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TITLE

MULTITARGET TRACK INITIATION USING A MODIFIED HOUGH TRANSFORM

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MULTITARGET TRACK INITIATION USING A MODIFIED HOUGH TRANSFORM

by

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1 Summary

A modified Hough Transform is proposed for multitarget track initiation. The proposed technique can initiate target tracks using data from as few as three scans. Simulated data as well as real radar plot data are used to test the initiator. Results show that its performance is superior to the conventional Hough transform in terms of false track rate without degradation in the probability of track detection.

2 Introduction

Multitarget tracking (MTT) algorithms have been under study for military radar systems for a number of years. There is a class of tracking algorithms known as probability data association (PDA) for tracking targets through clutter. The computational load of this tracking technique does not increase rapidly with the increasing numbers of targets but requires a separate track initiator. In the presence of a heavy clutter background, such as might arise in a surveillance radar, it is well known that it may be necessary to use retrospective techniques [1] for track initiation. With this approach, observations from several past scans of data are processed together to determine feasible target trajectories. One of the most popular batch techniques is the Hough transform [2]. The Hough transform track initiator is also recommended for situations involving a large number of targets [3].

When the conventional Hough transform is used in target track initiation, a track is determined by detecting the peak in the parameter space. To do this, a threshold must be used for distinguishing the peaks associated with tracks from peaks due to clutter. It requires a relatively large number of scans to establish peaks in the parameter space and the threshold for detecting the peaks is difficult to determine. As a result, the technique will be very slow in forming firm tracks and, in a dense clutter environment, may also declare false tracks.

A modified Hough Transform has been developed to overcome these difficulties. The modified Hough transform requires as few as three scans for track initiation and dramatically suppresses the number of false track declarations. Simulations are carried out to demonstrate the track initiation performance of the two schemes. These results are also illustrated using real radar data.

3 The Hough Transform

The Hough transform is a well-known technique used to identify straight lines in a noisy environment. It maps the points $r(x, y)$ in the image space (X–Y) into curves in the parameter space (ρ, θ) by the relationship

$$\rho = x\cos\theta + y\sin\theta. \qquad (1)$$

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That is, a point in the X–Y plane defines a curve in the $\rho-\theta$ plane. For points (x_i, y_i) on a straight line, they are related by

$$\rho_0 = x_i \cos\theta_0 + y_i \sin\theta_0, \qquad (2)$$

as illustrated in Fig. 1. For a group of points in the X–Y plane, a family of curves is formed in the $\rho - \theta$ plane. If the curves have the common intercept (ρ_0, θ_0) on the $\rho - \theta$ plane, the corresponding points are collinear, i.e. they are on the same straight line. For example, as shown in Fig. 2, there are six curves on the $\rho - \theta$ plane. Three of them intercept at a point and the other three at the other, which implies that points $\{(-1,-2.5),(0,4),(1,-5.5)\}$ on the X–Y plane are collinear and points $\{(1,5),(0,3),(-1,1)\}$ are also collinear. Based on observations on the $\rho - \theta$ plane, straight lines can be identified on the X–Y plane.

In order for a computer to process the image, both the X–Y plane and the $\rho - \theta$ plane are discretized. In such a case, the intercept points on the $\rho - \theta$ plane are indicated by peaks in a 3-D histogram. For example, in Fig. 3 is shown a typical histogram in the $\rho - \theta$ space from which we can see that there are a number of peaks indicating possible straight lines in the X–Y plane. However, not all the peaks are associated with the true straight lines. Some are caused by noise. Therefore, a threshold must be used to determine which peak can be associated with a line.

The Hough transform can be used for multi-target track initiation from a surveillance radar. A track is determined by detecting the peaks in the $\rho - \theta$ space. For an image compiled from a radar detections, or plots, from a sufficiently large number of scans, the standard Hough transform performs satisfactorily. However, in a realistic tracking environment, it is required that the tracking system must identify target tracks from a clutter background in a small number of scans. To detect a peak in $\rho - \theta$ space, a threshold must be used for distinguishing the peaks associated with real tracks form the peaks due to clutter plots. The Hough transform requires a relatively large number of scans to establish peaks in the $\rho - \theta$ space and the threshold for detecting the peaks is difficult to determine. Since clutter plots may form false tracks, the Hough transform is not able, with a small number of scans, to distinguish them from real tracks and hence declares them as real tracks. Keeping a time tag on the scan number of each data point may reduce the false tracks. However, this is achieved at the cost of a large increase in both computation load and memory. Furthermore, for the conventional Hough transform, the peaks in the parameter space indicate only the number of possible tracks and their positions. The time information is lost in the process. To remedy these difficulties, we propose a modified Hough transform for track initiation.

