FR-7952

Tracking System for Asynchronously Scanning Radars with New Correlation Techniques and an Adaptive Filter

B.H. Cantrell
J.D. Wilson

January 14, 1976

Naval Research Laboratory

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NRL Report 7952	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) TRACKING SYSTEM FOR ASYNCHRONOUSLY SCANNING RADARS WITH NEW CORRELATION TECHNIQUES AND AN ADAPTIVE FILTER		5. TYPE OF REPORT & PERIOD COVERED Interim report on a continuing NRL Problem 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Ben H. Cantrell and Jon D. Wilson		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Research Laboratory Washington, D.C. 20375		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NRL Problem R02-54 Project RF 12-151-403-4010 62712N
11. CONTROLLING OFFICE NAME AND ADDRESS Department of the Navy Office of Naval Research Arlington, Va. 22217		12. REPORT DATE January 14, 1976 13. NUMBER OF PAGES 29
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Automatic detection
Sensor integration
Track-while-scan
Tracking algorithms

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An Automatic Detection and Integrated Tracking system (ADIT) is being developed at NRL using the video outputs of two asynchronously scanning search radars located in close proximity. The automatic detectors should provide good false-alarm regulation over a variety of environmental conditions. The tracking system uses an adaptive α-β filter to develop a single track file from the detections from the two radars. The tracking system differs from previous single-radar tracking systems in the timing, filter update, correlation process, and track initiation as well as in the use of detections from two radars. The system has been operated against targets of opportunity at NRL's CBD facility and can maintain tracks on 50 to 60 targets in real time.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

CONTENTS

TRACKING SYSTEM FOR TWO ASYNCHRONOUSLY SCANNING RADARS WITH NEW CORRELATION TECHNIQUES AND AN ADAPTIVE FILTER

INTRODUCTION

In the past a number of automatic detection and tracking systems, each using detections from a single radar, have been constructed. This report describes a tracking system that uses detections from two asynchronously scanning radars in close proximity. The radars used are the SPS-12 and the SPS-39; provisions have been made to add the SPS-10 as a third radar at a later date. The general configuration is shown in Fig. 1. The detection and measurement procedures for each radar are described in Refs. 1 and 2. In addition Ref. 1 describes the general operation of the system. The SPS-12 is a two-dimensional (2D) radar with a scan period of 6 s. The SPS-39 is a three-dimensional (3D) radar with a scan period of 8 s which operates in a special mode using only two beams and thus acts as a 2D radar. This is used to decrease the multipath fading when both radars are considered together. Also, the operator can ask for height information on a specified target, and then the SPS-39 will perform an elevation scan over a small sector in azimuth about the target [1].

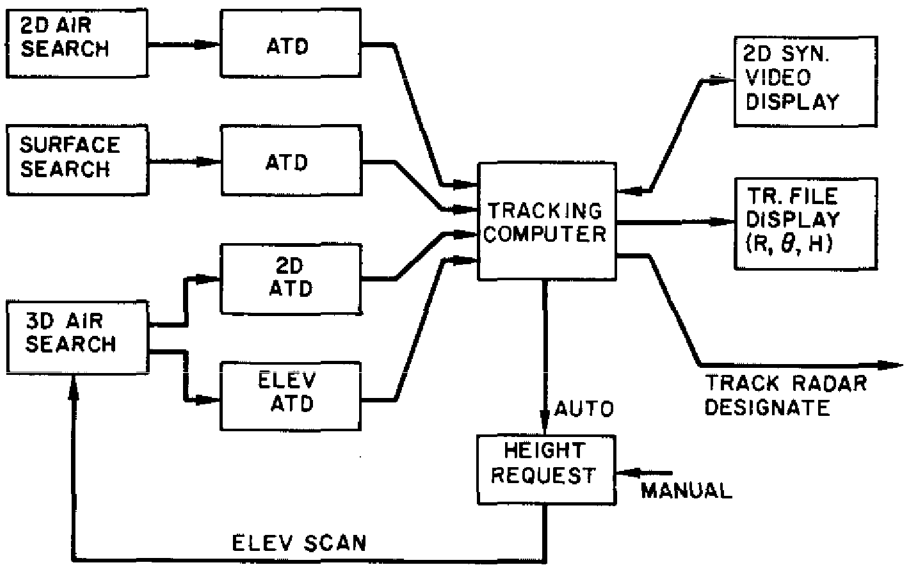

Fig. 1 — General configuration of the system

Manuscript submitted November 6, 1975.

The tracking system, which is the topic of this report, resides in a minicomputer (a Data General Nova 800). An earlier version of the tracking system is covered in Ref. 3. The current version of the tracking system described in this report incorporates a new correlator designed to minimize incorrect track-detection correlations, a new method of initiating new tracks, and an adaptive filter.

Three types of tracks are considered: clutter points (or slowly moving targets), target tracks, and tentative (or new) tracks. The tracks are correlated (associated) with the detections from the radars. The tracks are smoothed, and each target's position is predicted for the next time the radar will be over the target. To reduce the number of correlations to be performed, the tracks are stored in 64 sectors, and only those detections in the sector where the track is located and in neighboring sectors need be considered.

Most of the single-radar tracking systems use the radar itself for a clock, since the radar operates at a constant scanning rate. Although this system is similar to other tracking systems using a single radar, it differs from previous single-radar tracking systems in timing, filter updating, and track initiation as well as in the use of detections from two radars. The next section defines the basic system parameters and discusses the basic routines.

To speed processing on the minicomputer, most of the subroutines were merged into one program. This speeds the processing by eliminating the inefficient subroutine linkages generated by the FORTRAN compiler. In the following sections, discrete sections of in-line coding are discussed as though they were subroutines.

TRACKING SYSTEMS STORAGE FILES AND BASIC ROUTINES

When a track is established in the software of the computer, it is convenient to assign a track number to it. With this system all parameters associated with a given track are referenced by this track number. Each track number is also assigned a sector (region of space in azimuth) such that correlation can be performed efficiently. In addition to the track files a clutter map is maintained. A clutter number is assigned to each stationary or very slowly moving target. All parameters associated with a clutter point are referenced by this clutter number. Again, each clutter number is assigned a sector in azimuth for efficient correlation.

Track-Number and Clutter-Number Files

The track-number and clutter-number files are the same as those described by Richeson of APL [4]. The parameters for the files are as follows:

Parameter	Description
NT	Track number,
NTL	Last track number,
FULLT	Number of available track numbers,

NEXTT	Next track number available,
LASTT	Last track number not being used,
LISTT(256)	File whose 256 locations correspond to track numbers,
NC	Clutter number,
NCL	Last clutter number,
FULLC	Number of available clutter numbers,
NEXTC	Next clutter number available,
LASTC	Last clutter number not being used,
LISTC(256)	File whose 256 locations correspond to clutter numbers.

Only the operation of the track-number file will be described, since the operation of the clutter-number file is identical.

The track-number file is initiated by setting LISTT(I) = I + 1 for I = 1 through 255. LISTT(256) is set equal to 0 (denoting the last available track number in the file), NEXTT is set equal to 1 (the next available track number), LASTT is set equal to 256 (the last track number not being used), and FULLT is set equal to 255 (indication that 255 track numbers are available).

When a new track number is requested, the system checks to see if FULLT is 0. If FULLT is not 0, the new track is assigned the next available track number (NT = NEXTT). The next available track number in the list is found by setting NEXTT equal to LISTT(NT). FULLT is decremented, indicating that one less track number is available. Finally, LISTT(NT) is set equal to 512 (a number larger than the number of possible tracks). This is not necessary but helps in debugging the program.

