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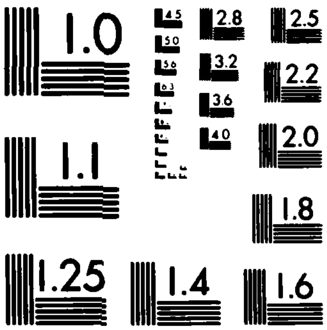

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AUGUST 1984

MIT Laboratory for Information and
Decision Systems, Cambridge, MA
Contract N00014-77-C-0532 (NR-041-519

LIDS-P-1397

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MULTI TARGET TRACKING BY DYNAMIC SCENE ANALYSIS

by

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1. Introduction

Multitarget tracking is dealt with in numerous papers over the last ten years. Specific review papers can be found in [1] to [5]. The main evolutionary path has come from the "nearest neighbor" principle, early "branching" procedures to late "hypothesis" generating methods, the latter represented by e.g. [6]. These methods suffer from excessive computational demands even for modest numbers of targets and many do not include the most difficult part, the track initiation.

A way to reduce the computational workload, though not commonly used, is to take advantage of formation flying aircrafts. A recent paper [7] uses an initiation process based on a "general/parallel search scheme" to find parallel flying objects. However, the method is a batch method using 5 to 8 scans of data and is not further used in the succeding tracking process. Early formation tracking concepts can be found in [8] to [10], with follow ups in [11] and [12]. Formations are here somewhat loosely defined as a set of returns far away enough from other returns not to cause ambiguity problems. The generality of the initiation methods presented in [8] and [9] respectively are also difficult to grasp. In [13] is shown that the maximum likelihood solution to track initiation of individual tracks in a dense detection environment is unrealistic in real time.

The group concepts of these papers should not be mixed up with the "clustering" used in e.g. [4]. This clustering is merely a way to order the returns into independent "clusters" prior to applying some method for finding out individual tracks. The clusters themselves are not used as tracking objects.

The approach of this paper is quite different from the above mentioned. An analysis is made per scan of the received returns based on their geometric interrelations only. From this, a large scale view of the tracking and the data received can be taken. Ultimately the ability of the human observer in identifying target formations, specific ECM patterns etc. would be desirable. However, a first step is taken with the objective to make feasible the initiation and tracking of large groups of targets. The analysis algorithm developed has the unique feature of defining a hierarcy of groups. This is the key feature both for its use in identification as well as in the initiation and tracking processes as described below. The method sets no limit on formation size and the track initiation phase is handled with the same ease as tracking as demonstrated in the example. The method is believed to be a good basis for multitarget tracking even in a more realistic radar environment and with other kinds of target behavior. It may either be selfcontained as in the example or a complement to hypothesis methods.

The method used is heuristic dictated by its specific requirements and the discrete kind of input data. Not much can be gained from nearby areas such as infra red scene analysis [14], robot vision [15] or pattern recognition [16]. However, the concept of "intraset distance" used in section 2.1 in this paper is found in [16], though differently defined. Pattern recognition methods will be of further use in the similarity correlation process, described in section 3.2. It consists of recognizing target groups in successive scans, subject to statistical fluctuations due to radar resolution and detection probability. This will be covered in following work.

2. The RSAA

The RSAA, Recursive Scene Analysis Algorithm, has been formulated according to four major objectives as outlined below.

2.1 Groups

The first objective is: find groups of targets. However, crucial for the result is the choice of group definition. It should be consistent with both the target formation behavior and the human observer's perception of target groupings in a more general sense. A heuristic, non-probabilistic definition is chosen as follows:

Definition: A group is a set of elements, groups or single targets, with a maximum intraset distance, MID, less than C (<1) times the distance to its nearest neighbor, DNN.

Where $MID = \max\limits_{i=1,N-1} (dnn_i)$

N = the number of targets in the group

dnn_i = the distance between the subset SG_i and its nearest neighbor NN_i

$SG_{i+1} = SG_i + NN_i$

SG_1 can be chosen arbitrarily.

2.2 Hierarcy of Groups

The group definition allows a hierarcy of groups to be established. The purpose of this is twofold. First, it gives a structure to a group that can be used both for pure identification but also for the scan to scan correlation. Second, it allows the tracking process to adjust the level of tracking to the present accuracy of the tracking. It is not always possible, nor necessary or even desirable, to track every single target individually. This is clearly demonstrated in the example.

