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Survey of Radar ADT

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This report surveys the state of the art of automatic detection and tracking for radars. This subject is reviewed under the three subtopics of (1) noncoherent integration techniques, (2) false alarm control, and (3) tracking system. In the area of noncoherent detection, various integrators such as the moving window, feedback integrator, two-pole filter, binary integrator, and batch processor are discussed. False alarms are controlled by using either adaptive thresholding,

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20. ABSTRACT *(Continued)*

nonparametric detectors, or clutter maps. A general outline of a track-while-scan systems is given and then a discussion of the tracking filter, maneuver-following logic, track initiation, and correlation logic is presented. Finally, methods of integrating data from both colocated and multisite radars are discussed.

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SURVEY OF RADAR ADT

INTRODUCTION

Since the earliest use of radar, radar operators have detected and tracked targets using visual inputs from PPIs and A-scopes. Although operators can perform these tasks very accurately, they are easily saturated and quickly become fatigued. To correct this situation, automatic detection and tracking (ADT) systems are being attached to many radars. Undoubtedly, as digital processing increases in speed and hardware decreases in cost and size, ADT systems will become associated with almost all but the simplest radars.

The purpose of this report is to survey the state of the art in ADT and update the ADT portion included in "Survey of Radar Signal Processing" [1]. Included in this discussion are various noncoherent integrators that provide target enhancement, thresholding techniques for reducing false alarms and target suppression, and algorithms for estimating target position and resolving targets. The other major topic that is covered is track-while-scan systems. An overview of the entire tracking system is given, followed by a discussion of its various components such as tracking filter, maneuver-following logic, track initiation, and correlation logic. Finally, the survey concludes with a discussion of radar netting, including both colocated and multisite systems.

NONCOHERENT INTEGRATORS

There are many different integrators that are used with radars. While the optimal integrator is never implemented, it will be introduced in order to compare the various practical integrators to it.

Optimal Detector

The radar detection problem is a binary hypothesis testing problem; i.e.,

$$H_0\text{: No target present}$$

$$H_1\text{: Target present}$$

While many criteria can be used to solve this problem, the most appropriate for radar is the Neyman-Pearson criterion. This criterion maximizes the probability of detection P_D for a given probability of false alarm P_{fa} by comparing the likelihood ratio to an appropriate threshold. It can be shown that the likelihood ratio can be reduced so that one should declare a target present in the jth range cell if

$$\prod_{i=1}^{n} I_0\left(\frac{A_i x_{ij}}{\sigma^2}\right) \geqslant T',$$

where n is the number of pulses within the beamwidth, x_{ij} is the ith envelop-detected returned pulse in the jth range cell, A_i is the signal amplitude on the ith pulse ($\{A_i\}$ are proportional to the square of the voltage antenna pattern as the antenna sweeps over the target), σ^2 is the noise power, I_0 is the Bessel

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function of zero order, and the threshold T' determines the P_{fa}. For small signals, the optimal detector can be approximated by

$$\sum_{i=1}^{n} A_i^2 x_{ij}^2 \geqslant T.$$

Most of the detectors implemented differ from the optimal detector in the weights (e.g., A_i) applied to the pulses.

Besides detecting targets, the detection process involves making angular estimates of the azimuth position of the target. Swerling [2] calculated the standard deviation of the optimal estimate by using the Cramer-Rao bound. His result holds for a large number of pulses within the beamwidth and the optimal estimate involves finding the location where the correlation of the returned signal and the derivative of the fourth power of the voltage antenna pattern is zero. Though this estimate is rarely implemented, its performance is approached by simple estimates such as the maximum value of the integrator or the midpoint between the initial and final crossing of the detection threshold.

A few of the most common integrators are shown in Fig. 1. Though they are shown as being implemented with shift registers, with today's technology they would probably be implemented with random access memory. The input to these detectors can be either linear, square-law, or log video. Since linear video is probably the most commonly used video, the advantages and disadvantages of the various integrators will be stated for this video.

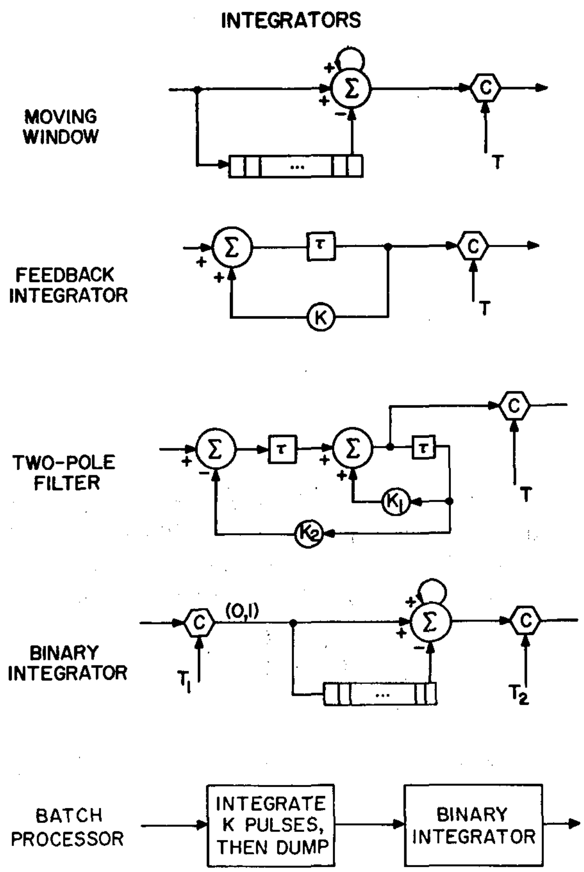

Fig. 1 — Block diagrams of various integrators

Moving Window

The moving window performs a running sum of n pulses in each range cell;