A track number is dropped by setting the last available track number LISTT(LASTT) equal to the track number NT, which is dropped. LISTT(NT) is set equal to 0 to denote the last track number, and LASTT is then set equal to the track number being dropped (LASTT = NT). The parameter FULLT is incremented, indicating that one more track number is available.

The track-number and clutter-number files maintain a linkage from one number to the next, and they operate rapidly, eliminating searching techniques.

Track and Clutter Parameter Files

Parameters associated with a given track number are as follows:

Parameter	Description
NR(NT)	Smoothed range stored every eight scans of the SPS-39,
RS(NT)	Smoothed range position } x_s (k),
AS(NT)	Smoothed azimuth position } x_s (k),
VRS(NT)	Smoothed range velocity } v_s (k),
VAS(NT)	Smoothed azimuth velocity } v_s (k),
RPT(NT)	Predicted range position } x_p (k),
APT(NT)	Predicted azimuth position } x_p (k),
ES(NT)	Elevation angle,
TT12(NT)	Last time the SPS-12 updated the target,
TT39(NT)	Last time the SPS-39 updated the target,
TT(NT)	Last time the target was updated,
TF(NT)	Time of targets first detection/elevation scan parameter,
TTL12(NT)	Next time the SPS-12 will see the target,
TTL39(NT)	Next time the SPS-39 will see the target,
OUT(NT)	Output for display,
RC(NC)	Range of the point clutter stored every eight scans of the SPS-39,
RPC(NC)	Range of the point clutter,
APC(NC)	Azimuth of the point clutter,
TC12(NC)	Last time the SPS-12 updated the clutter,
TC39(NC)	Last time the SPS-39 updated the clutter.

Parameter TF(NT) is used to store the time of the first detection until a firm track has been established. After a track has been established, it is used as a counter to determine on what scan of the SPS-39 an elevation scan will be performed on the target.

The parameter OUT(NT) is used for the display. Its format is as follows:

Bit	Condition
0	0 if the track is valid and 1 if it is invalid,
1	1 if the SPS-12 is detecting a target,
2	1 if the SPS-39 is detecting a target,
3	1 if the SPS-10 is detecting a target,
4	1 if the IFF is detecting a target,
5	1 if the track is being handed off,
6	1 if elevation information is requested,
7,8,9	heading of the target to the nearest 45°,
15	1 if the track is tentative.

Track-Number Assignment to Azimuth-Sector Files

The azimuth-range plane is separated into 64 equal azimuth sectors, each 5.625°. After a track is updated or initiated, the predicted position of the target is checked to see which sector it occupies, and the track is assigned to this sector. If the track is dropped or moves to a new sector, it is dropped out of the sector in which it was previously located. The parameters associated with sector files are as follows:

Parameter	Description
TBX(I)	First track number in sector I (a subscript of array IDT),
IDT(256)	Storage location, corresponding to one of the 256 track numbers and containing the next track number in sector I or a 0.
CBX(I)	First clutter number in sector I (a subscript of array IDC),
IDC(256)	Storage location, corresponding to one of the 256 clutter numbers and containing the next clutter number in sector I or a 0.

Only the assignment of track numbers to azimuth cells will be described, since the clutter-number assignment is identical, and the process is essentially the same as described in Ref. 3. The TBX(I) file contains the first track number in sector I. If TBX(I) = 0, there are no tracks in sector I. The IDT(256) file has storage locations corresponding to each of the possible 256 track numbers. The first track number in sector I is obtained from FIRST = TBX(I). The second track number in the sector is obtained by NEXT1 = IDT(FIRST). The next track number in the sector is obtained by NEXT2 = IDT(NEXT1).

This process is continued until a 0 is encountered, indicating that there are no more track numbers in the sector.

When a new track is added or a track moves from one sector to another, a track number must be added to the sector. When the track is a tentative (new) track, the track number NT is placed on the bottom of the stack. The file is traced as described until a 0 is encountered. If this occurs in IDT(NEXT), then IDT(NEXT) is set equal to NT and IDT(NT) is set equal to 0. If there were no tracks in this sector, then TBX(I) is set equal to NT and again IDT(NT) is set equal to 0. When the track being transferred into a sector is a firm track, the first track number in the sector is stored, the track number NT being added is made the first track number in the sector, and the track number NT in the IDT(NT) file is made equal to the original first track number in the sector. This dual procedure ensures that firm tracks are processed first from the beginning of the file followed by the tentative tracks from the bottom of the file.

When a track is dropped or moved out of a sector I, the track number must be removed from the sector files. To facilitate this process, as each track number NT is processed, the last track number processed is saved in NTL. If NT is the first track number in the sector, NTL is 0. To drop track number NT, the procedure is as follows. When NTL is 0, TBX(I) is set equal to IDT(NT), and IDT(NT) is set equal to 0. When NTL is not 0, IDT(NTL) is set equal to IDT(NT), and IDT(NT) is set equal to 0. This process shortcircuits the linkages through the sector file, eliminating the track number NT. Setting IDT(NT) equal to 0 has no function in the program other than as a debugging aid. The last step is to set NT equal to IDT(NTL) [or TBX(I)] to obtain the next track to be processed.

The flowchart for sector-file manipulation is shown in Fig. 2. A track does not change sectors if changing sectors would cause the track to miss an opportunity to be updated by the other radar.

Input Data Bank

The basic input data from the radars can be broken into two categories: radar measurements and control parameters. The parameters associated with the input data are as follows:

Input Parameters	Description
RM12(K)	Range measurement off the SPS-12, Kth detection,
AM12(K)	Azimuth measurement off the SPS-12, Kth detection,
TM12(K)	Time of measurement off the SPS-12, Kth detection,
RM39(L)	Range measurement off the SPS-39, Lth detection,

