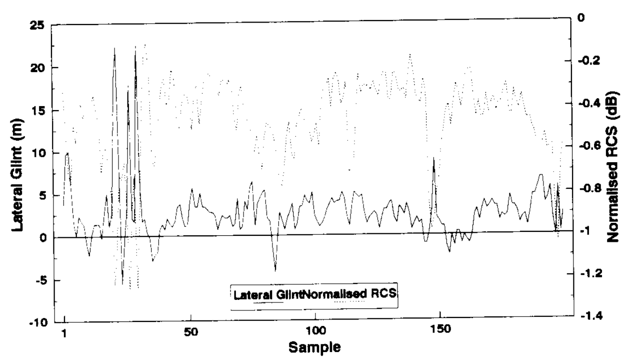

Fig. 3. Glint/received power versus sample for measured target.

The reader is referred to Singer's algorithm in [6] for a full description of the filter formulation. The values for $A_{\max}$, $P_{\max}$, and P_0 were accurately determined from the whole flypast profile to allow the filter to be stable during the simulation.

The simulation is run 50 times over data sets 4 500 samples long for a variety of rank detector lengths and number of guard cells. Simultaneously, the same data is placed in an identical filter, but with no glint spike censorship. Two regions of the track are evaluated. The first region illustrated in Fig. 4 consists of 50 blocks of averaged data in a region where the filter has stabilized and where accelerations are small. The second region illustrated in Fig. 4 also consists of 50 blocks of averaged data, but is in a region where accelerations are high and filter lag is expected.

The resulting difference in rms evaluation errors σ_e is expressed in terms of performance measure (PM) where

$$\mathrm{PM} = \frac{\sigma_e(\text{no preprocessor}) - \sigma_e(\text{preprocessor})}{\sigma_e(\text{no preprocessor})} \times 100.$$

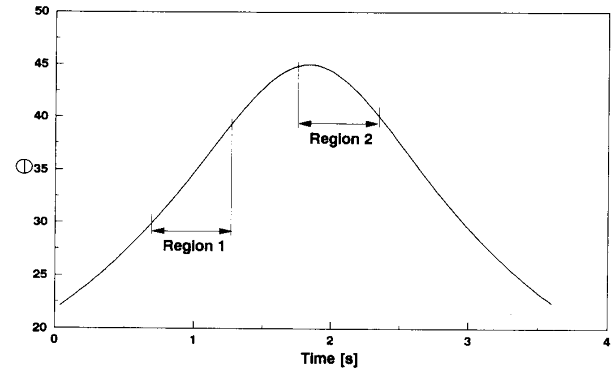

Fig. 4. Preprocessor evaluation regions.

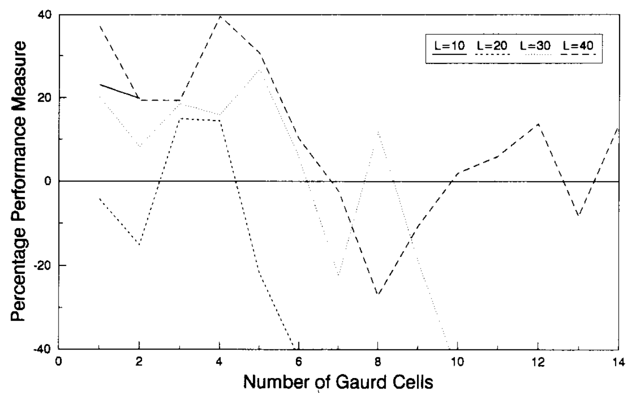

Fig. 5. PM for slowly varying received power in region 1 averaged over 50 runs.

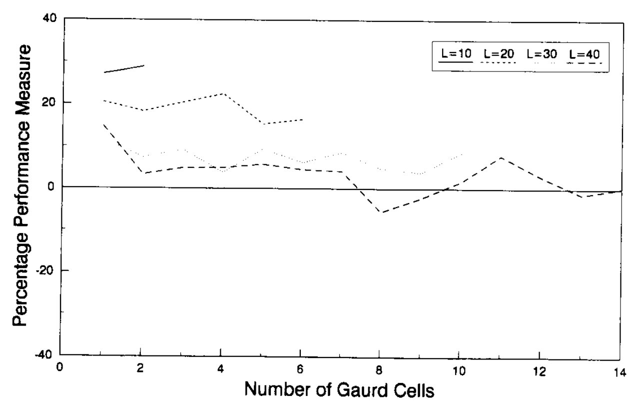

Fig. 6. PM for slowly varying received power in region 2 averaged over 50 runs.

