Aug. 5, 1969 A. RALSTON 3,460,137

TRACK INITIATION SYSTEM

Filed May 24, 1965 4 Sheets-Sheet 1

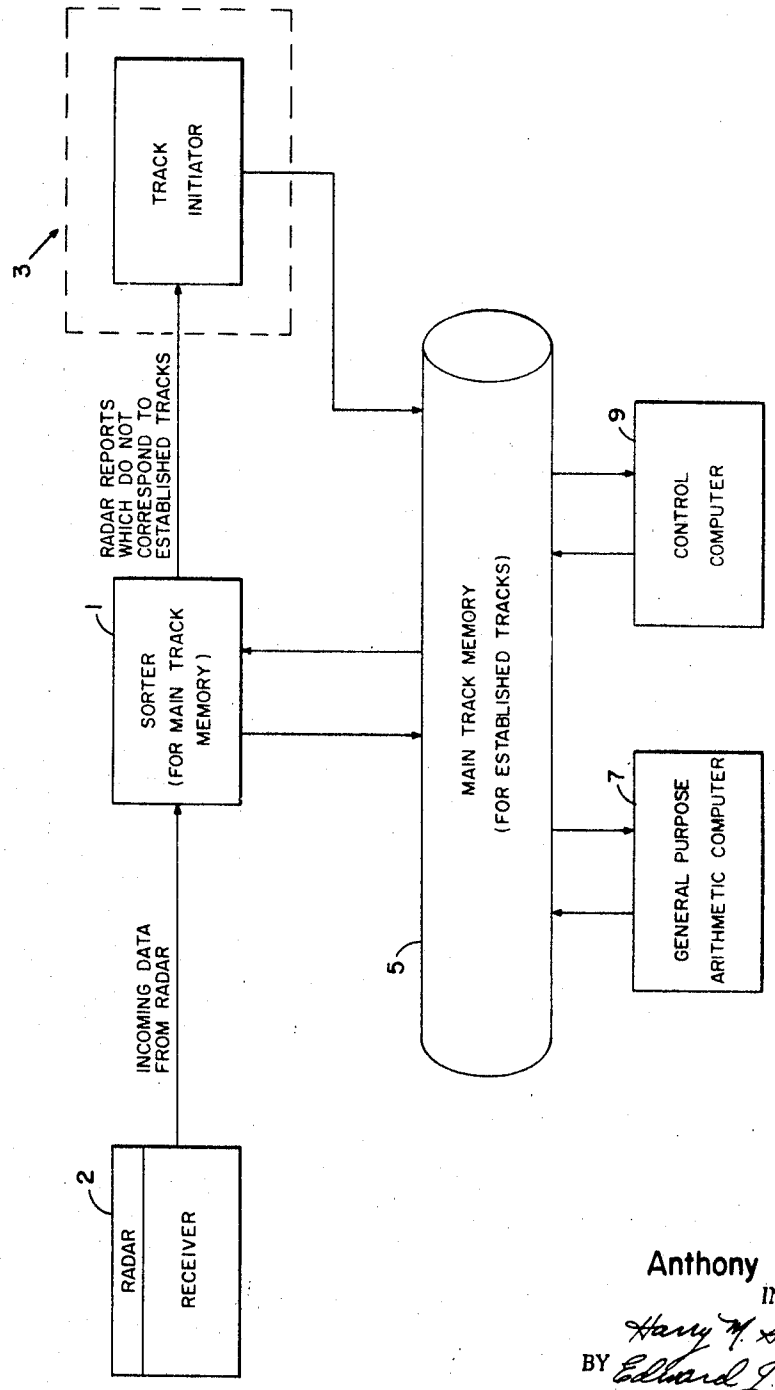


FIG. 1

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TRACK INITIATION SYSTEM

Filed May 24, 1965 4 Sheets-Sheet 2

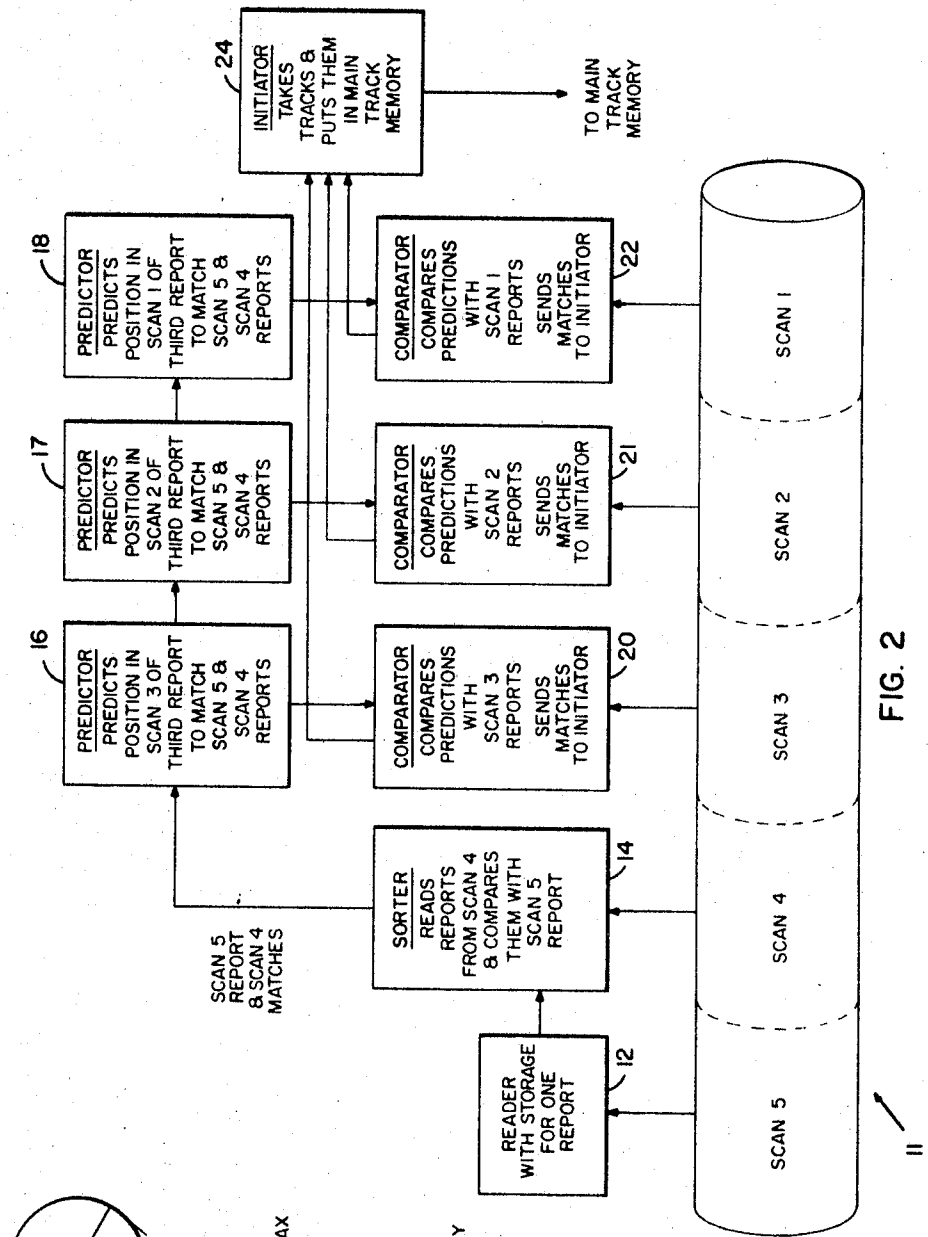


FIG. 2

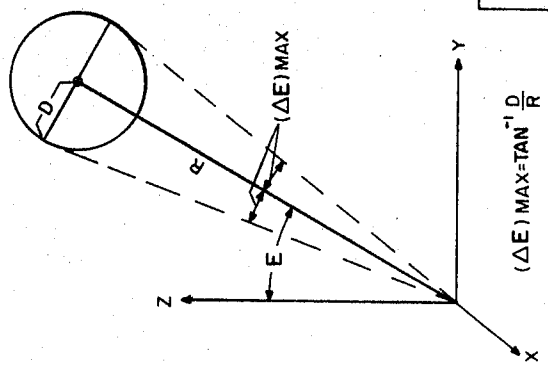


FIG. 5

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TRACK INITIATION SYSTEM

Filed May 24, 1965 4 Sheets-Sheet 3

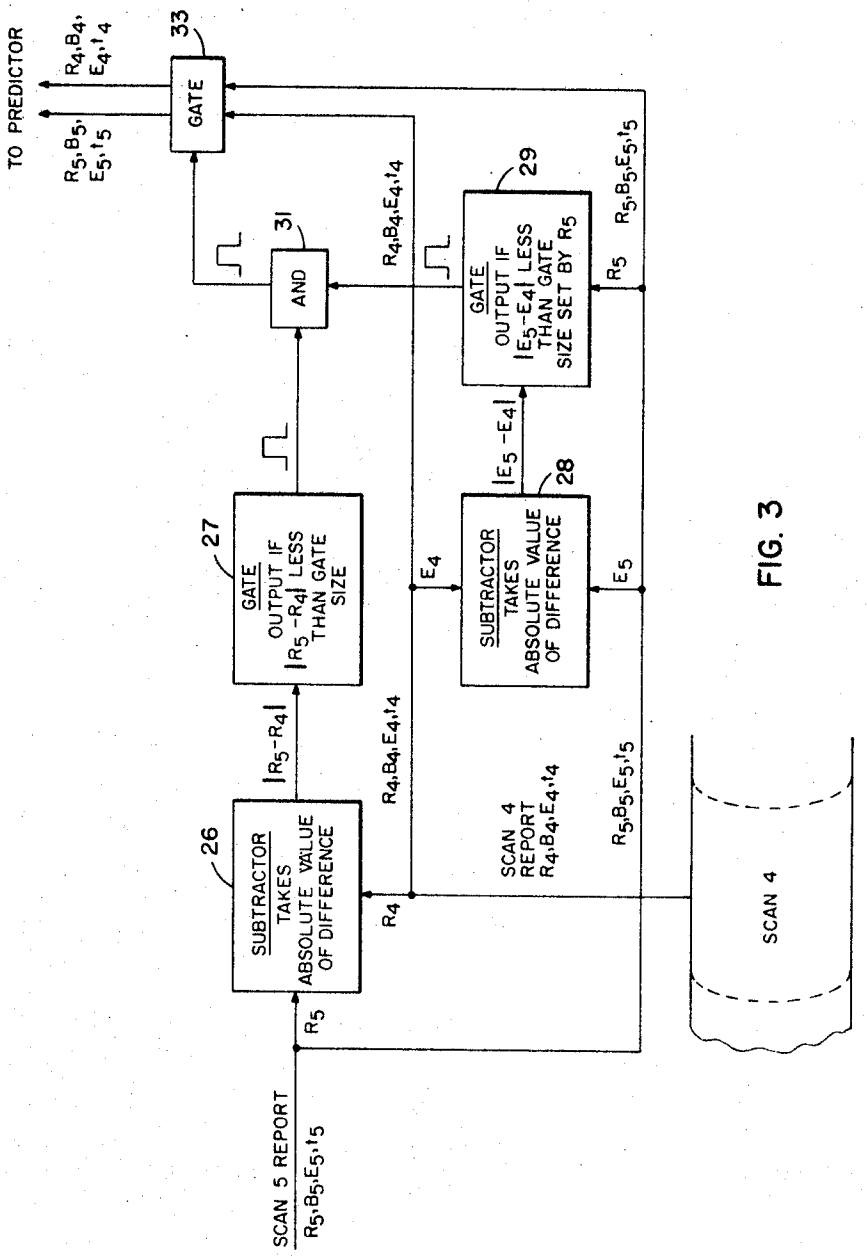


FIG. 3

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TRACK INITIATION SYSTEM

Filed May 24, 1965 4 Sheets-Sheet 4

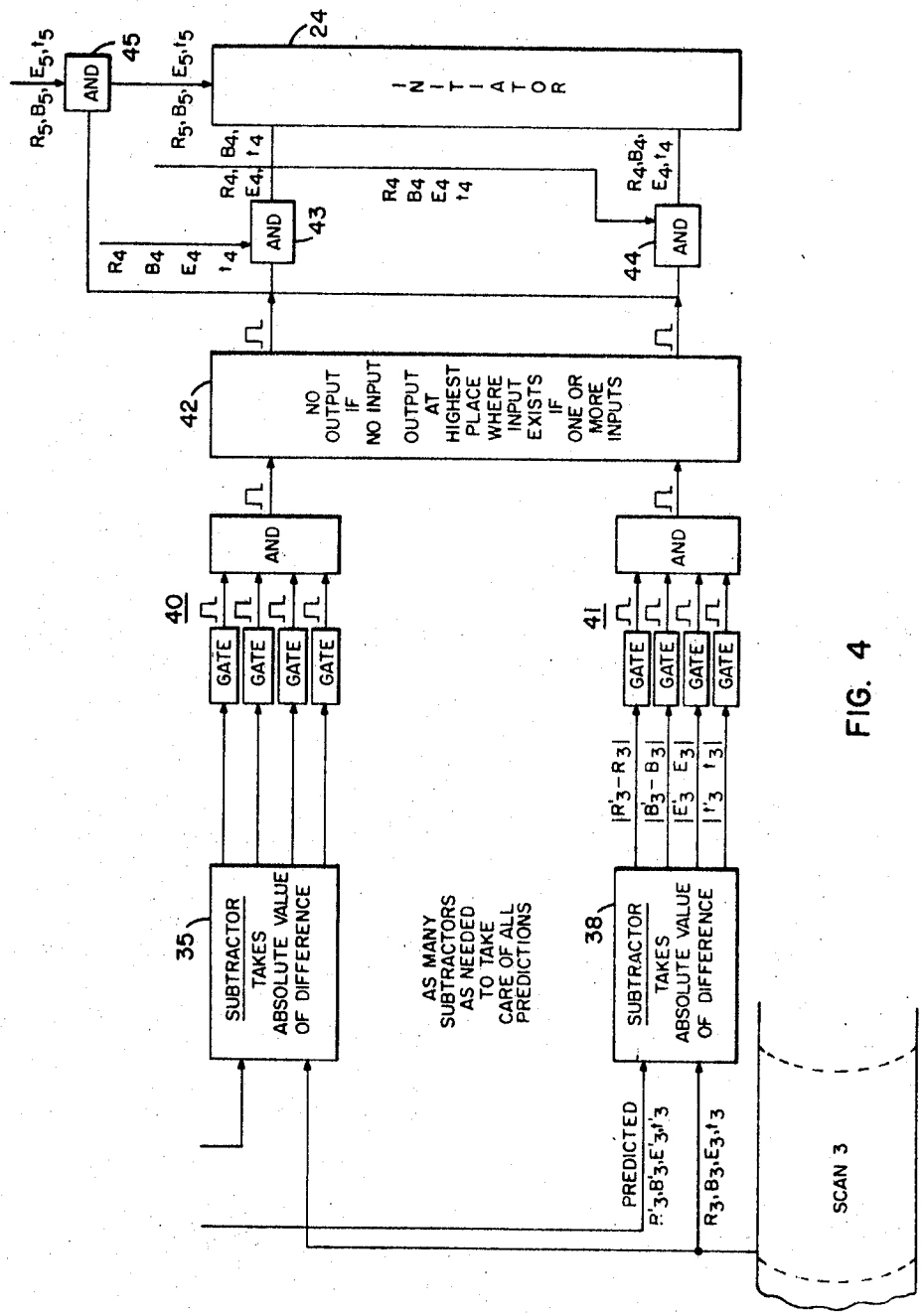


FIG. 4

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3,460,137

TRACK INITIATION SYSTEM

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Int. Cl. G01s 9/00
U.S. Cl. 343—5 14 Claims