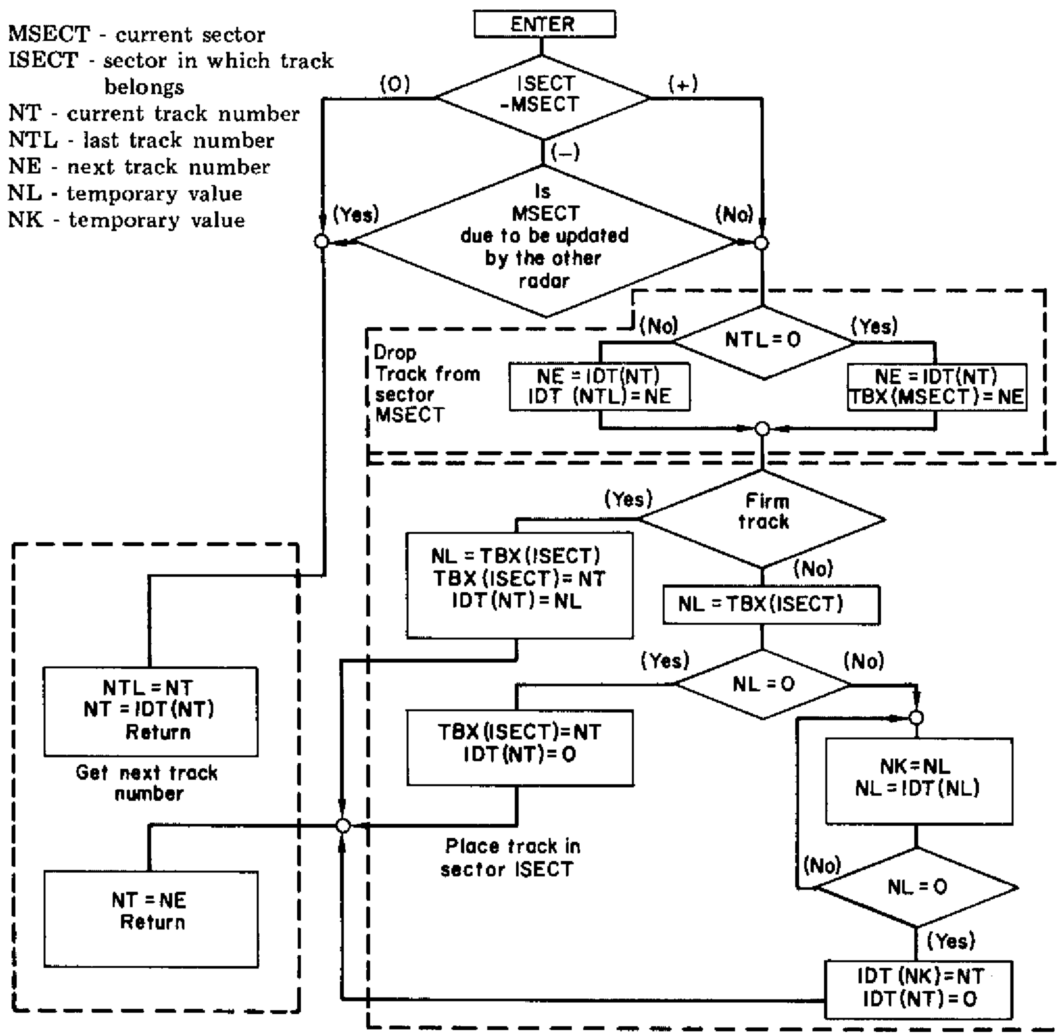

Fig. 2 — Flowchart for sector-file manipulation

AM39(L)	Azimuth measurement off the SPS-39, Lth detection,
TM39(L)	Time of measurement off the SPS-39, Lth detection,
EM39(L)	Elevation measurement off the SPS-39, Lth detection,
MRK12(I)	Time the SPS-12 crosses the Ith sector,
NP12(I)	Position of the pointer in the buffer at Ith sector crossing,
NB12(I)	Number of detections in the buffer in the Ith sector,
P1239(I)	Position of the SPS-39 when the SPS-12 crosses the Ith sector,
I12T	Sector the SPS-12 last crossed,
MRK39(J)	Time the SPS-39 crosses the Jth sector,
NP39(J)	Position of the pointer in the buffer at the Jth sector crossing,
NB12(J)	Number of detections in the buffer in the Jth sector,
P3912(J)	Position of the SPS-12 when the SPS-39 crosses the Jth sector,
I39T	Sector the SPS-39 last crossed.

The input data to the SPS-12 will be discussed first. Two small buffers are external to the computer. On each range sweep of the radar, one buffer is accepting data on detections, and the other is reading the data accumulated in it during the previous sweep. The buffers alternate on each range sweep of the radar. A binary counter that counts from K = 0 through 255 is used. Each time the data block RM12(K), AM12(K), TM12(K) is read via a DMA (direct memory access) channel into the computer, the counter is incremented by one. The counter total plus some prefixed constant represents the core location of each detection measurement in the computer. When the counter reaches 255 the next count goes to 0, and the counter is recycled. If the tracking system is working reasonably close behind the radar, the data are never written over before being used.

The timing and control parameters will now be discussed. There exist 64 equally spaced azimuth sectors of 5.625° (I = 1 through 64). As the radar crosses a sector boundary, five parameters associated with the Ith sector are read into the computer. The parameters are the time the SPS-12 crossed the Ith sector boundary MRK12(I), the value of the binary counter used for addressing the input data NP12(I), the number of target reports that occurred in the Ith sector NB12(I), the position of the SPS-39 at the sector boundary P1239(I), and the sector number I12T.

The data for the SPS-39 are read into the computer in the same manner but through a separate system. All data are read through a daisy-chain-priority DMA channel, with the SPS-12 sector information having top priority, followed by SPS-39 sector information, SPS-12 detection data, and SPS-39 detection data.

The clock used is a 15-bit binary counter that counts every 8 ms. The clock counts through approximately 4.4 min before recycling. Nothing in the program is ever referenced beyond about 1 min in the past; therefore clock recycling can easily be detected and compensated for.

Modulo Arithmetic

The external clock just discussed recycles about every 4.4 min. All time parameters in the program are referred to this clock. In addition the azimuth recycles every 360°. To appropriately handle these conditions in the program, modulo arithmetic is used. If the addition of two numbers, $A \oplus B$, is greater than the modulus, the modulus is subtracted from the sum. For a 15-bit representation of a number, A and B are both divided by 2, then added using a modulus of 14 bits. The result is multiplied by 2 to achieve the 15-bit representation. This procedure is required to keep the machine from overflowing.

In the case of subtraction, $A \ominus B$, the result should be small relative to the modulus. A large result implies a wraparound problem. A large positive result requires the subtraction of the modulus, a large negative result requires the addition of the modulus. Since only positive values are subtracted, overflow is not a problem.

Other Parameters

Other parameters used in the program are listed in this subsection. These include display, elevation scan, status, program, and dummy parameters. Some of these parameters are self-explanatory. Others will be described more thoroughly in later sections.

The program-related parameters are as follows:

Parameter	Description
I12D	Sector in which tracks are presently being updated by the SPS-12,
I39D	Sector in which tracks are presently being updated by the SPS-39,
V12	Rotational velocity of the SPS-12,
V39	Rotational velocity of the SPS-39,
VRMIN	Range velocity for determination of a target track or a clutter point,
VAMIN	Azimuth velocity for determination of a target track or a clutter point,
TCMAX	Time a clutter point is kept without an update,
TTMAX	Time a target track is kept without an update,

TTLAG	TTMAX + ϵ for the modulo clock,
TNMAX	Time a tentative track is kept without an update,
TFIX	Time after an initial detection before a decision is made,
KONST	Large number for determining a correlation,
CRC	Range correlation-region size for clutter points,
CAC	Azimuth correlation-region size for clutter points,
CRT(5)	Range correlation-region sizes for tracks,
CAT(5)	Azimuth correlation-region sizes for tracks,
KCRT(5)	Weighting factor for normalizing range error,
KCAT(5)	Weighting factor for normalizing azimuth error,
TAU(NT), TAB(NT), P1R(NT), P2R(NT), P1A(NT), P2A(NT), ERRR(NT), ERRA(NT)	Values used in determining the bandwidth of the tracking filter,
ALPHA($\beta\tau$), BETA($\beta\tau$)	Table of values of tracking-filter parameters.

The status parameters are as follows:

Parameter	Description
ISTA(1)	NTARGET, the number of target tracks,
ISTA(2)	Total number of tracks,

ISTA(3)	Number of clutter points,
ISTA(4)	NCATCH, the number of times ALPNM is called per scan (proportional to free processing time),
ISTA(5)	I12DEL, the present sector lag on the SPS-12,
ISTA(6)	NELEV, the number of targets in the elevation search,
ISTA(7)	ISKIP, with 1 indicating that sectors have been skipped on this scan.

ISTA(8) through ISTA(12) are not presently used.

The alphanumeric parameters are as follows:

Parameter	Description
IOPER	Operational code specifying request,
IPAR1	Parameter stating information about the request,
IPAR2	Parameter stating information about the request,
NUM	Number of targets that fulfill the request,
JTAR(32)	Track numbers that fulfill the request,
NHAND	Track number of the target being handed off to the tracking radar,
ISTART	Restart sector if NUM > 32.