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*This research was conducted while the author was a Visiting Research Scientist at the MIT Laboratory for Information and Decision Systems with partial support provided by the Office of Naval Research under contract ONR/N00014-77-C-0532 (NR041-519)

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2.3 Recursiveness

The RSAA completes an analysis of the received radar returns per each completed antenna revolution (scan). During the scan, as the returns enter the radar, the group structure is updated recursively. This is demonstrated in the example. The procedure is as follows for every single entering radar return:

- A search for its nearest neighbor, NN.
- A test for the new return to either
  - Form a pair with NN, i.e. a new group
  - Be included in the same group as NN
  - Be included, not in the same group, but in the supergroup of NN, etc.
- An analysis of the influence on the existing group structure by recalculating the MID and DNN for affected groups. This can lead to either
  - Forming of new groups
  - Dismissing of existing groups.

2.4 Group Data Organization

The group data should be organized for computational efficiency. This means that the data should be chosen to specifically support the recursive scheme described. No more data should be stored than are frequently used or are computationally burdensome to retrieve. The data stored are for each group:

- Number of targets in group
- Group level
- Group center coordinates
- NN index
- DNN
- MID
- Supergroup index
- Subgroup indices
- Some tracking logic

3. The RSAA in Multi Target Tracking

3.1 General

The result of the RSAA is correlated against the targets in the track file. Correlation is called ambiguous if two or more objects (groups or single returns) appear in the correlation gate of any of the tracked objects. The basic idea behind the use of the RSAA is to keep the correlation ambiguities as few as possible. This is achieved in two ways. An object may be distinguished from another by means of its size and structure in what is called the similarity correlation below. If this is not enough tracking is tried on a higher group level. However, alternatively (or complementary) hypothesis based methods can be applied to the ambiguous correlation problem with the big advantage given by the RSAA that were reoccuring groupstructures can be found these can be tracked as single objects, thus reducing substantially the number of hypothesis necessary.

3.2 Correlation and tracking procedure

The correlation procedure used is in three steps: First the predicted group and target positions on the tracking level of the trackfile are correlated with the group centers of the RSAA on the corresponding level. If the correlation is unambiguous the procedure advances to the second and third step for continuation of tracking on that level or on a lower level. If an ambiguous correlation arise, an unambiguous correlation is sought on a higher level in the first place. However, other options are available as indicated in section 3.1.

In the second step groups are correlated for similarity. When similarity is low, measures are taken depending on the nature of the change. When similarity is high, continued tracking is allowed on that level. However, the third step checks for the possibility of a more detailed tracking.

The third step checks for unambiguity on the level below the actual tracking level. This allows the tracking to be transfered to lower levels of the group structure as the tracking accuracy improves. This is of particular value in the track initiation phase as demonstrated in the example.

3.3 Dynamic Scene Analysis

To better deserve the title "Dynamic" the structure parameters of the tracked groups are monitored over a period of time; more than two scans. Parameters such as the number of returns and the exact geometric structure of the subgroups are subject to variations due to radar detection probability and resolution. The range and nature of these variations should be known if proper identification of the groups are to be done.

The geometric structure is of course also affected by formation changes. By monitoring structure parameter changes, in relation to the expected variations due to the radar measurement inaccuracies, formation changes may be detected before the formation elements are possible to track individually.

Three group levels are of particular interest:

- Tracking level; consistency in similarity correlation parameters.
- Level above tracking level; preparation of its use when conflicts arise on tracking level.
- Level below tracking level; monitoring outbreaks and group splitting.

4. Example

The ideas presented above are demonstrated on a track initiation case with 32 targets flying in formation as shown in Figure 1. Figure 1 shows a cartesian north-east coordinate system with two groups of sixteen targets, each of which consisting of four groups of four targets. Each four-group consists in turn of two groups of two. Distances between group members are as shown in the figure. All targets are going south with a speed of 200 m/s maintaining the formation shown.

The targets are observed by a radar making one scan, from west to east, every 5 seconds. Thus, all targets move 1000m between scans. To demonstrate the basic ideas without too many details, ideal radar detection, accuracy and resolution are assumed.

4.1 The RSAA

The performance of the RSAA is demonstrated in figures 2 to 8. As ideal radar performance is assumed, identical results are obtained from every scan. Only absolute position coordinates are changing, due to the speed of the targets.