This invention relates to a system which causes a track initiation on a main track memory device. More particularly, this invention relates to a system which looks for two matching reports in two most recent scans of a radar and then looks for a third report matching these two in one of three previous scans. In determining the two matching reports, range is used as the basic quantity for initial sorting with elevation used for finer sorting.

Since radar data is generally very accurate, only three reports on a given target are required to initiate a track. Assuming this, the problem then is to develop some criterion of the m reports in n scans type which when satisfied will cause a track to be initiated. This criterion will have to achieve a high probability of initiation in as short a time as possible after the initial detection of the target and a low probability of initiating false tracks. Moreover, the criterion should be capable of easy reduction to computer operations so that track initiation will be logically simple and require a minimum of equipment.

If one assumes that initiation will be attempted after each scan on the reports from that scan (that is, one looks for three reports on a target; one of which was in the most recent scan) one question presented is how many previous scans will have to look for the other two reports? If a large number are used, a lot of storage is required, while if too small a number is used, a risk is presented of delaying the initiation of a track for too long a time even with the high detection probabilities.

It is therefore an object of this invention to provide a system which causes a track initiation of a main track memory device.

A further object of the present invention is the use of three reports in five scans of the same target to cause a track to be initiated.

A still further object of the invention is a track initiation system which is capable of easy reduction to computer operations.

The invention further resides in and is characterized by various novel features of construction, combinations, and arrangements of parts with are pointed out with particularity in the claims annexed to and forming a part of this specification. Complete understanding of the invention and an introduction to other objects and features not specifically mentioned will be apparent to those skilled in the art to which it pertains when reference is made to the following detailed description of a specific embodiment thereof and read in conjunction with the appended drawing. The drawing, which forms a part of the specification, presents the same reference characters to represent corresponding and like parts throughout the drawing, and wherein:

FIGURE 1 shows a simple block diagram of the computing facilities required at a forward acquisition radar;

FIGUREE 2 illustrates the track initiator in block diagram in accordance with the invention;

FIGURE 3 shows the sorter in block diagram according to the present invention;

FIGURE 4 illustrates the comparator in block diagram in accordance with the invention; and

FIGURE 5 shows a vector diagram in accordance with the invention.