An elevation search is performed every four scans for the specified target. The elevation parameters are as follows:

Parameter	Description
NDESTAR(4)	Track numbers of targets designated by the radar operator on the present scan for elevation searches on the next scan,
IAZIM(16)	Eight azimuth-range pairs designated to the SPS-39 in order to perform elevation searches,
NTARPR(8)	Previously designated track numbers on which elevation searches will be performed on the next scan,
NCOUNT	Number of previously designated targets for which elevation searches are requested on the next scan.

The following are dummy parameters often used in the system:

Parameter	Description
RM	Measured range of a detection corresponding to a track or a clutter point,
AM	Measured azimuth of a detection corresponding to a track or a clutter point,
TH	Measured time of a detection corresponding to a track or a clutter point,
$NDEL_1$	Time difference,
$NDEL_2$	Time difference,
D	Distance from the predicted position to the nearest detection under correlation or equal to KONST,
DI	Distance from the predicted position to detection under correlation,
DELR	Difference between the predicted position and the target report in range,
DELA	Difference between the predicted position and the target report in azimuth,
ISECT	Sector identifier,
MSECT	Sector identifier,
IH	Sector identifier.

The values of the least-significant bit for certain parameters are as follows:

Parameter	Least Significant Bit
Range position	62.5 ft (19.05 m),
Azimuth position	0.010986°,
Range velocity	0.25 ft/s (7.62 cm/s),
Azimuth velocity	0.000244 deg/s,
Time	0.008 s.

Smoothing Filter

A track is updated by computing a smoothed position and velocity. Then its position for the next update is computed. The filter used is an $\alpha - \beta$ filter [5]:

$$x_s(k) = x_p(k) + \alpha[x_m(k) - x_p(k)] \quad (1a)$$

and

$$v_s(k) = v_s(k-1) + \beta[x_m(k) - x_p(k)]\,T_1, \quad (1b)$$

where

$x_p(k+1) = x_s(k) + v_s(k)T_2$ (computed elsewhere),

T_1 = DELT, the time between the current time and the last update, and

T_2 = time between the current time and the next update.

The internal parameter names for $x_s(k)$, $v_s(k)$, and $x_p(k+1)$ were listed for both range and azimuth on page 4. Because the time intervals between updates are nonuniform, the parameters are adjusted by

$$\alpha = 1 - e^{-2\xi\omega_0 T_1} \quad (2)$$

and

$$\beta = 1 + e^{-2\xi\omega_0 T_1} - 2e^{-\xi\omega_0 T_1}\cos\omega_d T_1, \quad (3)$$

where ξ is the damping coefficient and ω_0 is the system bandwidth. These values are stored in a table for quantized values of $\omega_0 T_1$. The bandwidth is adaptively adjusted by computing

$$p_1(k) = e^{-\omega_a T_1} p_1(k-1) + (1 - e^{-\omega_b T_1})\mathcal{E}(k)\mathcal{E}(k-1), \quad (4)$$

$$p_2(k) = e^{-\omega_b T_1} p_2(k-1) + (1 - e^{-\omega_b T_1})\mathcal{E}(k)\mathcal{E}(k), \quad (5)$$

and

$$\omega_0 = 0.5\,|p_1(k)/p_2(k)|, \quad (6)$$

where ω_a and ω_b are constants and $\mathcal{E}(k)$ is the error between the measured and predicted positions on the kth update [6].

There are several precautionary notes. First, roundoff error and overflow conditions must be considered in the routine. Second, the azimuth wraparound problem must be handled.

Calculation of the Time Until the Next Update

The calculation of T_2, the time until the target is next illuminated by either radar, is as follows. Each time a track is operated on, the time it takes for the radar under consideration to make a complete revolution is stored (T_{12} or T_{39}). The next update time is found by choosing the minimum of T_{12} and T_{39}. The time T_2 is found by subtracting the current time from this next update time.

EXECUTIVE

The section of the program coding called the executive controls the basic timing of the program as shown in Fig. 3. The basic idea of the executive is to update tracks with detections a few sectors behind the position of each radar. This is achieved by using the detections from the radar whose detections are the oldest in time on a sector basis to update the track file. This method of update always uses detections which occur first in time to update the tracks before later detections are considered, except when the radars are near a crossover point, at which time an inversion can occur. However this inversion occurs over a short time interval and in different sectors on a scan-to-scan basis. If a target is detected on both radars in the crossing-sector region, both detections are used to update the track. However the first detection processed, even if a time inversion occurred, is given significant weight by the filter and the second is given almost zero weight. This does not adversely affect the track unless the time inversion is long, a situation which is impossible. For a detection on one radar and not the other, or none on either one, the track update is not affected.

In the computer program that achieves this updating the values of I12T and I12D run from 0 through 63 and represent the last sector crossing of the SPS-12 and the next sector to be updated on the SPS-12 respectively. If I12DEL=I12T$\ominus$I12D is greater than 20 (where $\ominus$ denotes modulo subtraction), the system is said to be overflowing (processing lagging too far behind the radar). In this case new update times for each track are computed in the sectors skipped, and the system returns to the beginning of the executive. This essentially ignores all the data in these sectors; the tracks are not updated. If I12DEL is less than 5, the prográm is said to be caught up. Operator requests are accepted, and data are sent to the alphanumeric display. The parameter I12DEL is a measure of the processing lag behind the radar. The processing lag is monitored only for the SPS-12 radar, since it is rotating faster than the SPS-39.

The basic timing of the program will now be examined. In Fig. 3 the indices of MRK12(...) and MRK39(...) run from 1 to 64 while I12D and I39D run from 0 to 63. Therefore it is necessary to add 1 to I12D and I39D when computing the time difference IDIF = MRK12(I12D+1) - MRK39(I39D+1). The recycling of the clock is neglected for the moment, and if IDIF >0, detections from the SPS-39 are used to update tracks in sector I39D, since they occurred earlier than those in sector I12D of the SPS-12. The clock recycling problem is solved as follows. The sector-crossing times MRK12(I12D+1) and MRK39(I39D+1) are fairly close together in real time, and if the times are on opposite sides of zero on the clock, the magnitude of the difference is much larger than 16,384. (The clock recycles every 2^{15} = 32,768 counts.) By considering the sign on IDIF, the executive can determine which detections (SPS-12 or SPS-39) occurred earlier in time, in order to choose which radar will update the tracks next.

Once the radar has been chosen, the clutter-mapping routine is entered. The clutter routine operates three sectors in advance of the current sector (I12D $\oplus$ 3 or I39D $\oplus$ 3) and