Figure 2 shows the group of two formed when the first two returns are received. The third return has a distance from the previous group which exceeds what is required to be included in that group. The constant C, from section 2.1, is choosen to .6. Instead a new group is formed with the last return and the previous group as subgroups, as shown in Figure 3. The fourth return, as shown in figure 4, forms a group of two with the third return within the existing supergroup and not affecting the first group of two. The fifth return results in a new supergroup being formed with the fifth return and the previous group of four as subgroups, as shown in figure 5. Now four levels of groups have been formed. Figure 6 and 7 show another case where a new subgroup is formed within the highest level group but only affecting a part of the group structure. Figure 8 shows the final result of the RSAA with five groups levels.

4.2 Correlation and Tracking

Figure 8 shows what is seen by the radar after the first scan. On a radar screen this can be shown at any chosen level of detail. Here the envelope of the highest group level and its center of gravity are shown in figure 9. After the second scan the same return data structure is found by the RSAA but translated 1000m to the south. According to the correlation procedure explained in section 3.2 a position correlation is first tried on the highest group level. The correlation gate at the second scan consist primarily of a circle of radius $T.v_{max}$ (T=scan time and v_{max}=target maximum speed) centered at the first scan group center. Within this circle a nonambiguous correlation with the highest level group from the second scan is made. The next step in the correlation procedure, the similarity correlation, gives a perfect match between the two groups. This is due to the ideal measurement conditions and that no relative motion has taken place within the group. These two steps of correlation have now proved the identity of the observed groups at the highest level and thus tracking is allowed. First, however, position correlation is tried on the level below. This correlation fails to be nonambiguous. Both groups of the second level (groups of sixteen targets) fall within the correlation gate, no matter from which of the first scan groups the correlation is tried. Thus tracking stays on the first level. The result is shown in figure 10. The length of the velocity vector is chosen to show the predicted position of the center of gravity one scan time ahead.

Tracking is performed with two regular, uncoupled, non-adaptive Kalman filters, one for each coordinate. The covariances of the Kalman filters are used to determine the correlation gates in the usual way. The details of this are not essential to the present case, and not shown here. Important, however, is the general property that the covariances and thus the correlation gate, decrease with increasing scan numbers. They decrease from the initial values to reach a steady state plateau determined by the target maneuver and measurement accuracy parameters. The result of the decreasing correlation gate is shown on the third scan.

At the third scan the result of the RSAA is correlated against the predicted positions of the track file. First, again, the correlation takes place on the tracking level. Here, again, the position correlation is nonambiguous and the similarity correlation shows a perfect match. However, in the third step of the correlation procedure the groups on the level below the tracking level also correlate unambiguously due to the smaller correlation gate. As the similarity correlations show a good match on this level also, the tracking is transferred to this level. This is done prior to the filter update. The velocity and covariance data of the tracking level are given to the subgroups and their filters respectively. This results now in the tracking of the two groups of sixteen targets as shown in Figure 11.

In the same way the tracking accuracy has improved on the fourth scan to allow unambiguous correlation and tracking of the groups of four, as shown in Figure 12. In the following scans the increase in the tracking accuracy is not enough to permit tracking on even lower levels. Figure 13 shows the repeated tracking of the groups of four.

Cont

5. Conclusions

The paper ~~has~~ presented a radar scene analysis algorithm. It ~~has been~~ was shown to easily cope with track initiation of a large formation of aircrafts, a problem giving previous methods big problems. The method is believed to be a general multi target tracking tool but further work must be done to include a more realistic radar environment and other kinds of target behavior.

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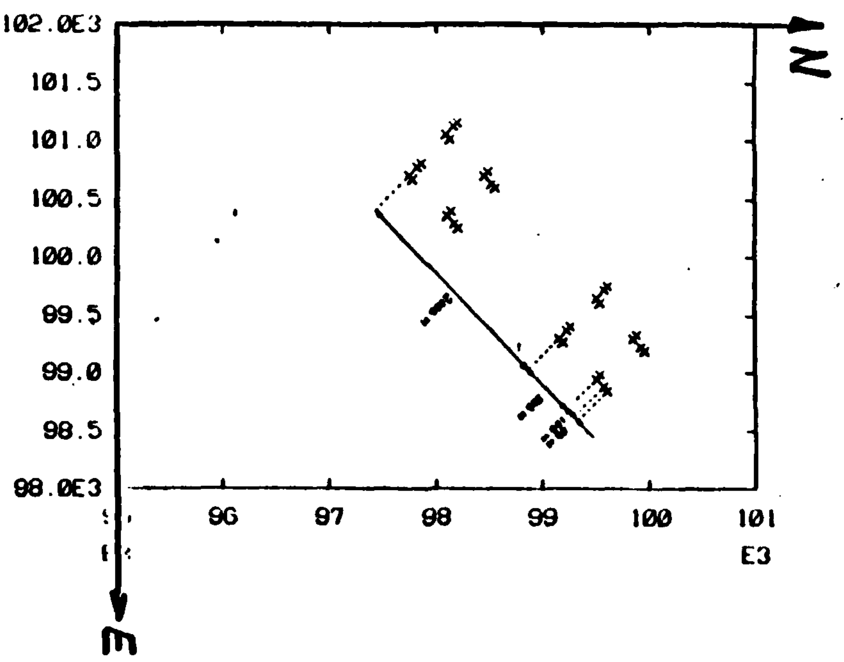