$$S_i = S_{i-1} + x_i - x_{i-n},$$

where S_i is the sum on the ith pulse and for notational convenience the subscript for the jth range cell has been dropped. The detection performance of this detector is only 0.5 dB worse than the optimal detector. The angular estimate that is obtained by either taking the maximum value of the running sum or taking the midpoint between the first and last crossing of the detection threshold has a bias of $n/2$ pulses which is easily corrected. The standard deviation of the estimation error of both estimators is about 20% higher than the Cramer-Rao lower bound. The major disadvantage of this detector is that the last n pulses for each range cell must be saved, resulting in a large storage requirement for large beamwidth radars. However, because of the current availability of large memories of reduced size and cost, this problem has essentially disappeared.

Feedback Integrator

The amount of storage required can be reduced significantly by using a feedback integrator

$$S_i = K\,S_{i-1} + x_i.$$

Although the feedback integrator applies an exponential weighting into the past, its detection performance is only 1 dB less than the optimal integrator. Unfortunately, difficulties are encountered when using the feedback integrator to estimate the azimuth position. The threshold crossing procedure yields estimates only 20% greater than the lower bound, but the bias is a function of the signal-to-noise ratio (S/N) and must be estimated. On the other hand, the maximum value, though it has a constant bias, has estimates that are 100% greater than the lower bound. Furthermore, the exponential weighting function essentially destroys the radar sidelobes. Because of these problems, I would recommend that the feedback integrator never be implemented.

Two-Pole Filter

The two-pole filter requires the storage of an intermediate calculation in addition to the integrated output (see Fig. 1). However, with this rather simple device, a weighting pattern similar to the antenna pattern can be obtained. The detection performance is within 0.15 dB of the optimal detector (i.e., better than the moving window) and its angular estimates are about 20% greater than the Cramer-Rao lower bound. The problems with this detector are 1. it has rather high detector sidelobes, 15 to 20 dB and 2. it is extremely sensitive to interference (i.e., the filter has a high gain resulting in a large output for a single sample that has a high value).

Binary Integrator

The binary integrator is also called a binary moving window, an m-out-of-n detector, a dual threshold detector, or rank detector. The input samples are quantized to 0 or 1 depending on whether or not they are greater than a threshold T_1. The last n 0s and 1s are summed and compared to a detection threshold T_2. For a large number of pulses, the detection performance of this detector is 2 dB less than the moving window because of the hard limiting of the data, and the angular estimation error is 25% greater than the Cramer-Rao lower bound. There are several reasons why this detector is used: 1. it is easily implemented, 2. it ignores interference spikes which cause trouble with integrators that directly use signal amplitude, and 3. it works extremely well when the noise has a non-Rayleigh density. For log-normal noise statistics, the binary integrator is less than a decibel from the optimal detector while the moving window is 10 dB from the optimal detector [3]. The binary integrator should always be used if there are only two pulses on target, a condition that occurs with many 3-D radars.

Batch Processor

This detector is a combination of an integrator and dump and a binary integrator (it could also use a moving window instead of a binary integrator). The detector should be used when there are a large number of pulses. For instance, if there are 80 pulses within the 3-dB beamwidth, one could integrate 16 pulses (this is called a batch) and then use the five batches as an input to either a binary integrator or moving window integrator. The performance is only slightly worse than the moving window but the batch integrator is much easier to implement than the moving window. The angle estimate is given by

$$\hat{\theta} = \frac{\Sigma\, B_i \theta_i}{\Sigma\, B_i},$$

where B_i is batch amplitude and θ_i is azimuth angle corresponding to the center of the batch.

FALSE ALARM CONTROL

If fixed thresholds are used with the previously discussed integrators, the detections will resemble the output of a PPI. In the presence of clutter, this can result in an enormous number of detections which will saturate and disrupt the tracking computer associated with the radar system. Of course, one can limit the number of false alarms with a fixed threshold system by setting a very high threshold. Unfortunately, this would reduce target sensitivity in regions of low noise (clutter) return. What is desired is a detector that will detect a target when it has a higher return than its immediate background. Two such approaches are adaptive thresholding and nonparametric detectors. Both of these approaches assume that the samples in the range cells surrounding the test cell (called reference cells) are independent and identically distributed; and furthermore, it is usually assumed that the time samples are independent. Both kinds of detectors test whether the test cell has a return sufficiently larger than the reference cells.