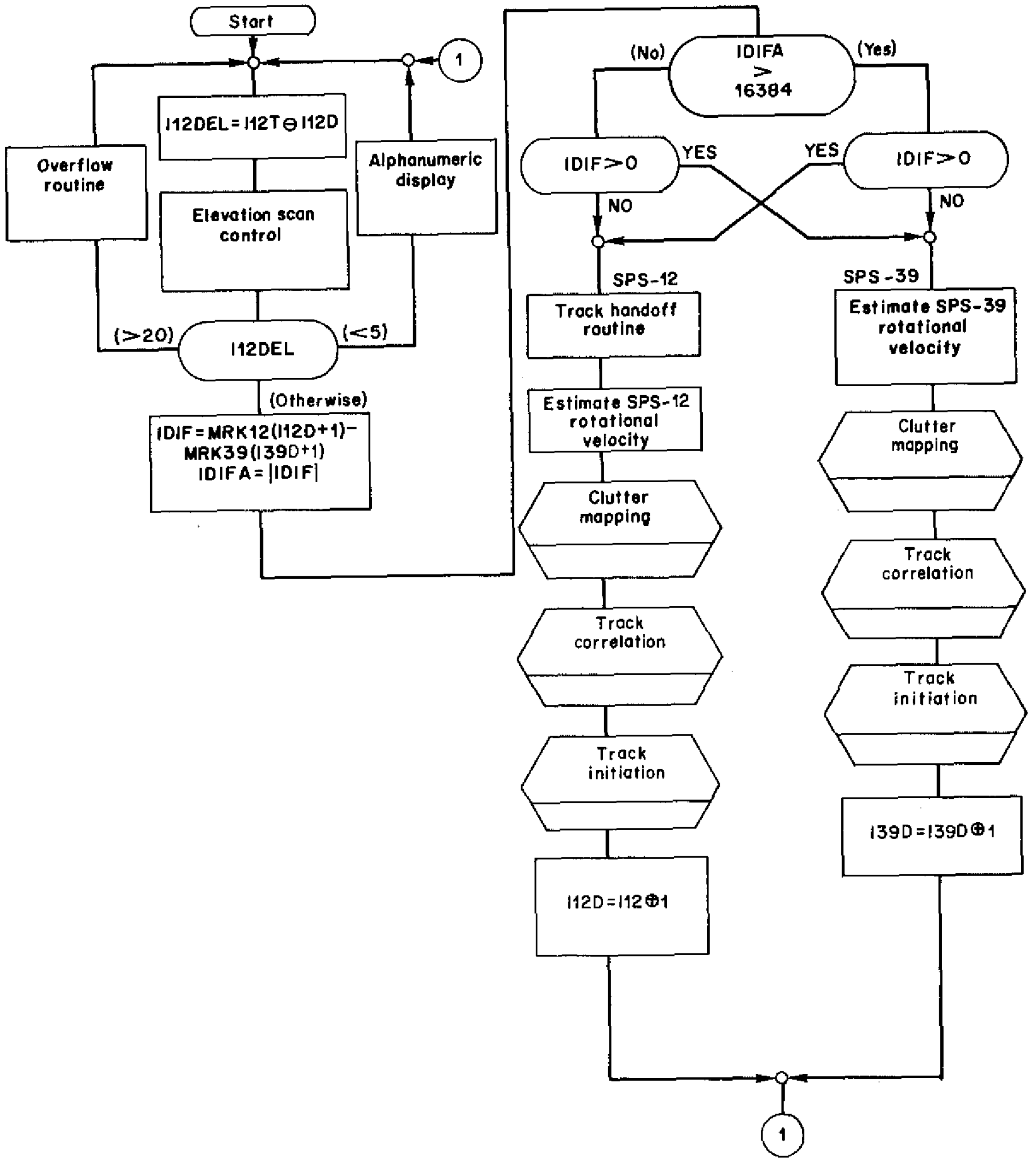

Fig. 3 — Flowchart of the executive

removes from the detector file all detections that correlate with the clutter points. Then in the tracking routine the remaining detections are used to update the target tracks in the current sector (I12D or I39D). Finally in the track-initiating routine each detection in the sector behind the sector counter (I12D ⊖ 1 or I39d ⊖ 1) that is not correlated with either a clutter point or a track is used to initiate a clutter point and a tentative track.

The sector counter is incremented, and the routine returns to the beginning of the executive to determine which sector will be updated next, and by which radar. In essence the executive closely updates tracks with detections occurring sequentially in time.

CLUTTER MAP

The clutter map removes from the detection files radar detections associated with clutter points or slowly moving targets. The flowchart for the clutter map using detections from the SPS-12 is shown in Fig. 4.

The clutter map operates three sectors in advance of the sector location I12D (where tracks are to be updated), and all detections from the SPS-12 associated with clutter points are removed before any tracks are updated. The clutter numbers in the clutter sector files are called up one by one to be updated. The following time differences are calculated for each clutter point: time since the last update by the SPS-12, given by MRK12(I12D ⊕ 4) - TC12(NC), and the time since the last update by the SPS-39, given by MRK12(I12D ⊕ 4) - TC39(NC). If both the time differences exceed 40 seconds, the clutter point is dropped from the clutter number and sector files, and the next clutter number in the sector is obtained. If the clutter point has been updated by the SPS-12 within the last second, then it has been updated by the SPS-12 on the current scan of the radar and is being considered again because it has changed sectors. In this case the clutter point is ignored and the next clutter point is obtained. If, as is the usual case, the clutter point has been recently updated, but not on the current scan of the SPS-12, the clutter number is presented to the correlation part of the clutter map.

The correlator attempts to correlate each clutter point in sector I12D ⊕ 3 with all detections in sectors I12D ⊕ 2, I12D ⊕ 3, and I12D ⊕ 4. A detection is said to correlate with a clutter point if the distance DELR, which is the difference between the range to the clutter point and the range to the detector, is less than some distance CRC and if the angle DELA, which is the difference between the azimuth angle of the clutter point and the azimuth angle of the detection, is less than some angle CAC. If the detection does not correlate with the clutter point, the next detection is examined. If the detection does correlate, the effective distance DI of the detection from the clutter point is approximated by

$$DI = KI * DELR + K2 * DELA.$$

For the radars involved, the measurement-error variances dictate a CRC of 2000 feet ($\approx$600 m) and a CAC of 1.4°, and the values of the least significant bit of range and azimuth dictate K1 and K2 of 4 and 1 respectively. The detection that correlates with clutter and has minimum effective distance is the one chosen to update the clutter point.