4 Modified Hough Transform

Like the standard Hough transform, the modified Hough transform starts with locating lines in a composite image containing the superposition of candidate target detections in a series of scans. The targets we considered have curve trajectories which can be approximated as straight lines over a reasonably short time interval. Suppose we receive three reports r_n, r_{n+1}, and r_{n+2} at scans $n, n+1$, and $n+2$. Based on these three data points, we obtain three curves ρ_n, ρ_{n+1}, and ρ_{n+2} in the parameter space. The difference function is formed as

$$\Delta\rho_n = \rho_n - \rho_{n+1} \qquad (3)$$

There are two pieces of information that can be derived from the zero crossing of $\Delta\rho_n$, denoted by $\Delta\rho_n(0)$. First, it indicates the coordinate θ where ρ_n and ρ_{n+1} intercept, which is denoted by $\theta_{\Delta\rho_n(0)}$. Second, if we consider the points in the image space as vectors, the sign of the slope at the zero crossing depends on the pointing direction of the vector $(\mathbf{r}_n - \mathbf{r}_{n+1})$. It is also noted that the acceleration of a target is physically limited. Therefore, this information may also be made use of for track initiation. Based on the above observations, three criteria are established for track initiation:

1. The zero crossing points $\theta_{\Delta\rho_n(0)}$ and $\theta_{\Delta\rho_{n+1}(0)}$ must be at the same proximity; i.e.

$$|\ \theta_{\Delta\rho_n(0)} - \theta_{\Delta\rho_{n+1}(0)}\ | \leq \sigma_\theta, \qquad (4)$$

   where $\Delta\theta \leq \sigma_\theta \leq m\Delta\theta$ is a tolerance value, as shown in Fig. 4, and m is any positive integer.

2. The slopes at the zero crossing points $\theta_{\Delta\rho_n(0)}$ and $\theta_{\Delta\rho_{n+1}(0)}$ must have the same sign.

3. The distance that a target travels in time t_n must be of the same order as the distance in time t_{n+1}. That is, by denoting distance between r_{n+1} and r_{n+2} as $d_{n+1,n+2}$, it is required that

$$|\ d_{n+2,n+3}\ | \leq c \times |\ d_{n+1,n+2}\ | \qquad (5)$$

   where c is a constant that depends on a physical model.

If all the three criteria are satisfied, we say that r_n, r_{n+1}, and r_{n+2} are collinear and they form a possible track. It is interesting to note that with only Criterion 1 satisfied, we obtained the standard Hough transform, where a peak in the histogram indicates a track. The value of the peak is one greater than the number of zero-crossings within the interval σ_θ. We have illustrated the modified Hough transform initiation using three scans, even though it applies to an arbitrary number (> 3) of scans.

5 Results

Simulations were carried out to study the performance of the initiator. In the simulations, five scans are used for initiation and $c = 10$. Fig. 5 compares probabilities of track detection, at different measurement noise levels, for the standard Hough transform initiation and the modified Hough transform initiation. The standard Hough transform is implemented with Criterion 3 as an additional condition. The probability of track detection is defined as

$$p_d = \frac{N_d}{N_t} \qquad (6)$$

where N_d = total number of true tracks detected,
N_t = total number of tracks.

The measurement noise is normally distributed, with its power normalized with respect to the unit in the X–Y plane. p_d is evaluated without clutter. Each curve in Fig. 5 is obtained by averaging the results from 1000 trails. The probability of track detection is also evaluated for different values of σ_{theta}. It can be seen that p_d increases as σ_{theta} increases and that the two initiation algorithms have very similar performance in terms of probability of track detection.

In Fig. 6, the false track rates are compared at different levels of clutter-to-target ratio $r_{c/t}$, for both the standard Hough transform initiation and the modified Hough transform initiation. The false track rate is defined as

$$p_f = \frac{N_f}{N_t} \qquad (7)$$

where N_f = total number of false tracks,
N_t = total number of tracks.

The clutter-to-target ratio is defined as

$$r_{c/t} = \frac{\overline{M}_c}{M_t} \qquad (8)$$

where $\overline{M}_c$ = mean number of clutter points in a single scan,
M_t = number of true targets in a single scan.