Adaptive Thresholding

The basic assumption of the adaptive thresholding technique is that the noise density is known except for a few unknown parameters. The surrounding reference cells are then used to estimate the unknown parameters and a threshold based on the estimated parameters is obtained. The simplest adaptive detector, shown in Fig. 2, is the cell-averaging CFAR (constant false alarm rate) investigated by Finn [4]. If the noise has a Rayleigh density, only the parameter σ needs to be estimated and the threshold is of the form $T = K\Sigma x_i = Kn\sqrt{\pi/2}\,\hat{\sigma}$. However, since T is set by an estimate $\hat{\sigma}$, it must be slightly larger than the threshold one would use if σ were known a priori. The raised threshold causes a loss in target sensitivity and is referred to as a CFAR loss. This loss has been calculated and is given in [5].

If there is uncertainty about whether or not the noise is Rayleigh distributed, it is better to threshold the data earlier and use a binary integrator as shown in Fig. 3. The reason why this detector is robust to the noise density is that by setting K to yield a "1" with probability 0.1, a $P_{fa} \approx 10^{-6}$ can be obtained by using a 7-out-of-9 detector. While noise may be non-Rayleigh, it will probably be very Raleigh-like out to the tenth percentile. Furthermore, one can use a slow feedback to control K in order to maintain a desired P_{fa} either on a scan or sector basis.

If the noise power varies from pulse-to-pulse basis (as it would in jamming when frequency agility is employed) one must CFAR each pulse and then integrate. While the binary integrator performs this type of CFAR action, analysis [6] has shown that the ratio detector shown in Fig. 4 is a better detector. A comparison of the ratio detector with other commonly used detectors when the jamming level varies by 20 dB per pulse is shown in Fig. 5.