Figure 1: Target Formation

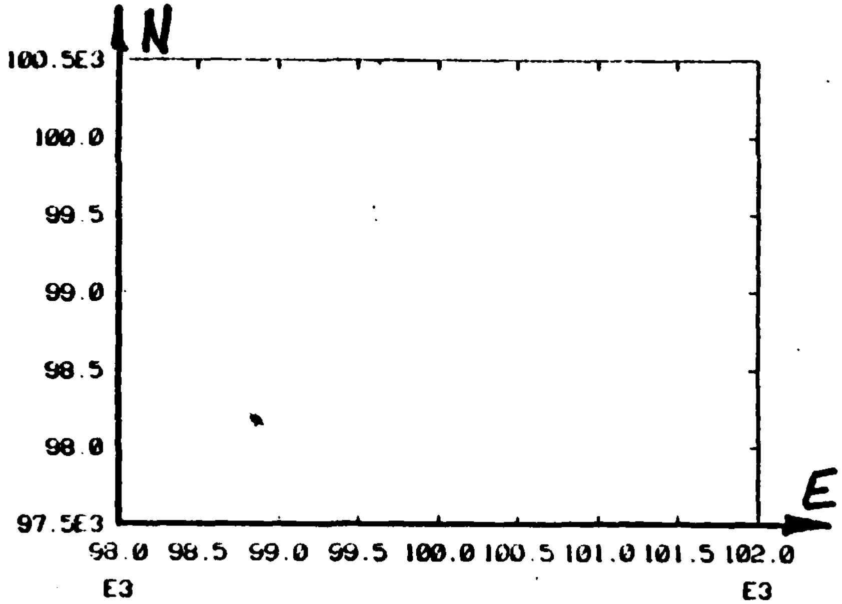

Figure 2: RSAA result after two returns.

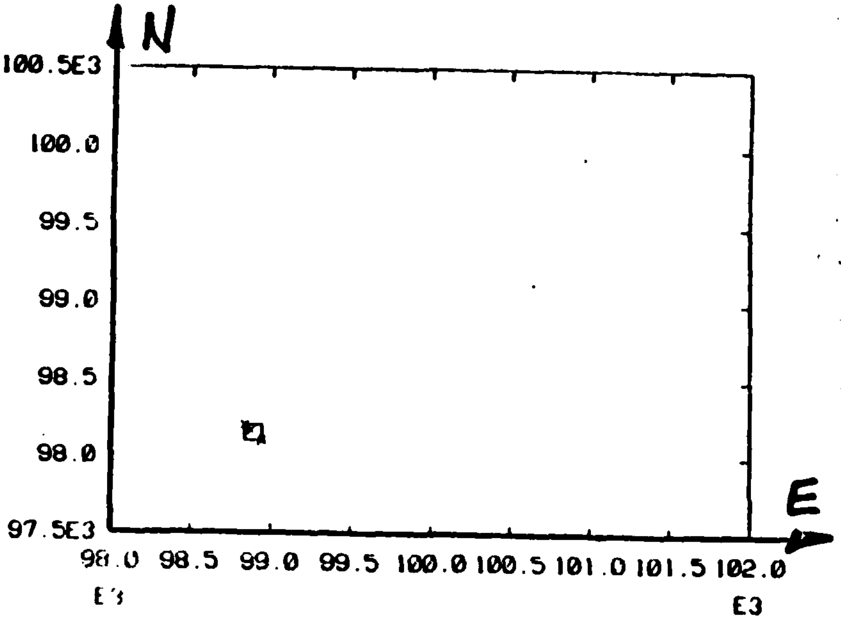

Figure 3: RSAA result after three returns.