In FIGURE 1, a sorter **1** has incoming data from a radar receiver **2**. This data has originally come from a

symmetrical three antenna radar, not shown, which rotates once in 15 seconds so that all 360° are scanned once every 5 seconds. A given 5 second period (e.g. $0 \leq t < 5$, $5 \leq t < 10$ etc.) will be called a scan. Consecutive scans will be numbered **1, 2, 3, 4, 5** . . . where the higher number represents the more recent scan. The data available for track initiation is a composite of the pulse returns from the target and involves only positional and time information. The sorter **1** sorts the radar reports which do not correspond to established tracks from those that do and feeds those that do not to the track initiator **3**. The track initiator decides what is a track and causes all new tracks to be written into the main track memory **5**. A general purpose arithmetic computer **7** and a control computer **9** are provided for input-output functions of the forward acquisition radar (FAR) system shown in FIGURE 1.

This invention is particularly concerned with the track initiator **3**. This is shown in greater detail in FIGURE 2. The initiator must determine what is and what is not a true target track. To do this initiation will be attempted after each scan on the reports from that scan and on the reports of at least two other scans since it takes three reports on a given target to initiate a track. Since (1) the probability of detection of a target within the effective operation range of the radar is high (the possibility of detection and initiation outside the effective range of the radar is possible but if this happens with the initiation scheme, it can be considered just so much extra good fortune but does not have to be counted on); (2) the amount of storage required for past scans must be kept down as much as possible; and (3) the more scans looked at, the higher the probability of false tracks; looking for the other two reports in four previous scans is reasonable. This results in a 3 out of 5 system with 1 report from scan **5** and two reports from scans **1, 2, 3,** and **4**.

To find the two reports from scans **1, 2, 3,** and **4**, a general technique is to try and find one possible match in scans **4, 3, 2,** and **1** for the report in scan **5** and then using these two reports, predict the time and position of the third report. However, to do this, one would have to perform the following operations for each scan **5** report:

(1) Look for matching reports in scan **4** and for each match, predict the position and time of the third report in scans **3, 2,** and **1**, and search these scans in turn for a third matching report.

(2) If no track is found in step **1**, look for matching reports in scan **3**, predict positions into scans **2** and **1**, and then search.

(3) If step **2** also produces no track, look in scan **2** for reports matching the scan **5** report, predict into scan **1**, and then search scan **1**.

This procedure will initiate a track with a bigger probability than any other 5 scan scheme (where one report is required to come from scan **5**). However, it has two major drawbacks. The procedure is time consuming, requires a great deal of equipment, and it is logically cumbersome.

This invention replaces this general method (hereafter called 3 out of 5) by using just step 1 above (hereafter called 5, 4, 1, of 3). That is, one looks for two matching reports in the two most recent scans and then looks for a third report matching these two in one of the three previous scans. This scheme has obvious equipment, time, and logical advantages. The loss of probability of finding a track is small as can be seen in Table 1.

In Table 1, it has been assumed that a constant probability of detection per scan of a target is present if it is in the effective range of the radar and zero probability is present outside this range. Thus, the number of scans in

the table is the number of scans after the target is within the effective range of the radar before a track for this target is initiated.

TABLE 1

Probability of initiation of a track after n scans, for the 3 out of 5 system, the 5, 4, 1 of 3 system and a system requiring 3 reports in 3 consecutive scans, as a function of detection probability per scan.

90% detection prob.				95% detection prob.		
Prob. of track initiation with—				Prob. of track initiation with—		
3 out of 5	5,4,1 of 3	3 consecutive reports	Number of scans	3 out of 5	5,4,1 of 3	3 consecutive reports
.729000	.729000	.729000	3	.857375	.857375	.857375
.947700	.874800	.801900	4	.985982	.943113	.900239
.991440	.962280	.874800	5	.998840	.989970	.941103
.995814	.984150	.947700	6	.999482	.996400	.983967
.998220	.994210	.967446	7	.999808	.998960	.990080
.999380	.997776	.981888	8	.999955	.999490	.994356
.999839	.999158	.991016	9			
.999966	.999698	.994813	10			

The first step in the 5, 4, 1 of 3 system is one of sorting out those reports in scan **4** which match a given report in scan **5**. In this comparison, test radar coordinates, range, bearing, elevation, and time (R, B, E, and t) are used. Range is used in this system as the basic quantity for initial sorting with elevation used for finer sorting. It is desirable to have as few matches as possible between a scan **5** and scan **4** so that amount of prediction that will have to be done will be minimized. The use of elevation information for finer sorting gives an easy way of doing this. If R is the range of the scan **5** report and D is the maximum distance the target can travel between reports, then the maximum change in elevation is given by

$$\Delta E_{\max.} = \tan -1 \frac{D}{R} \qquad (1)$$

This can be seen easily by referring to FIGURE 5. Barring "pathological" cases, D will be less than 10 times the maximum target velocity (in m.p.s.), and for ranges over 300 miles, it will be very nearly 5 times the maximum velocity. It is expected that the FAR system will initiate tracks almost always at a range (slant range not ground range) of about 600 miles from the radar. It should be noted that although ΔE_{max} increases as range decreases, the number of targets will also decrease with decreasing range since the volume depends on R^3.