The actual number of clutter plots M_c is a random process, which is assumed to be Poisson distributed. The distribution of the clutter locations in the image space is assumed to be uniform. In order not to complicate the analysis, no measurement noise was added and hence a small $\dot{\sigma}_\theta = 1.5°$ was used. Each value of p_f in the figure is obtained using 1000 trials. It can be seen that the false track rate is reduced greatly by using the modified Hough transform for track initiation. In essence, Criterion 2 is the key to reduce the false track rate.

Real data were used to evaluate the performance of both the standard and modified Hough transforms. The data were collected from an AN/FPS-117 radar located on the Canadian portion of the North Warning System in order to examine more closely the high false alarm rates that were observed from time to time. Although some of the data show "high" false alarm rates, there was no controlled procedure to insure that data were recorded for all high false alarm conditions or the worst false alarm conditions. However, informal communications with air surveillance personnel indicated that the recorded data gave a fair representation of the range of conditions seen. Tracks of air targets arise from commerical airlines flying on north Atlantic routes. For the purposes of our track initiation experiment, only the primary radar plot position information was used. All information pertaining to secondary radar, target ID etc was stripped off. Probability of detection for the raw radar detection is estimated at 0.75. The FPS-117 is the long range L-band radar with a 12-second scan interval in azimuth. Elevation coverage is from $-6°$ to $+20°$. The range resolution is about $300 meters$ and the beamwidth in both azimuth and elevation is about 2 °. Analysis of the data revealed that high false alarm rates occurred due primarily to bird clutter and sea clutter.

The following results illustrate the performance of the two initiation techniques with real data. The tracking results were obtained using the same tracking scheme except for the track initiation. In track initiation, a relatively large $\sigma_\theta = 10°$ was used to ensure a high probability of track detection, because the measurement noise level was unknown. The tracking scheme includes a conventional Kalman filtering and nearest neighbour data association. From the results obtained using the standard Hough transform (Fig. 7), it can be seen that there are a lot of false tracks. On the other hand, when the modified Hough transform was used, most of these false tracks were eliminated (Fig. 8), resulting in clear tracks in the image space.

6 Conclusions

A modified Hough Transform has been proposed for multitarget track initiation. Result obtained from simulations show that the false track rate is reduced greatly by using the modified Hough transform instead of the standard Hough transform, while the probability of track detection is similar to the standard Hough transform. The use of real radar data also demonstrated that the standard Hough transform performs very poorly. However, the modified Hough transform was demonstrated to be able to establish the correct tracks and elliminate most of the false tracks initiated by the conventional approach.

References

[1] R. J. Prengamman, R. E. Thurber, and W. G .Bath, "A Retrospective Detection Algorithm for Extraction of Weak Targets in Clutter and Interference Environements," *Proceedings of the IEE 1982 International Radar Conference*, London, Oct. 18-20, 1982, pp.341-345.

[2] S. S. Blackman, *Multiple-Target Tracking with Radar Applications*, Artech House, Inc.

[3] D. P. Casasent and J. Slaski , " Optical Track Initiator for Multitarget Tracking", *Applied Optics*, Vol. 27, pp.4546 - 4553 , 1988

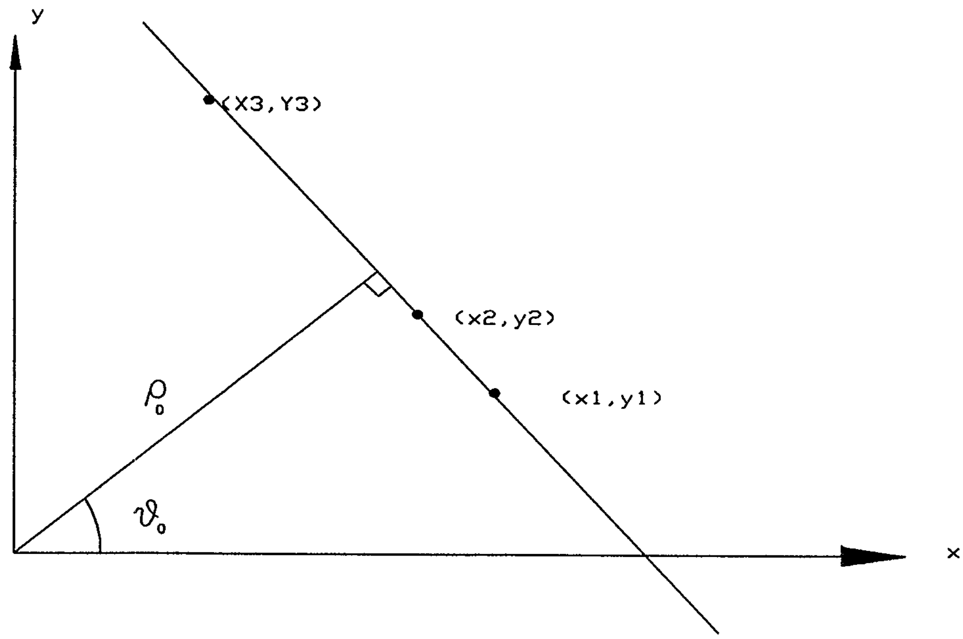

Figure 1: Normal parametric representation of a straight line.