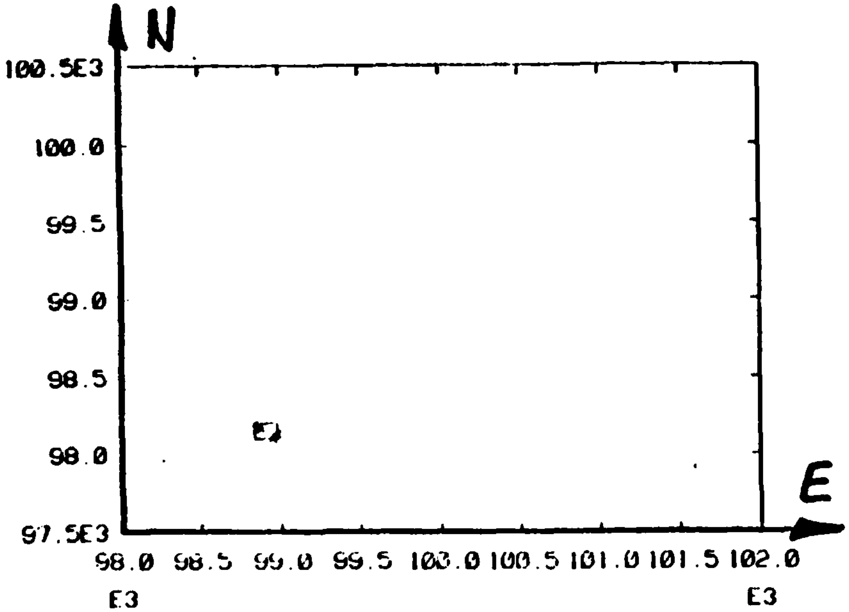

Figure 4: RSAA result after four returns.

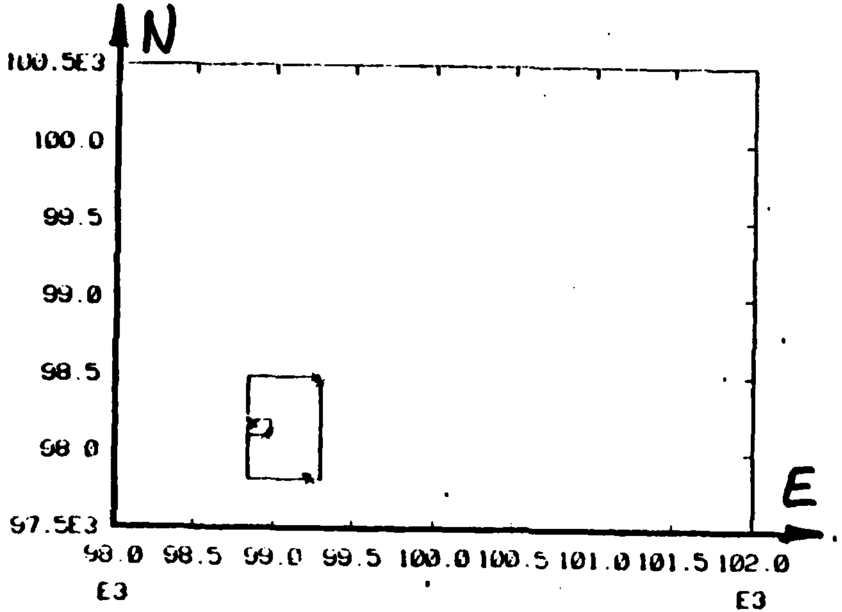

Figure 6: RSAA result after eight returns.