Once the possible matches from scan **4** are found, one must now predict where the third report (if any) is in scans **3**, **2**, and **1** although if a match is found in scan **3**, one need not predict into scans **2** and **1** etc.). In the prediction, it is assumed that the target travels in a straight line. In order to determine the gate sizes within which a third report will be accepted as being on a straight line with the other two, the following factors must be taken into account:

(1) The noise in the radar data and roundoff in computations.

(2) The deviation of the true path from linearity and errors in linear prediction with coordinates other than rectangular.

(3) The difficulty in predicting the time of the third report.

Consider predicting into scan **3** from scans **5** and **4** and let the coordinates of three points (on a true track) in these three scans be (R_5, B_5, E_5, t_5), (R_4, B_4, E_4, t_4), and (R_3, B_3, E_3, t_3). Then one would like to estimate

$$Q[(t_3-t_4)-(t_4-t_5)]=\text{Max} \qquad (2)$$

for if one predicts assuming $t_3-t_4=t_4-t_5$ than a knowledge of Q will enable one to set the gate sizes properly. The quantity Q depends on three factors: ground range, ground speed (i.e. the speed of the projection of the trajectory onto the ground plane), and direction of flight. Two directions of flight (in the ground plane) make $(t_3-t_4)-(t_4-t_5)=0$ independent of ground range and speed. These are a direction on a radial line from the radar and a direction on a perpendicular to the line from the radar to the projection of (R_4, B_4, E_4). The maximizing direction of flight will be, therefore, approximately half way in between these two.

It has been assumed that the ground rectangular coordinates of (R_4, B_4, E_4) are (O, D) since this simplifies the computations but does not affect the generality of the result. The basic assumption made in this derivation is that the quantity Q is small (and similarly that B_4-B_5 is small) which enables one to linearize in terms of these quantities. Basically, this means one has assumed large ground ranges which is the case in a FAR system.

The initiation process of this invention is made up of a number of separate processes (sorting, predicting, etc.). For this reason, doing a different part of the processing on several reports simultaneously is required. This requires access not only to different scans at the same time but even possible multiple access to a single scan. Because of this type of operation, a magnetic drum is used for the report storage.

In order to better understand the operation of the system described in the figures, a description of their components referred to is first presented. FIGURE 2 is a block diagram of entire track initiator and contains a magnetic drum **11**, a reader **12** with storage for one report, a sorter **14** to find the scan 4 matches, three predictors **16** through **18**, three comparators **20** through **22**, and an initiator **24**.

The reports from the radar are stored on the drum. By storing each report laterally along the drum and dividing the length into 5 sections, one for each of the five scans, 1000 reports for each scan can be stored circumferentially around the drum. If each report has only about 50 bits of information, a single drum would be all that is needed for the 250 axial bits. Control information may be included on the drum, such as a designation of which of the three antennas picked up the report. This could be used to ease the sorting problem. For instance, numbering the 3 antennas counterclockwise and assuming the radar rotates counterclockwise, if the scan **5** report was picked up by antenna **2**, the scan **4** matches will generally come from antenna **1** and cannot come from antenna **3**. Control information which could be included is a bit to indicate when a report in scans **1** to **4** has already been used to initiate a track. This would decrease the possibility of false tracks. Note that this process would generally require simultaneous access to more than one report in the same scan since sorting and comparing would also be going on while this bit was being written. Ground range along with radar coordinates might be stored in the drum to be used in setting gates.

The predictors **16** through **18** are simple special purpose computers which are well known in the art. This computer would serially compute the prediction by simple linear prediction for each pair of reports and store these predictions for use by the comparators. This prediction could be performed in either radar or local rectangular coordinates. The predictors must, of course, have sufficient facility to take care of the prediction for the case of the maximum number of matches between scans **5** and **4**.

The initiator **24** is provided to take tracks and put them in the main track memory **5**. It will take the three reports and go to the main track memory to set up the new track. It must provide sufficient facility to take care of the simultaneous initiation of three tracks, one from each of the three comparators.