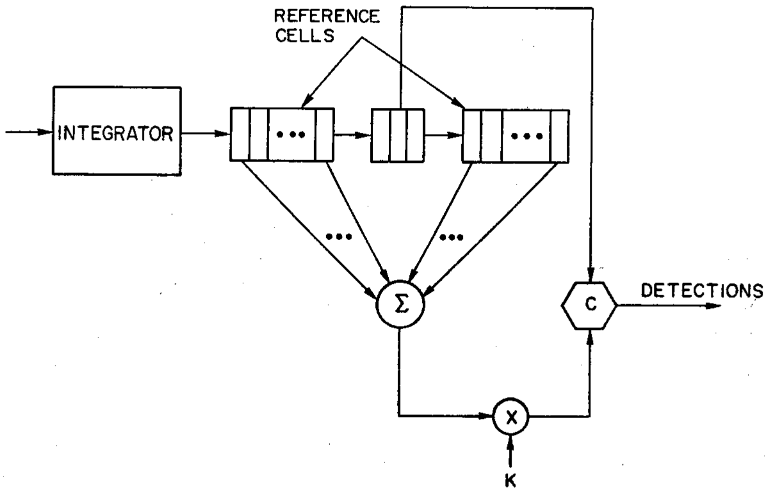

Fig. 2 — Cell-averaging CFAR

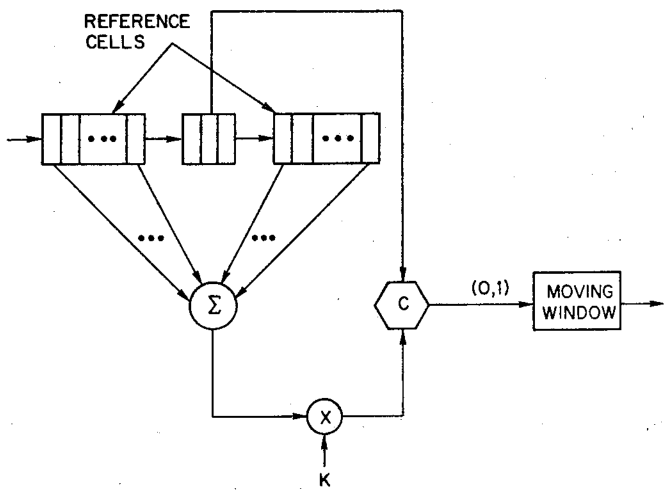

Fig. 3 — Implementation of binary integrator

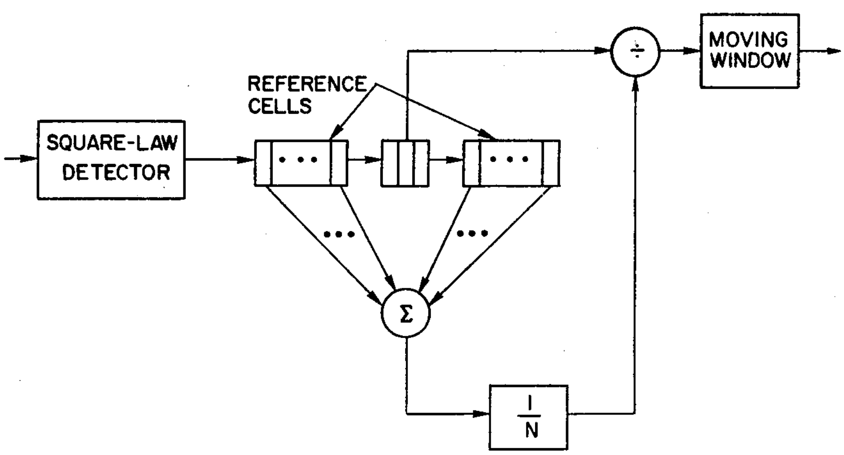

Fig. 4 — Ratio detector

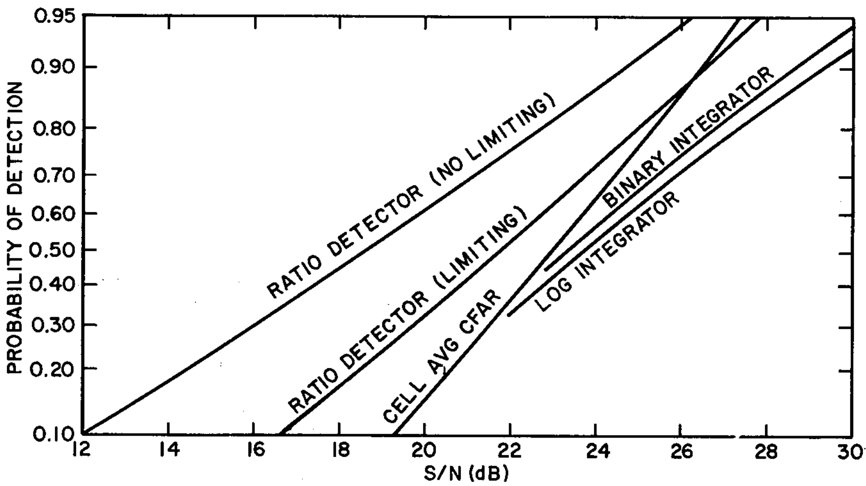

Fig. 5 — Curves of probability of detection *vs* signal-to-noise ratio for ratio detectors, cell-averaging CFAR, log integrator and binary integrator for Rayleigh fluctuating target. Maximum Jamming/noise = 20 dB; N = 6 pulses; $P_{fa} = 10^{-6}$.

If the noise samples are dependent in time or have a non-Rayleigh density, such as the chi-square density or log-normal density, it is necessary to estimate two parameters and the adaptive detector is more complicated. Usually several pulses are integrated so that a Gaussian assumption can be used for the integrated output. Then the two parameters that must be estimated are the mean and variance and a threshold of the form $T = \hat{\mu} + K\hat{\sigma}$ is used. Though the mean is easily estimated in hardware, the usual estimate of the standard deviation,

$$\hat{\sigma} = \frac{1}{N} \Sigma \, (x_i - \bar{x})^2,$$

where

$$\bar{x} = \frac{1}{N} \Sigma \, x_i,$$

is more difficult to implement. Consequently, sometimes the mean deviate defined by

$$\hat{\sigma} = A \, \Sigma |x_i - \bar{x}|$$

is used because of its ease of implementation.

Clutter Mapping

A clutter map uses adaptive thresholding where the threshold is calculated from the return in the test cell on previous scans rather than from the surrounding reference cells on the same scan. This technique has the advantage that for essentially stationary environments (e.g., land based radar against ground clutter), the radar has inter clutter visibility—it can see between large clutter returns. Lincoln Laboratory [7] in their Moving Target Detector (MTD) used a clutter map (setting their threshold using the return from the last eight scans) for the zero doppler filter very effectively. There remain several unanswered questions concerning the use of clutter maps with radars whose frequency agility extends over a large bandwidth.

Nonparametric Detectors

The most common way nonparametric detectors obtain CFAR is by ranking the test sample with the reference cells. Under the hypothesis that all the samples are independent samples from an unknown density function, the test sample has a uniform density function. For instance, referring to the ranker in Fig. 6, the test cell is compared to 15 of its neighbors. Since in the set of 16 samples, the test sample has equal probability of being the smallest sample (or equivalently any other rank), the probability that the test sample takes on values 0, 1, ..., 15 is 1/16. A simple rank detector is constructed by comparing the rank to a threshold K; and putting out a 1 if the rank is larger, a 0 otherwise. The 0s and 1s are summed in a moving window. This detector incurs a CFAR loss of about 2 dB, but achieves a fixed P_{fa} for any unknown noise density as long as the time samples are independent. This detector is incorporated into ARTS-3A post processor used in conjunction with the FAA's ASR radar. The shortcomings of this detector are 1. it is fairly susceptible to target suppression (e.g., if a large target is in the reference cells, the test cell cannot receive the highest ranks) and 2. only certain values of P_{fa} can be obtained.