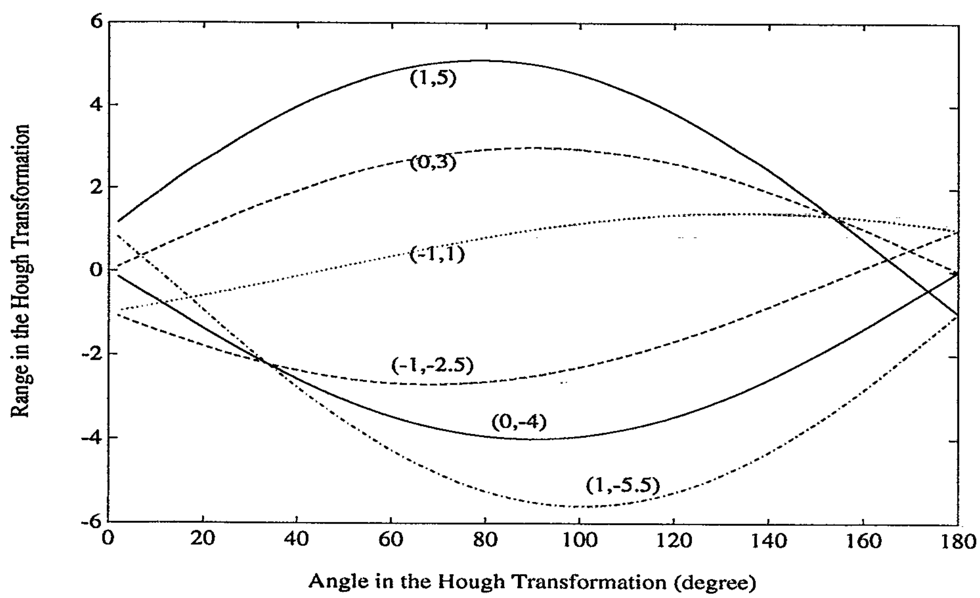

Figure 2: Amongst the curves on the $\rho - \theta$ plane, three of them intercept at a point and the other three at the other. This implies that points $\{(-1,-2.5),(0,4),(1,-5.5)\}$ on the X–Y plane are collinear and points $\{(1,5),(0,3),(-1,1)\}$ are also collinear.

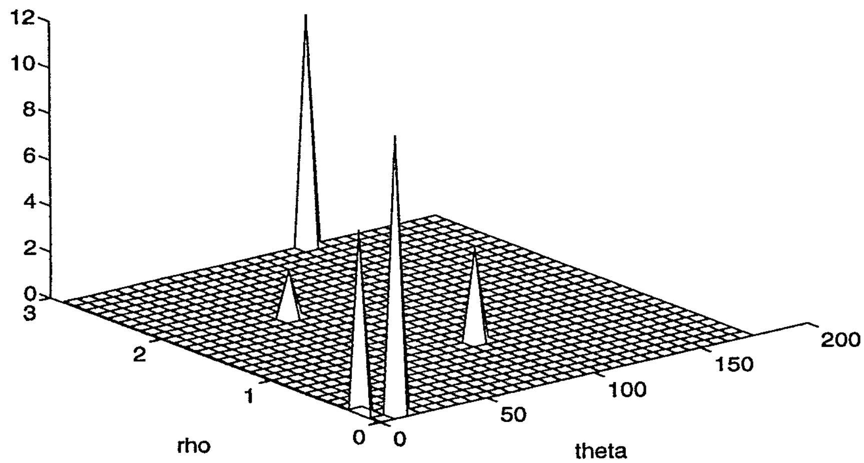

Figure 3: Histogram in $\rho - \theta$ space.