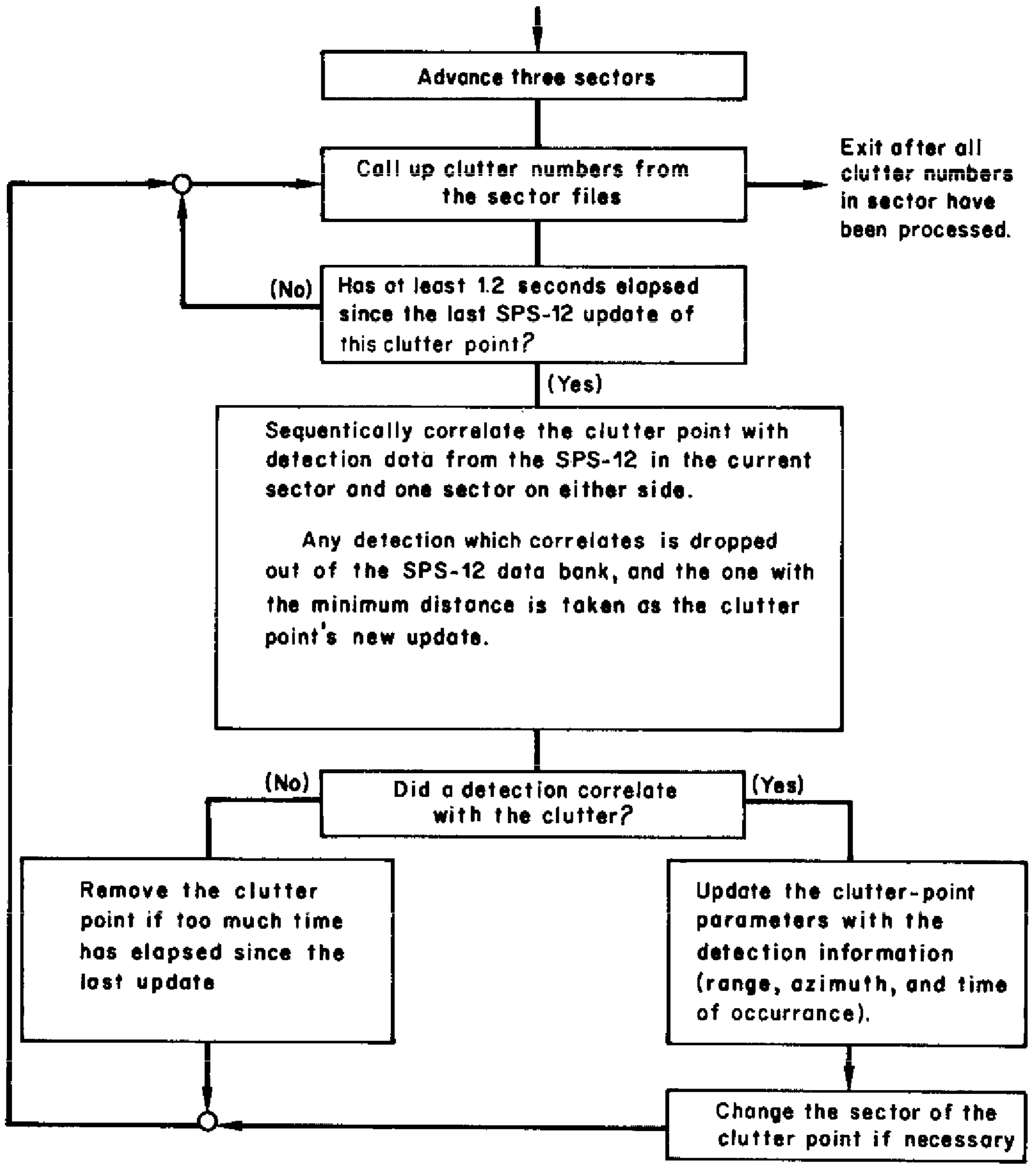

Fig. 4 — Clutter map for the SPS-12

Any detection that correlates with a clutter point is removed from the input buffer file as follows: The location of the parameters of the first detection in a sector I is contained in NP12(I + 1) and the number of detections is in NB12(I + 1) (sectors being numbered from 0 to 63 and subscripts from 1 to 64).

A detection is removed from the sector by replacing its parameters of range, azimuth, and time by the parameters of the last valid detection in the sector and decrementing the contents of NB12(I + 1) by one. In this manner all good detections in a sector are listed sequentially from the core locations of the first detection in the sector through the number of good detections left.

When a detection updates a clutter point, the measured positions and time of the detection are stored in RPC(NC), APC(NC), and TC12(NC). If the clutter point changes sectors, the clutter number is dropped out of the current clutter-sector file and reinserted in the correct sector file. Whether a clutter point is updated or not, after all good detections have been examined, the next clutter number is obtained for processing. After all clutter points lying in this sector I12D + 3 have been processed, the routine attempts to update tracks in sector I12D. Clutter points are updated with detections from the SPS-39 in a similar manner.

One additional function is performed on the clutter files once every eight scans of the SPS-39. The range of clutter point NC is saved in RC(NC), and eight scans later the current range of the clutter point is compared to the stored range. If the range change corresponds to a radial velocity greater than 45 knots, the clutter point is changed to a target by removing the clutter point from the clutter sector files and establishing a track as will be described later.

In summary, the clutter file stores the locations of the clutter points or slowly moving targets and removes the detection from the radars associated with them. If too long a time has elapsed between updates, the clutter point is dropped.

TRACK CORRELATION AND UPDATING

Before the correlation process begins, the tracks which have already been updated on the current scan by this radar are flagged. This can occur when a track changes sectors. The correlation process and track updating with detections from the SPS-12 are shown in Fig. 5.

The track correlator attempts to minimize incorrect correlations by multiple passes through the track files with incremented correlation-region sizes. The track updating takes place in only one sector (primary sector). The tracks located in the two sectors in advance of the primary sector (secondary sectors) are correlated with detections also but are not updated. If a detection correlates with a track located in the primary sector and is the minimum-distance correlation with the target, the detection is used to update the target track and is dropped from the detection file. A new track which is being updated is transformed to a target track about 20 seconds after initiation. The flag denoting that it was a new track is removed. If the track is in a secondary sector, the detection is flagged.

This flag prohibits the detection from updating a track in the primary sector on some later pass through the track file using a larger correlation region size on the basis that the detection has already been demonstrated to be closer to some other track. Each track which correlates with a detection is also flagged. This prevents the correlator from accessing the track again.

Obviously, the finer the correlation-region increments, the better the correlation will perform in terms of the only judgment criterion available to it: the proximity of detection to a predicted track position. Based on simulated data on randomly generated targets and clutters, five correlation-region sizes were chosen; the smallest region is 2000 feet ($\approx$600 m) by 1.4°, and the largest correlation region is 14,000 feet ($\approx$4250 m) by 5.6°. In most instances this correlation procedure prevents a track which is not detected on the current scan from stealing a detection from a nearby track.

When more than one detection correlates with a track, the "closest" detection is chosen by using the detection with the minimum DI given by

$$DI = K1 * DELR + K2 * DELA,$$

where DELR and DELA are differences in position similar to those defined in the clutter mapping. The coordinates of this detection are used in the smoothing filter to update the track parameters. Then the time this track will be seen by either radar is calculated, and the position of the track at that time is predicted.

Before a return to the executive the tracks must be prepared for the next correlation process. First all flags are removed from the tracks, and any unflagged tracks in the primary sector are "coasted," using the stored velocities, or dropped if too much time has elapsed since the last update. Then each track that has changed sectors is placed in the correct sector file. Target tracks are placed at the top of the sector file, and new tracks are placed at the bottom. This insures that as the tracks are sequentially processed by the correlator, the established target tracks will have the first opportunity to be updated with each incremental correlation region.

Track correlation for the SPS-39 is handled similarly, with an addition provision for retaining elevation information. Also, every eight scans of the SPS-39 the smoothed range of each track is compared to a range saved from eight scans in the past. Any track with a radial velocity less than 56 knots is converted to a clutter point and removed from the track-sector files. This process is performed at a time that is offset by four scans from the process to convert clutter points to targets (as was described in the section on the clutter map).

TRACK INITIATION

After all clutter points and tracks have been updated with the detections, any unused detections are used to initiate both clutter points and tentative tracks. This technique speeds processing by eliminating a formal decision process to differentiate clutter points and tracks. A detection of a clutter point will be updated on later scans in the clutter