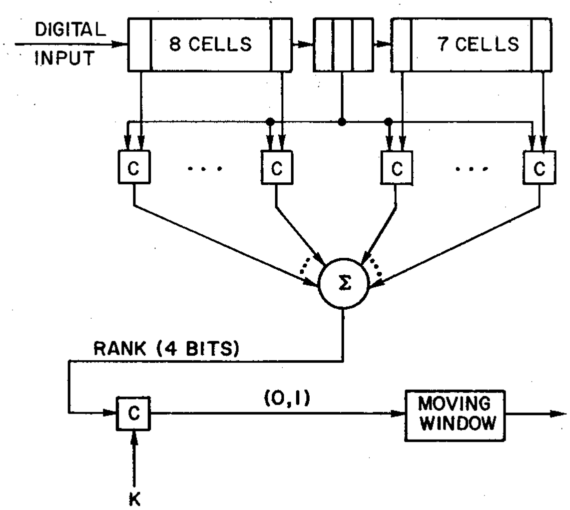

Fig. 6 — Rank detector

If the time samples are dependent, the rank detector will not yield CFAR. A modified rank detector, called the modified generalized sign test (MGST) [8], is an attempt to maintain a low P_{fa} and is shown in Fig. 7. This detector can be divided into three parts: a ranker, an integrator (in this case a two-pole filter), and a threshold (decision process). A target is declared when the integrated output exceeds two thresholds. The first threshold is fixed (equals $\mu + T_1/K$ from Fig. 7) and yields $P_{fa} = 10^{-6}$ when the reference cells are independent and identically distributed. The second threshold is adaptive and maintains a low P_{fa} when the reference samples are correlated. The device estimates the standard deviation of the correlated samples with the mean deviate estimator, where extraneous targets in the reference cells have been excluded from the estimate by use of a preliminary threshold T_2.

The rank and MGST detectors are basically 2-sample detectors. They decide a target is present if the ranks of the test cell are significantly greater than the ranks of the reference cells. Target suppression occurs at all interfaces (e.g., land, sea), where the homogeneity assumption is violated. However, there exist some tests, such as Spearman Rho and Kendall Tau tests, that only depend on the test cell. These tests work on the fact that as the antenna beam sweeps over a point target, the signal return

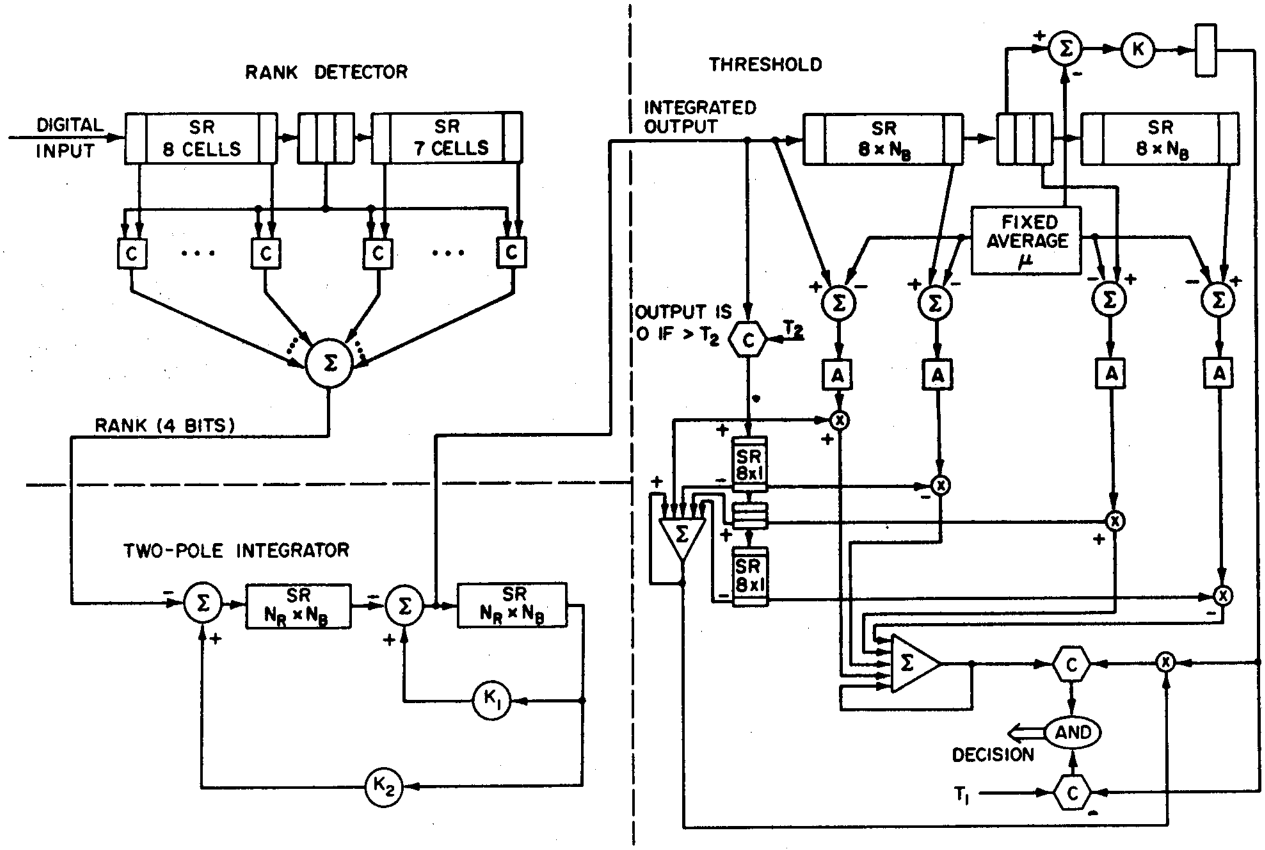

Fig. 7 — Modified generalized sign test processor

increases and then decreases. Thus, for the test cell, the ranks should follows a pattern—first increasing and then decreasing. Although these detectors do not require reference cells and hence have the useful property of not requiring homogeneity, these detectors are not generally used because of the large CFAR loss taken for moderate sample sizes [9].