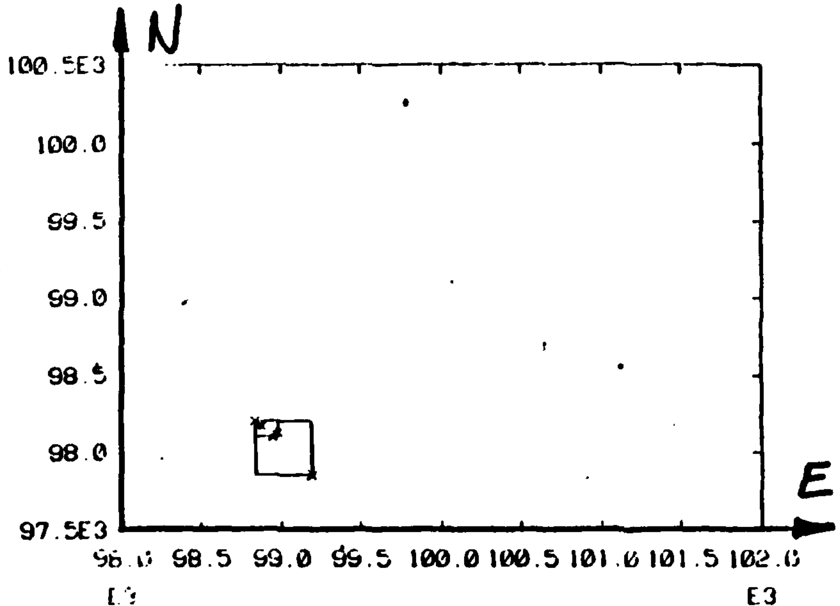

Figure 5: RSAA result after five returns.

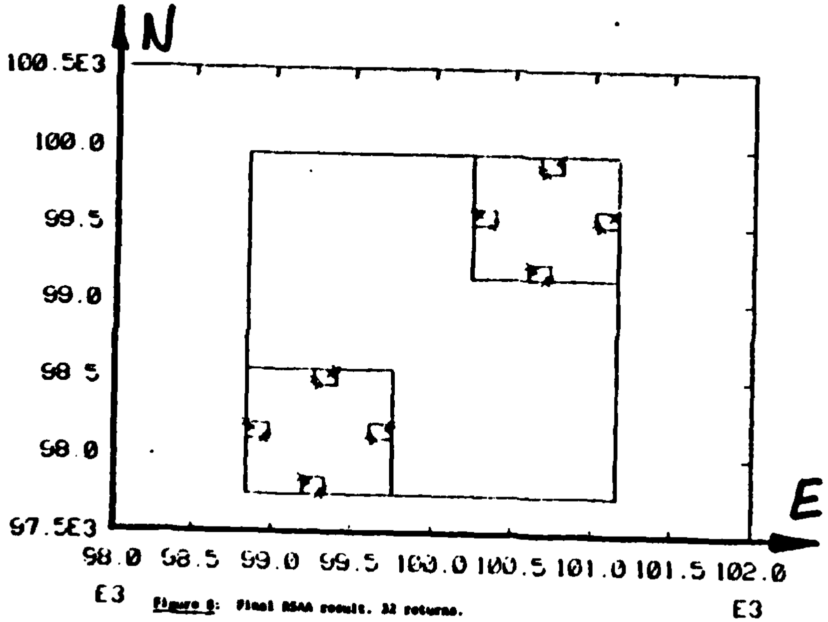

Figure 8: Final RSAA result. 32 returns.

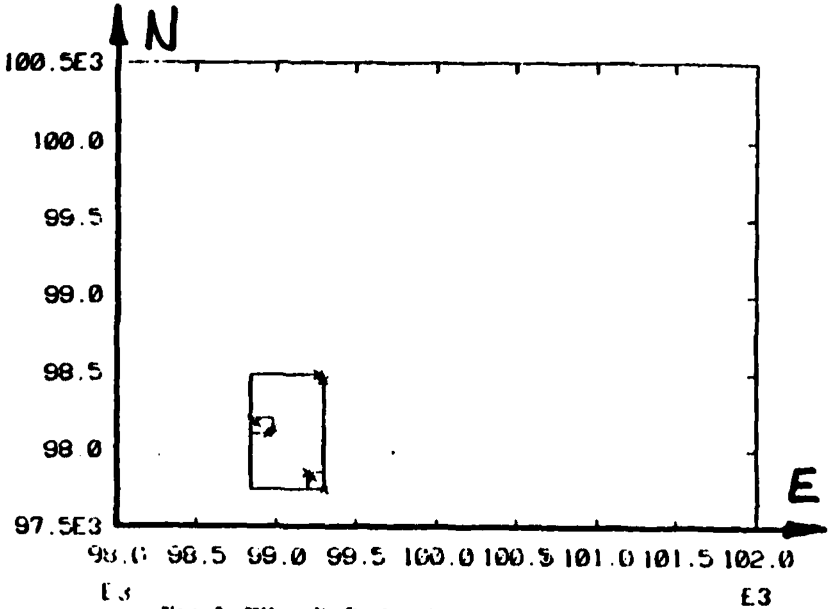

Figure 7: RSAA result after two returns.