A block diagram for a specific sorter is shown in FIGURE 3. Since 1000 reports must be sorted each 5 ms., each sort must be performed in 5 μs. However, the actual sorting process can take more time if one starts sorting on one report before the previous one is completed. Also, if the reports are stored in a convenient sequential form,

this can be made use of with magnetic cores as well as with the drum. This is done by providing proper buffering between the drum and sorter. Also, multiple reading heads and more than one sorter may be provided so that more than one report can be sorted simultaneously. The sorter's operation is such that reports from the scan **5** section of the drum and reports from the scan **4** section of the drum are subtracted with respect to their range R and elevation E. Subtractor **26** subtracts the R_5 from the R_4 and sends its output to gate **27** which will provide an output only if the output of the subtractor **26** is less than the gate size. That is, gate **27** will have an output only if the absolute value of difference between ranges R_5 and R_4 is less than a constant preset amount of range difference which has been set by the gate size of gate **27**. Subtractor **28** does the same with respect to the elevations and sends it to a gate **29**. Gate **29** also will have an output only if the output of the subtractor **28** is less than the gate size which is set by R_5. That is, gate **29** will have an output only if the absoute value of difference between elevations E_5 and E_4 is less than an elevation difference contained in the gate size of gate **29**. The amount of allowable elevation difference ΔE_{max} is set by the range R_5 because of the large possible change in ΔE_{max} with range. See Equation 1. The outputs of the gates **26** and **28**, if any, are trigger pulses which are fed to an AND gate **31**. The output of the AND gate **31** controls the transmission of the scan **4** and scan **5** reports to the predictor **16** by gate **33**. Gate **33** has an output only when AND gate **31** has an output.

A specific block diagram of one of the comparators used in this specific embodiment is shown in FIGURE 4. As soon as one match is found in the comparing process for a given report, the process may be stopped. Subtractors **35** and **38** find the difference in the components of the predicted scan and the true scan. The outputs of these subtractors are gated by gates **40** through **45** as shown, and they are fed to supply the initiator **24**.

Operation

The reports around drum **11** are numbered from 1 to N. The reports are processed in scan **5** in order from 1 to N. The following operations are completed on each drum revolution:

(1) A report (call it report *n*) is picked up by reader **12** from scan **5**.

(2) Sorter **14** sorts out the reports in scan **4** which match reports *n*–1 and feeds the matches to predictors.

(3) Predictor **16** predicts into scan **3** for a report *n*–2. That is, it takes all the pairs involving report *n*–2 and its matches in scan **4** and predicts into scan **3**.

(4) A comparator **20** searches for a third report in scan **3** corresponding to report *n*–3 and any of its matches in scan **4**. If a corresponding report is found, a track is initiated on the main track memory **5** by initiator **24**.

(5) Predictor **17** predicts into scan **2** for a report *n*–4.

(6) Comparator **21** searches in scan **2** for a third report corresponding to report *n*–5 and causes a track to be initiated if a match is found.

(7) Predictor **18** predicts into scan **1** for a report *n*–6.

(8) Comparator **22** searches in scan **1** for a third report corresponding to a report *n*–7, and initiator **24** initiates a track if a match is found.

Steps 5 through 8 are performed only if a track has not already been initiated for the report in question. The 8 reports are processed simultaneously and the total number of drum revolutions required per scan is *N*+7.

At the end of one scan period, scan **5** will become scan **4**, scan **4** becomes scan **3** etc., and a new scan **5** will be stored. Rather than actually transferring reports on the drum, the designation of the banks is changed by switching the equipment. This requires some slack time every 5 seconds, as at the end of each revolution one must transfer the predictions to comparators, scan **4** matches and scan **5** report to predictors, and scan report to sorter. This is accomplished by requiring a slack period at the end of each drum revolution. This slack is also used to set up the gate sizes for the sorter and comparators.

A preferred embodiment of the invention has been chosen for purposes of illustration and description. The preferred embodiment illustrated is not intended to be exhaustive nor to limit the invention to the precise form disclosed. It is chosen and described in order to best explain the principles of the invention and their application in practical use to thereby enable others skilled in the art to best utilize the invention in various embodiments and modifications as are best adapted to the particular use contemplated. It will be apparent to those skilled in the art that changes may be made in the form of the apparatus disclosed without departing from the spirit of the invention as set forth in the disclosure, and that in some cases certain features of the invention may sometimes be used to advantage without a corresponding use of other features. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described. Accordingly, it is desired that the scope of the invention be limited only by the appended claims.