A basic disadvantage of all nonparametric detectors is that one loses amplitude information, which can be a very important discriminant between target and clutter [10]. For example, a large return ($\sigma >$ 1000 m^2) in a clutter area is probably just clutter breakthrough.

Target Suppression

All detectors are susceptible to target suppression to one extent or another. There are basically three approaches to this problem: one can use clutter maps which have no reference cells; secondly, one can try to remove large returns from the calculation of the threshold [8, 11]; or finally, one can try to diminish the effects of large returns by either limiting or using log video. The technique that should be used is a function of the particular radar system and its environment.

Target Resolution

A single, large target will probably be detected many times; e.g., in adjacent range cells, azimuth beams, and elevation beams. Therefore, all automatic detectors have algorithms for merging the individual detections into a centroided detection. However, most algorithms have been designed so that they will rarely ever split a single target into two targets—a decision resulting in poor range resolution capability. For instance, a commonly used merging algorithm [12] has a range resolution of approximately two and a half pulsewidths. Inherently, the range resolution is a pulsewidth or less depending on the signal-to-noise ratios and the phase difference between the two targets. Since the number of targets in a raid can be important, this problem is currently under investigation.

TRACKING SYSTEM

A general outline of a track-while-scan system (tracking systems for surveillance radars whose nominal scan time is from 4 to 12 s) is considered first. Then the tracking filter, maneuver-following logic, tracking initiation, and correlation logic is discussed in detail. Finally, methods of integrating data from several radars is discussed.

System Outline

Almost all track-while-scan systems operate on a sector basis. A typical series of operations is shown in Fig. 8. For instance, if the radar has reported all the detections in sector 11 and is now in sector 12, the tracking program would start by correlating (trying to associate) the clutter points (stationary tracks) in sector 10 with detections in sectors 9, 10, and 11. Those detections that are associated with clutter points are deleted (are not used for further correlations) from the detection file and are used to update the clutter points. Next, firm tracks in sector 8 are correlated with detections in sectors 7, 8, and 9. By this time all clutter points have been removed from sectors 9 and below. Those detections that are associated with firm tracks are deleted from the detection file and are used to update the appropriate track.

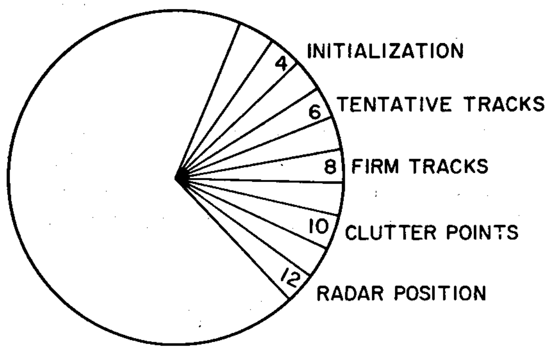

Fig. 8 — Various operations of a track-while-scan system performed on a sector basis

Usually, some provision is made for giving preference to firm tracks (with respect to tentative tracks) in the correlation process. By performing the correlation process two sectors behind firm track correlations (Fig. 8), it is impossible for tentative tracks to steal detections belonging to firm tracks. In other tracking systems the correlation for firm and tentative tracks is performed in the same sector; however, the generalized distance D between tracks and detections is incremented by ΔD if the track is tentative.

Finally, detections that are not associated with either clutter points or tracks are used for initiation purposes. The most common initiation procedure is to initiate a tentative track; later the track is dropped or else made a firm track or clutter point. An alternate approach [13] is to establish both a clutter point and a tentative track. If the detection came from a stationary target, the clutter point will be updated and the tentative track will eventually be dropped. On the other hand, if the detection came from a moving target, the tentative track will be made firm and the clutter point will be dropped. The latter method requires less computer computation time when most of the detections are clutter residues.

The correlation procedure is made in a sector framework to avoid the necessity of correlating all tracks with all detections. The procedure can be implemented very easily by defining two computer arrays: a sector file and a track file. The sector file for sector I contains the first track number in sector I, and the track file for track J contains the next track number in the same sector as track J or a 0, indicating that the track is the last track in the sector.

Tracking Filters

Before proceeding, the coordinate system in which the tracking will be performed is discussed. The target location measured by the radar is in spherical coordinates: range, azimuth, elevation, and possibly range rate. Thus, it may seem natural to perform tracking in spherical coordinates. However, this causes difficulties since the motion of constant-velocity targets (straight lines) will cause acceleration terms in all coordinates. A simple solution to this problem is to track in a cartesian coordinate system. Although it may appear that tracking in cartesian coordinates will destroy the accurate range track, it has been shown [14] that the inherent accuracy is maintained.

The most commonly used filter is the α-β filter described by

$$x_s(k) = x_p(k) + \alpha[x_m(k) - x_p(k)],$$

$$V_s(k) = V_s(k-1) + \beta[x_m(k) - x_p(k)]/T,$$

and

$$x_p(k+1) = x_s(k) + V_s(k)T,$$

where $x_s(k)$ is the smoothed position, $V_s(k)$ is the smoothed velocity, $x_p(k)$ is the predicted position, $x_m(k)$ is the measured position, T is the scanning period (time between detections), and α and β are the system gains.