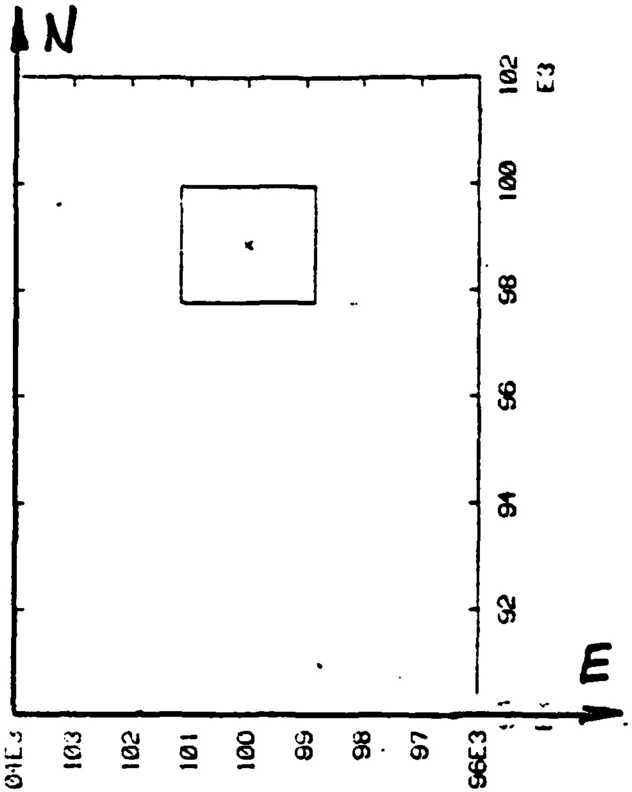

Figure 9: Tracking result after scan 1.

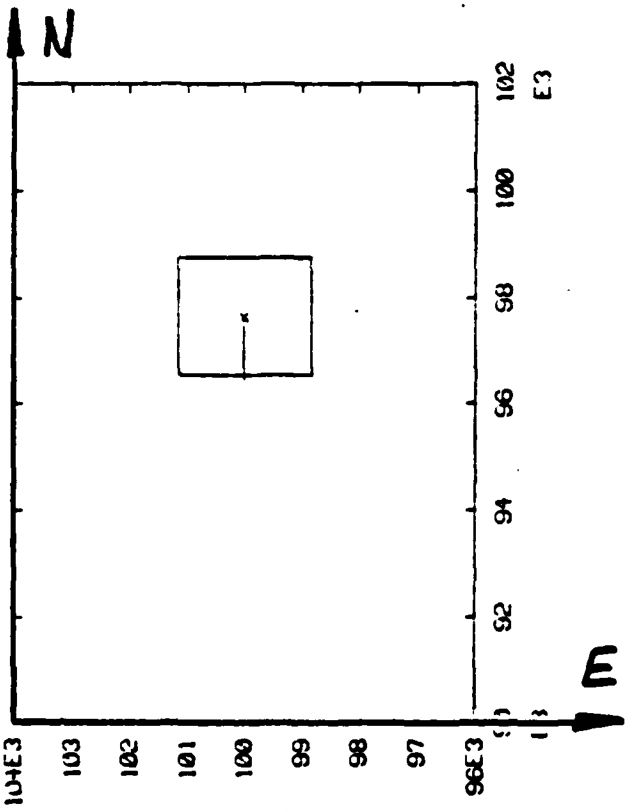

Figure 10: Tracking result after scan 2.