I claim:

1. A track initiator comprising a source of radar reports; storage means for storing said reports; said source of radar reports being stored on the storage means so that different scans of the radar are identified in order of their appearances; sorter means for comparing the reports of a last scan with the reports of a second to last scan in order to find matcehs within certain limits; said sorter means having an output only when a match occurs; first means for comparing matches of the last and second to last scan reports to produce a predicted report in at least one previous scan to the second last scan; second means comparing the predicted position with actual reports in the previous scans; said second means having an output when a match of the predicted report and an actual report occur; and initiator means responsive to the output of said second means for producing a track initiating output signal.

2. A track initiator as set forth in claim **1**, wherein said radar reports contain at least range and elevation information; and said sorter means uses the range information to identify matching reports in the last and second to last scans.

3. A track initiator as set forth in claim **2**, wherein said sorter means further uses elevation information to identify matching reports in the last and second to last scans.

4. A track initiator as set forth in claim **3**, wherein said sorter uses range information for initial identification and elevation information for finer identification.

5. A track initiator as set forth in claim **4**, wherein said sorter means comprises a radar means for reading and storing reports from the last scan of the radar; first and second subtractor means each having first and second inputs and an output which is the difference of said inputs; said first input of said first subtractor means being connected to an output of said radar means to receive range information from the reports of the last scan therefrom; said second input of said first subtractor means being connected to said storage means for receiving range information from reports in the second to last scan; said first input of said second subtractor means being connected to an output of said radar means to receive elevation information from the reports of the last scan therefrom; said second input of said second subtractor means being connected to said storage means for receiving elevation information from the reports in the second to last scan; and gate means connected to the outputs of the first and second subtractor means and to the storage means so as to pass the range and elevation information of reports that match.

6. A track initiator as set forth in claim 5, wherein said gate means comprises inputs of first and second gates connected to the outputs said first and second subtractor means respectively; said first and second gates each having an output when its input is less than its gate size; an AND gate having inputs connected to receive the outputs of said first and second gates; a third gate being so constructed as to have outputs equal to any signals on its first and second inputs when receiving an input on its third input; means connecting the reports of the last and second to last scan reports to said first and second inputs of said third gate respectively; means connecting an output of said AND gate to the third input of said third gate; and means connecting the outputs of said third gate to said first means.

7. A track initiator as set forth in claim 6, wherein said gate size of the first gate is preset at a constant predetermined value; and the gate size of said second gate is determined by range information of the last scan report which information is fed into said second gate by a further connection to a control input of said second gate.

8. In a forward acquisition radar system having a first sorter means for receiving incoming data from a radar receiver and from a main track memory means; said data containing reports from scans of a radar means; said sorter means having first and second outputs, said which contain reports not corresponding to established sorter means sorting the incoming data so that the data tracks in the main track memory means are fed to the first output, and the other data is fed to the second output; said second output being connected to said main track memory means; said first output being connected to a track initiator which has an output connected to said main track memory means; computer means connected to the main track memory means so as to cause the output of said track initiator to initiate a new track in the memory means; the improvement lying in the track initiator which comprises a storage means for storing the reports in accordance to the different scans of the radar; a second sorter means for comparing the reports of a last scan with the reports of a second to last scan in order to find matches within certain limits; said second sorter means having an output only when a match occurs; first means for comparing matches of the last and second to last scan reports to produce a predicted report in at least one previous scan to the second to last scan; second means comparing the predicted position with actual reports in said previous scans; said second means having an output when a match of the predicted report and an actual report occur; and the initiator means responsive to the output of said second means for producing a track initiating output signal to said main track memory means.

9. A forward acquisition radar system as set forth in claim 8, wherein said radar data contain range, elevation, bearing, and time information; and said second means uses the range information to identify matching reports in the last and second to last scans.

10. A forward acquisition radar system as set forth in claim 9, wherein said sorter means further uses elevation information to identify matching reports in the last and second to last scans.

11. A forward acquisition radar system as set forth in claim 10, wherein said sorter uses range information for initial identification and elevation information for finer identification.

12. A forward acquisition radar system as set forth in claim 11, wherein said first means comprises first, second, and third predictors connected to first, second, and third comparators which made up said second means; said first, second, and third predictors and comparators are connected respectively to the first, second, and third previous scans to the second to last scan for cycle operation; each comparator having an output connected to the initiator means.

13. A forward aquisition radar system as set forth in claim 12, wherein said second and third predictors and comparators will not cycle if an output is obtained by said first comparator, and said third predictor and comparator will not cycle if said second comparator has an output.

14. A forward acquisition radar system as set forth in claim 13, wherein said storage means is a magnetic drum means.

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MALCOLM F. HUBLER, Assistant Examiner

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343—7