The optimal filter for performing the tracking when the equation of motion is known is the Kalman filter [15]. The Kalman filter is a recursive filter that minimizes the least-square error. The Kalman filter is usually not implemented because of the complexity of the calculations required. It is fairly simple to show that under certain conditions the α-β filter can be made equivalent to the Kalman filter by setting

$$\alpha = \frac{2(2k-1)}{k(k+1)},$$

and

$$\beta = \frac{6}{k(k+1)}$$

on the kth scan. Thus, as time passes, α and β approach zero, applying heavy smoothing to the new samples. In practice, α and β usually take on only three values: an initial value, an intermediate value, and a steady-state value.

Maneuver-Following Logic

Benedict and Bordner [16] noted that in track-while-scan systems there is a conflicting requirement between good noise smoothing (implying small α and β) and good maneuver-following capability (implying large α and β). Although some compromise is always required, the smoothing equations should be constructed to give the *best* compromise for a desired noise reduction. Benedict and Bordner defined a measure of transient-following capability and showed that α and β should be related by

$$\beta = \frac{\alpha^2}{2-\alpha}.$$

Thus, an (α, β) pair satisfying the above equation can be chosen so that the tracking filter will follow a specified g turn.

The trouble with the preceding method is that if high-g turns are followed, the noise performance is rather poor. To rectify this situation, a turn detector employing the two correlation regions shown in Fig. 9 is used. If the detection is in the nonmaneuvering correlation region, the filter operates as usual. When the target falls outside the inner gate but within the maneuver gate, a maneuver is declared and the filter bandwidth is increased (α and β are increased). To avoid the problem of the target fading and a false alarm appearing in the large maneuver gate, the track should be bifurcated when a maneuver is declared. That is, two tracks are generated: the old track with no detection and a new maneuvering track with the new detection and increased bandwidth. The next detection (or two) is used to resolve the ambiguity and remove one of the tracks. Other solutions are to adjust the bandwidth as a function of the measurement error [13] and to use the Kalman filter with a realistic target-maneuvering model [17].

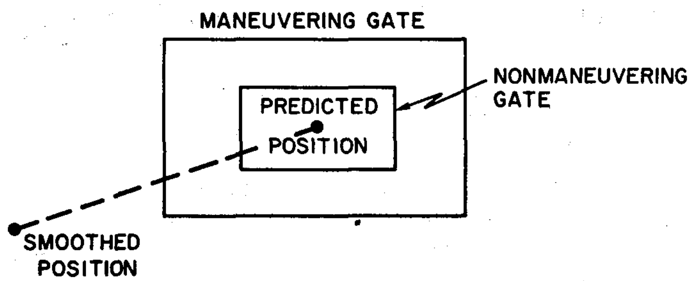

Fig. 9 — Maneuver and nonmaneuver gates centered at the target's predicted position

Track Initiation

Detections that do not correlate with clutter points or update tracks are used to initiate new tracks. If the detection does not contain doppler information, the new detection is usually used as the predicted position (in some systems, one assumes a radially inbound velocity), and a large correlation region must be used. Since the probability of obtaining false alarms in the large correlation region is large, one should drop the track if no correlation is obtained on the second scan; and also one should never declare a track firm until a third detection (falling within a smaller correlation region) is obtained. The usual initiation criteria are three out of four and three out of five although one may require four detections in regions with high false alarm rates. The possible exceptions for using only two detections are when doppler information is available (so that a small correlation region can be used immediately) or for "pop-up" (close) targets in a military situation.

An alternative track initiation logic [18] uses a sequential hypothesis-testing scheme. When a correlation is made on the ith scan, Δ_i is added to the likelihood; when a correlation opportunity is missed, Δ_i' is subtracted from the likelihood. The increments are set by the state of the tracking system and are a function of the closeness of the association, the number of false alarms, the a priori probability of targets, and the probability of detection. Although this method will inhibit false tracks in dense detection environments, it will not necessarily establish the correct tracks. To initiate tracks in a dense detection environment, APL [19] has investigated "retrospective processing" where the detections over the last eight scans are saved and used to initiate straight-line tracks using a collection of filters matched to different velocities.

Firm tracks that are not updated in 30 to 40 seconds are usually dropped.

Correlation Logic

Several procedures will now be given for associating detections with tracks. Of special interest are the conflicting situations of multiple tracks competing for a single detection or of multiple detections lying within a track's correlation gate.

To limit the number of detections that can update a track, correlation gates are used. A detection can never update a track unless it lies within the correlation gate that is centered at the track's predicted position. The correlation gate should be defined in r-θ coordinates, regardless of what coordinate system is being used for tracking. Furthermore, the gate size should be a function of the measurement accuracy and prediction error so that the probability of the correct detection lying within the gate is high (at least 0.99). In some tracking systems, the correlation gate is fed back to the automatic detector, and the detection threshold is lowered in the gate to increase the P_D.