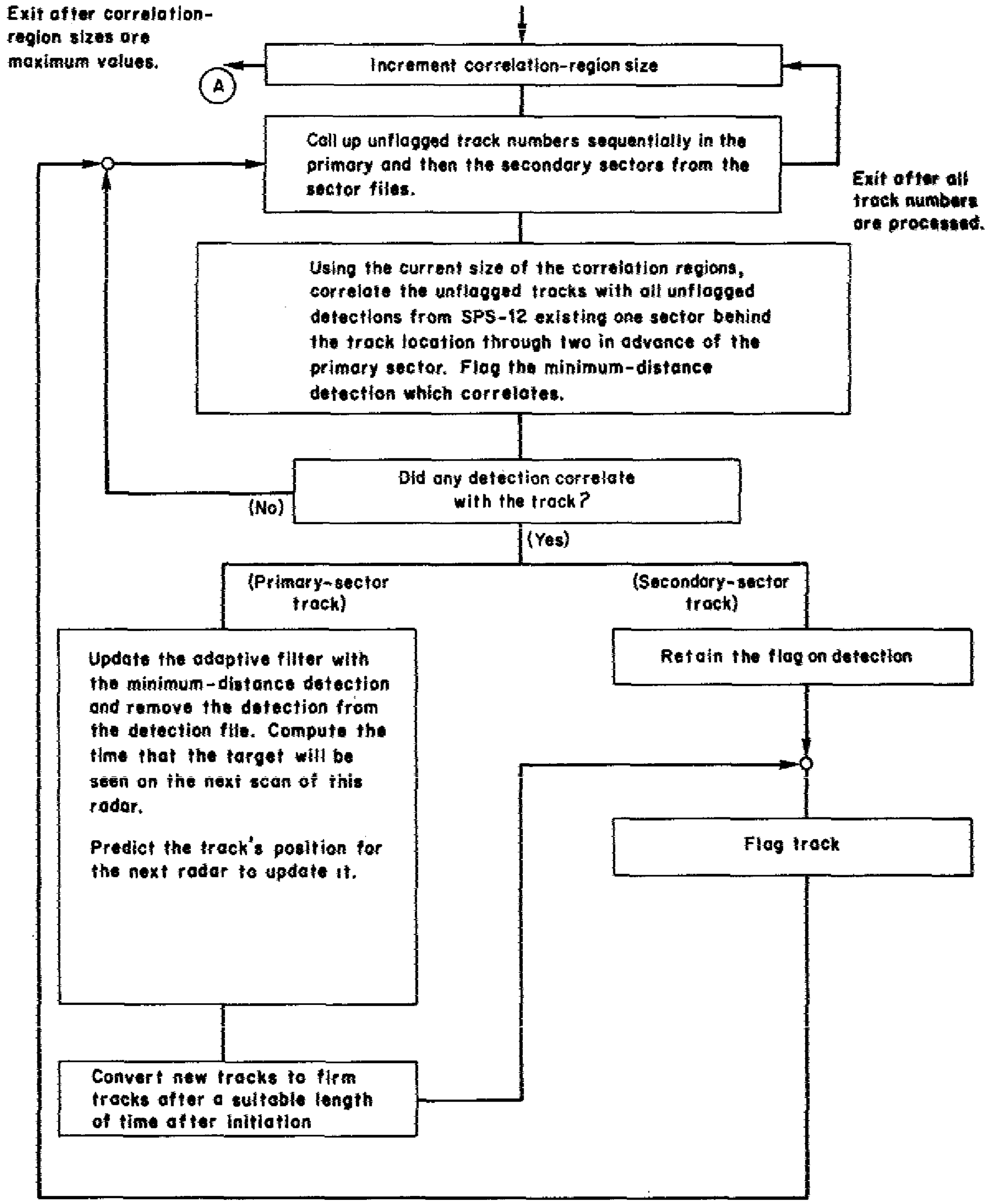

Fig. 5 — Correlation process and track updating with detections from the SPS-12

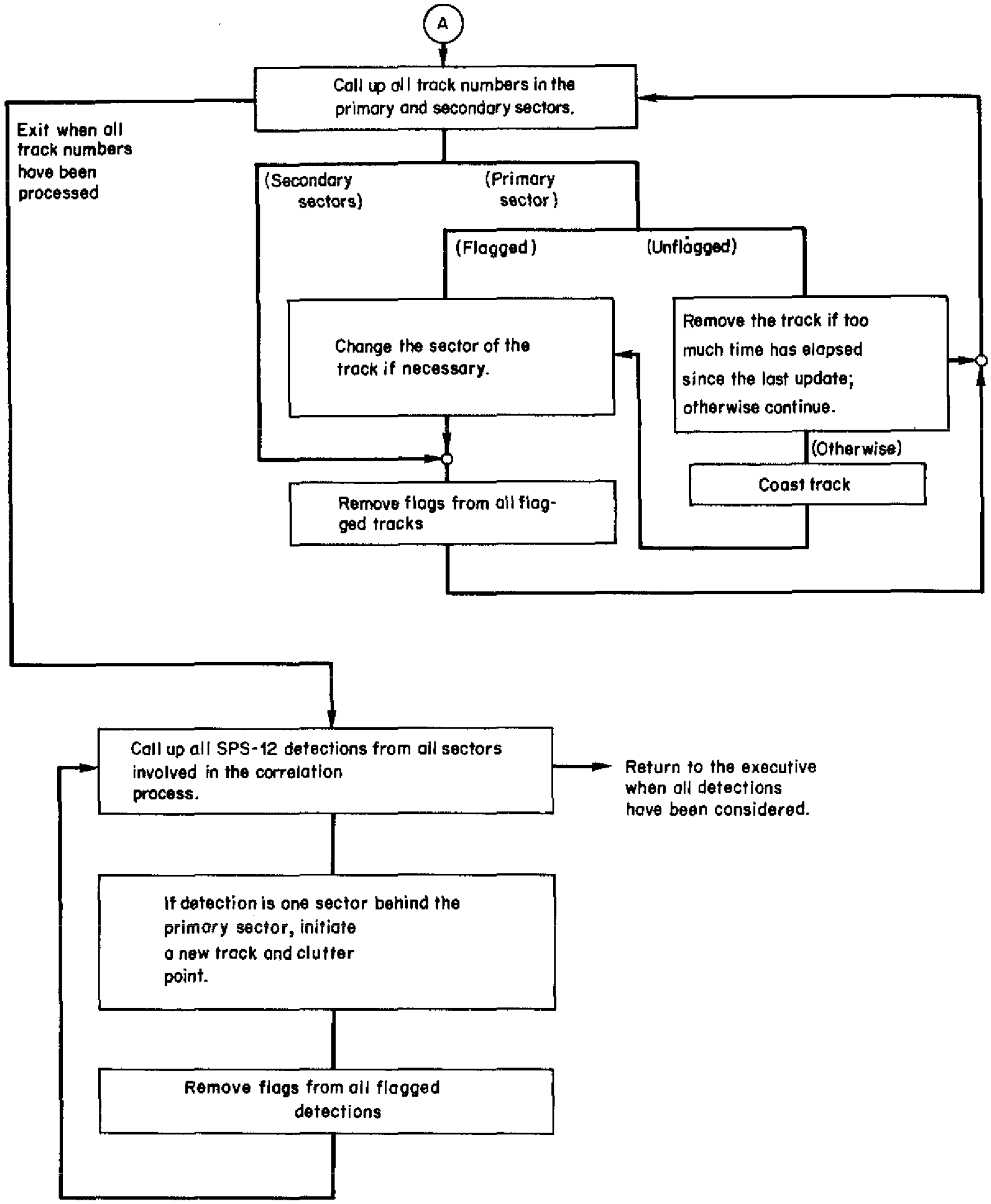

Fig. 5 (continued) — Correlation process and track updating with detections from the SPS-12 map, and the tentative track will be dropped. A detection of a fast-moving target will not be updated in the clutter map because of the relatively small clutter-correlation region and will be quickly converted to a track. In this manner it is not necessary to establish a tentative track, track it, estimate velocity, and then decide if the tentative track should be converted to a firm track or dropped into the clutter map.

The mechanics of this process for a detection from the SPS-12 are as follows. A track is initiated by assigning a track number, setting the detected and smoothed positions equal to the detection position, and setting the velocities equal to zero. The parameters used in the tracking filter are initialized, and the target classification parameter, OUT, is set to +1. The times TT(NT) and TT12(NT) are set to the time of detection, and TT39(NT) is set to a value TTLAG seconds behind the time of detection to indicate that the SPS-39 radar has not yet updated the track. The times TTL12(NT) and TTL39(NT), which denote the next times each radar will see the target, are calculated. A clutter point is initiated by assigning a clutter number, setting the clutter range and azimuth equal to the detection range and azimuth, and setting the times of last update TC12(NC) and TC39(NC) to the time of detection and the time of detection minus TTLAG respectively.

In summary, new clutter points and tracks are established after it is determined that a detection cannot be used to update any of the current clutter points or tracks. Minimum time elapses before a detection is established as a track or a clutter point.