The PM is expressed as a percentage where a positive value indicates an improvement in elevation tracking. The results of the simulation appear in Figs. 5–8.

IV. CONCLUSION

From Figs. 5–8, it can be seen that the preprocessor has the largest effect on region 2. This is due to the minimization of the block variance when data outliers are censored resulting in an increase in the Kalman gain allowing the measurement to dominate the estimate. This can allow an improvement in tracking of 15% on average on highly dynamic targets. The tracking improvement in region 1 where the elevation accelerations are small are inconclusive. Reference [9] contains a broader study into glint-induced errors and details the contents of this paper.

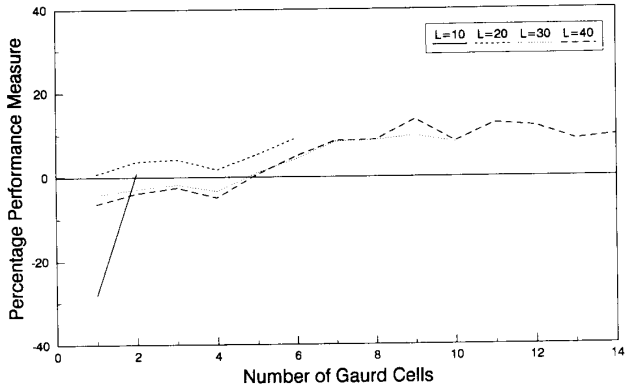

Fig. 7. PM for rapidly varying received power in region 1 averaged over 50 runs.

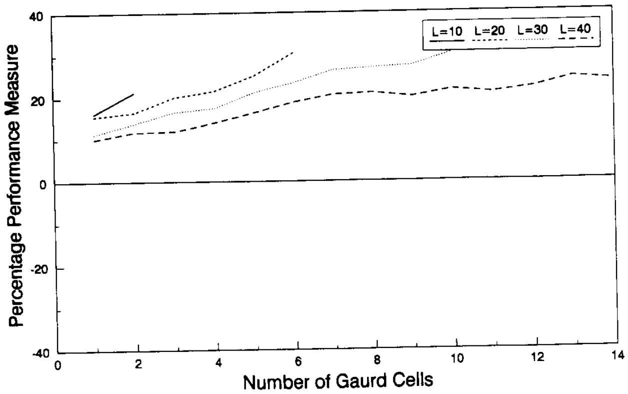

Fig. 8. PM for rapidly varying received power in region 2 averaged over 50 runs.

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REFERENCES

[1] Skolnik, M. I. (1981)
Introduction to Radar Systems.
New York: McGraw-Hill, 1981, 170–172.

[2] Hewer, G. A., Martin, R. D., and Zeh, J. (1987)
Robust preprocessing for Kalman filtering of glint noise.
IEEE Transactions on Aerospace and Electronic Systems, **AES-23**, 1 (Jan. 1987).

[3] Trunk, G. V., Cantrell, B. H., and Queen, F. D. (1972)
Modified generalized sign test processor for 2-D radar.
IEEE Transactions on Aerospace and Electronic Systems, **AES-10**, 5 (Sept. 1974), 574–582.

[4] Sandhu, G. S., and Saylor, A. V. (1985)
A real-time statistical radar target model.
IEEE Transactions on Aerospace and Electronic Systems, **AES-21**, 4 (July 1985).

[5] Masreliez, D. J., and Martin, R. D. (1977)
Robust Bayesian estimation for the linear model and robustifying the Kalman filter.
IEEE Transactions on Automatic Control, **AC-22** (1977), 361–371.

[6] Singer, R. A. (1970)
Estimating optimal tracking filter performance for manned maneuvering targets.
IEEE Transactions on Aerospace and Electronic Systems, **AES-6**, 4 (July 1970), 473–483.

[7] Nullin, C. M., and Aas, B. (1987)
Experimental investigation of correlation between fading and glint for aircraft targets.
In *Proceedings of Radar-87 Conference*, Oct. 1987, 540–543.

[8] Woolcock, C. (1978)
Target echoing characteristics (TEL/4).
EMI Electronics, UK, Doc. IMP-W1-9-153 (Apr. 1978), 41.

[9] Guest, I. W. (1991)
The study and minimization of target induced angular tracking errors in tracking radar.
M.Sc. Dissertation, Univ. of Pretoria, South Africa, 1991.