When several detections are within the correlation region, the usual and simplest solution is to associate the closest detection with the track. Specifically, the measure of closeness is the statistical distance

$$D^2 = \frac{(r_p - r_m)^2}{\sigma_r^2} + \frac{(\theta_p - \theta_m)^2}{\sigma_\theta^2}$$

where (r_p, θ_p) is the predicted position (r_m, θ_m) is the measured position, σ_r^2 is the variance of $r_p - r_m$, and σ_θ^2 is the variance of $\theta_p - \theta_m$. Since the prediction variance is proportional to the measurement variance, σ_θ^2 and θ_r^2 are sometimes replaced by the measurement variances. Statistical distance rather than Euclidean distance must be used because the range accuracy is usually much better than the azimuth accuracy.

Problems associated with multiple detections and tracks are illustrated in Fig. 10; two detections are within gate 1, three detections are within gate 2, and one detection is within gate 3. Table 1 lists all detections within the tracking gate, and the detections are entered in the order of their statistical distance from the track. Tentatively, the closest detection is associated with each track, and then the tentative associations are examined to remove detections that are used more than once. Detection 8, which is associated with tracks 1 and 2, is paired with the closest track (track 1 in this case); then all other tracks are reexamined to eliminate all associations with detection 8. Detection 7 is associated with tracks 2 and 3; the conflict is noted but is resolved by pairing detection 7 with track 2. When the other association with detection 7 is eliminated, track 3 has no associations with it and consequently will not be updated on this scan. Thus track 1 is updated by detection 8, track 2 is updated by detection 7, and track 3 is not updated.

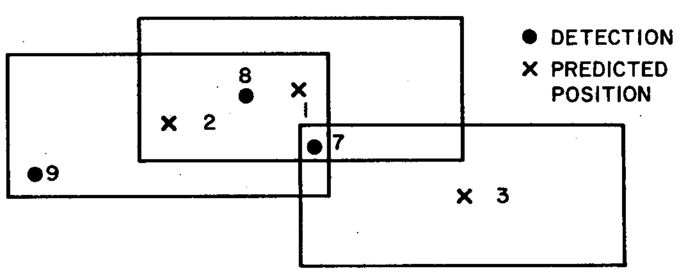

Fig. 10 — Examples of the problems caused by multiple detections and tracks in close vicinity

Table 1 — Association Table for the Example Shown in Fig. 10

Track Number	Closest Association		Second Association		Third Association	
	Detection Number	D^2	Detection Number	D^2	Detection Number	D^2
1	8	1.2	7	4.2	—	—
2	8	3.1	7	5.4	9	7.2
3	7	6.3	—	—	—	—

An alternate strategy is to always pair a detection with a track if there is only one correlation with a track. As before, ambiguities are removed by using the smallest statistical distance. Thus track 3 in the example is updated by detection 7, track 1 is updated by detection 8, and track 2 is updated by detection 9.

Radar Netting

There are many ways of integrating radar data from multiple radars into a single system track file. The type of radar integration that should be used is a function of the radar's performance, the environment, and whether the radars are colocated or not. Several integration methods are:

1. *Track Selection*—Generate a track with each radar and choose one of the tracks as the system track.

2. *Average Track*—Generate a track with each radar, and weight the individual tracks to form a system track.

3. *Augmented Track*—Generate a track with each radar, choose one of the tracks as the system track, and use selected detections from the other radars to update the system track.

4. *Average Detection*—For a given time interval average all radar detections on single target and use average detection to update the system track.

5. *Detection-to-Track*—Use all radar detections to update the system track; tracks may or may not be initiated using all detections from all radars.

Theoretically, the detection-to-track method of integration yields the best tracks because no information is lost. However, the detections must be weighted properly and care must be taken to prevent bad data from corrupting good data.

The fundamental work on colocated radar integration has been performed for the U.S. Navy where a typical naval ship has both 3-D and 2-D radars within several hundred feet of one another. Various radar integration techniques have been investigated; however, the one favored by the U.S. Navy is the detection-to-track integration philosophy. Presently, the U.S. Navy is placing an Integrated Automatic Detection and Track (IADT) system (called SYS-1 [20]) aboard the DDG-2/15 class of ships and is putting a similar IADT system (SYS-2) aboard the New Threat Upgrades (NTU) ships.

When exchanging tracking information between noncolocated sites, the methods used are a function of whether the sites are fixed or mobile and what communication links are available. There are numerous programs for netting sea, land, and air based radars: e.g., Naval Tactical Data Systems (NTDS), ROCC (joint U.S.-Canadian system, an upgrade of SAGE system), Netted Radar Program (NRP), and various programs involving airborne sensors such as AWACS, NIMROD, and the E2-C.

The two major problems associated with multisite operation are 1. how can one automatically obtain gridlock (i.e., properly locating and aligning radars) using targets of opportunity and 2. what should one transmit over the communication link given that the available bandwidth is not sufficient to transmit all the tracking data.

CONCLUDING REMARKS

Though there are universal tracking systems that can work well with a variety of radar systems, there is no such thing as a universal detector that will work well with a variety of radars in different environments. Each detector should be designed specifically for the radar and the environment in which it is to operate. That is, the automatic detector should be considered an integral part of the radar system.

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