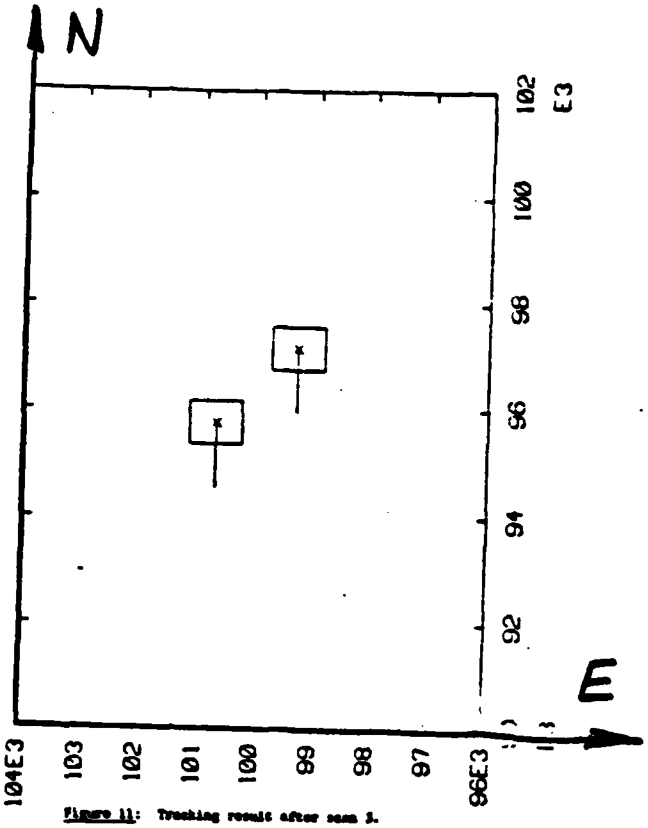

Figure 11: Tracking result after scan 3.

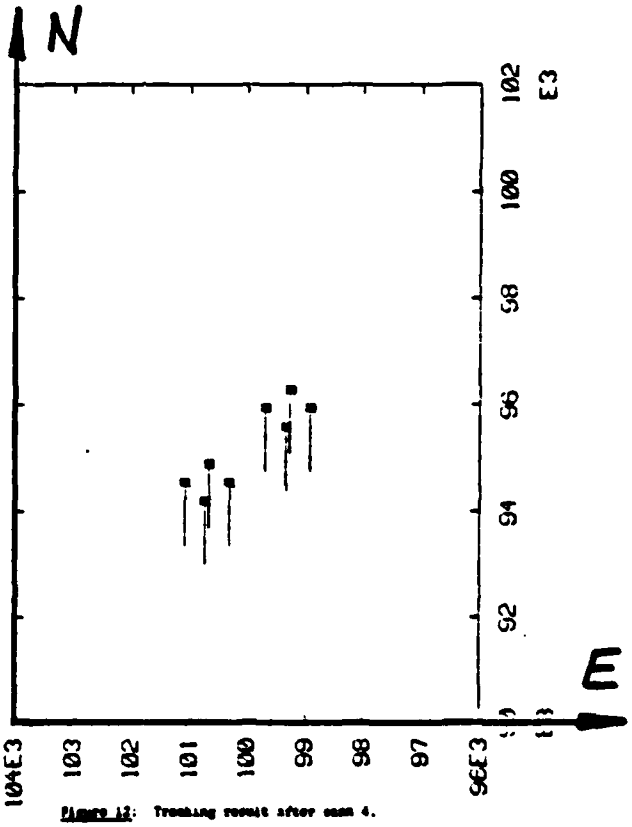

Figure 12: Tracking result after scan 4.

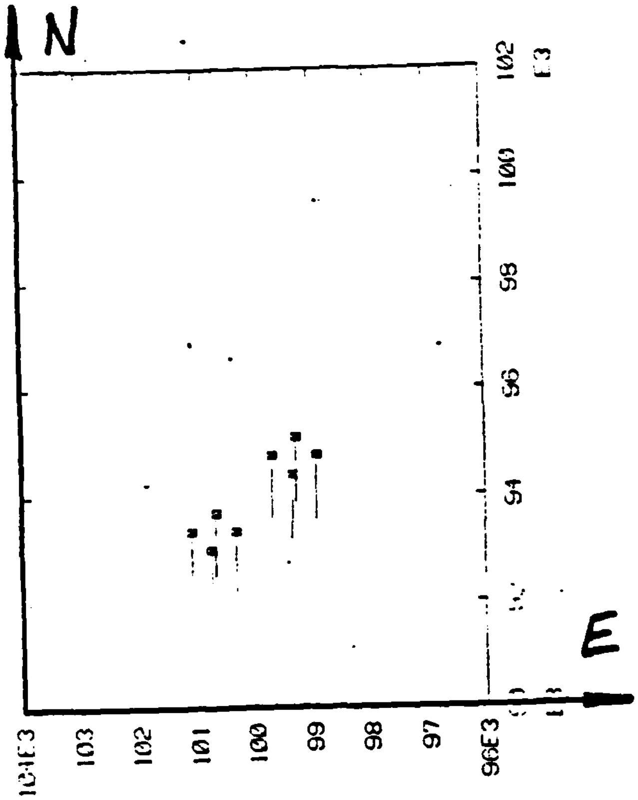

Figure 13: Tracking result after scan 5.