ALPHANUMERIC DISPLAY

Data requests for the alphanumeric display are processed by subroutine ALPNM. This subroutine is called by the executive on an available-time basis, that is, when all available tracks four sectors behind the radar have been processed.

General Operation

The radar operator enters three parameters (IOPER, IPAR1, and IPAR2) via a DMA channel. IOPER is presently a number between 1 and 8 specifying a request, and IPAR1 and IPAR2 are parameters stating information about the request. After the request has been processed, IOPER is set to -1. NUM is the number of targets that fulfill the request, and JTAR(32) contains the track numbers that fulfil the request.

Inside the computer, track numbers run 1 to 256, whereas on the outside (display) they run 0 to 255. If more than 32 numbers fulfill a request, NUM is set to 96 and ISTART is set to an appropriate value so that the remaining track numbers can be given when the operator repeats his request. The track numbers are displayed on a monitor ten at a time along with the range, azimuth, and elevation of each target. If more than ten targets fulfil the request, the list may be paged through cyclicly.

Approximately every 1/2 second the display equipment interrogates the location IOPER to see if it has been reset to -1, signifying completion. When a -1 is found, the appropriate values NUM and JTAR(...) are read via a DMA. The operational details of the display equipment will be presented in a future report (by J. Alter).

Operator Requests

The appropriate parameters for the different operator requests are the following:

- IOPER = 1 is a request for target handoff, IPAR1 is the track number, and IPAR2 = 1 means cancel the handoff request;
- IOPER = 2 is a request to list targets within an azimuth interval, IPAR1 is the first azimuth, and IPAR2 is the second azimuth;
- IOPER = 3 is a request to list targets inside or outside a designated range, IPAR1 is the range, IPAR2 = 1 means inside, and IPAR = 2 means outside;
- IOPER = 4 is a request to target parameters and IPAR1 is the track number;
- IOPER = 5 is a request to list all targets;
- IOPER = 6 is a request to list tentative tracks;
- IOPER = 7 is a request to list high-closing-velocity targets and IPAR1 is the velocity;
- IOPER = 8 is a request to list targets under elevation search.

The output parameters for all requests are

NUM = number of tracks,

JTAR(1) = track number,

... = ... ,

JTAR(NUM) = track number.

All searches are performed by searching through all sectors using the sector files TBX(...) and IDT(...).

ELEVATION SEARCHES

Azimuth angles at which the SPS-39 will perform elevation scans are calculated by subroutine ELEV. Subroutine ELEV is called by the executive once per scan of the SPS-39, approximately when the SPS-39 crosses its 61st azimuth sector. When the SPS-39 goes through 0°, azimuth-range pairs for elevation scans are written via a DMA from the computer into a shift register. The radar azimuth converter is compared to the designated azimuth. When the two are equal, four elevation scans are performed (this covers approximately 7° of azimuth), and detections are made in a range interval centered at the designated range. There can be as many as eight designated azimuths per scan.

Designated Targets

Elevation scans are performed on two types of targets: those the operator has just designated and those that have been previously designated. The operator either designates new targets or drops old targets by entering coded track numbers into NDESTAR(4). The eight least significant bits represent the track number, and the ninth bit is 1 if a target is newly designated and 0 if a target is to be dropped. If a target number NT is designated, NT is stored in NTEMP(...), and TF(NT) is set to 4. NTEMP(...) is a storage area for the track numbers on which elevation scans are to be performed, and TF(...) is a counter that indicates how many SPS-39 scans occur before the next elevation scan on this target. Every time one attempts to update a target in TRK39, TF(...) is decreased by 1 until it equals 1. When TF(NT) equals 1, TF(NT) is set back to 4, NCOUNT is increased by 1, and NT is stored in NTARPR(NCOUNT), which is an array of targets previously designated.

As an example, assume that there are INUM targets newly designated and NCOUNT targets previously designated. If (INUM + NCOUNT) $\leq$ 8, all track numbers are stored into NTEMP and NCOUNT is set to 0. If (INUM + NCOUNT) $>$ 8, the INUM targets newly designated and the first (8 - INUM) targets previously designated are stored in NTEMP(...).

NCOUNT is reset to INUM + NCOUNT - 8, and the unused previously designated targets are stored in the first NCOUNT locations of NTARPR(...). Then the update times on the next scan of the SPS-39 are found for each target; these items are used to calculate predicted positions of the targets using Eqs. (1). Approximately 3° is subtracted from all the predicted azimuths. These new azimuths now represent the angles where the elevation scans will begin. The azimuths are next ordered, and the range-azimuth pairs for each target are stored in consecutive locations of IAZIM(...). If fewer than eight targets are designated on a scan, the rest of the array is filled with zeros. This array is used by the SPS-39 to perform the desired elevation scan.

Status Parameters

Since subroutine ELEV is called once and only once per scan, this routine provides a convenient place for setting the status parameters. These parameters are given on pages 10 and 11 and are self-explanatory.

MONTE CARLO SIMULATION

To test the tracking logic and to obtain an estimate of the processing time, a computer simulation was written to generate radar data: range, azimuth, and time estimates for clutter points and targets. The simulation that generates radar data on tape is described in Ref. 3.

SUMMARY

This tracking system differs from previous single-radar tracking systems in the timing, filter update, correlation process, and track initiation as well as in the use of detections from two radars. The system timing is determined from an external clock which replaces the scan rate of a single radar. The time of each radar detection and the time of each radar's passage through azimuth sectors are recorded. This allows the program to update tracks with detections which occurred earliest in time and provides the time information required in the filter updates. The clock is also used to keep tracks from being updated twice by the same radar in the same scan and is used for dropping old tracks and initiating new ones.

The filter adjusts its smoothing parameters according to the time increment between updates and the bandwidth. The bandwidth is set adaptively. The correlator attempts to approximate a total crosscorrelation between tracks and detection in both directions and yet can be simply implemented. The track initiation provides rapid convergence to the true situation. This saves processing time by allowing clutter points to be immediately captured rather than be processed through the track updating system before being declared as clutter points.

CURRENT STATUS

The full system has been operated against targets of opportunity but has not been operated sufficiently to evaluate it. The initial impressions are that the system can maintain tracks on 50 to 60 targets in real time, all software-implemented functions seem to be operating properly, and too many detections are currently being made on clutter points. This last observation is partially due to the radars, the antenna patterns, and the siting of the antennas and partially due to not having experimented sufficiently to optimize the detection parameters.

Currently a track bifurcation scheme and a dual clutter map (separate clutter maps for each radar) are being developed in simulation.

REFERENCES

1. G.V. Trunk, B.H. Cantrell, and D.F. Queen, "Basic System Concept for Integrating a 2D and a 3D Radar and Designs of Automatic Detection Systems," NRL Report 7678, Mar. 7, 1974.

2. B.H. Cantrell, G.V. Trunk, and F.D. Queen, "A Detector Design for the SPS-10 Radar," NRL Report 7734, June 19, 1974.

3. B.H. Cantrell, G.V. Trunk, and J.D. Wilson, "Tracking System for Two Asynchronously Scanning Radars," NRL Report 7841, Dec. 5, 1974.

4. K.E. Richeson, "Fleet Systems Report, Radar Detection System Software," SMS-FS-513, MWD-2-351, Nov. 1971, John Hopkins University, Applied Physics Laboratory.

5. B.H. Cantrell, "Gain Adjustment of an Alpha-Beta Filter With Random Updates," NRL Report 7647, Dec. 21, 1973.

6. B.H. Cantrell, "Adaptive Tracking Algorithm," NRL Memorandum Report 3037, Apr. 1975.