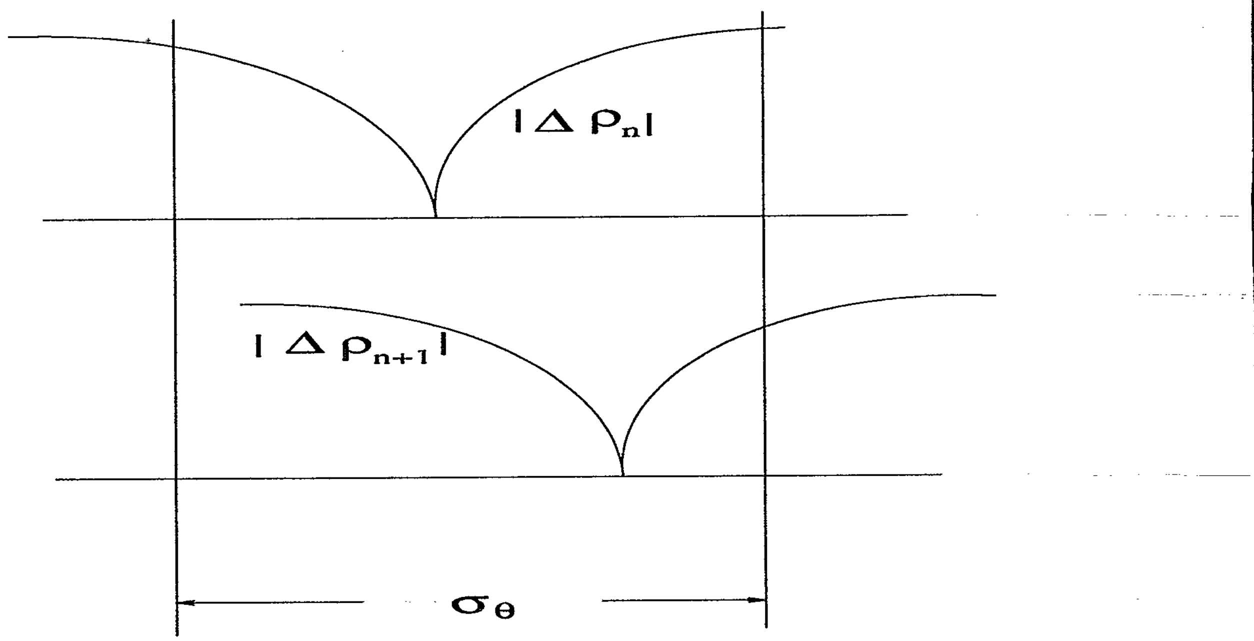

Figure 4: The zero crossing points $\theta_{\Delta\rho_n(0)}$ and $\theta_{\Delta\rho_{n+1}(0)}$ are within the tolerance range σ_θ.

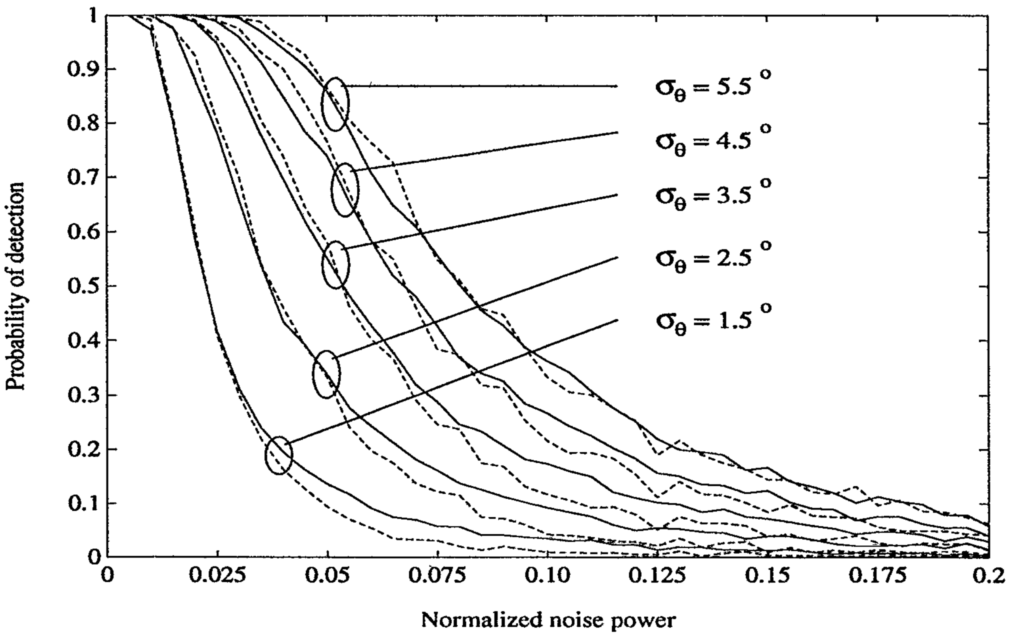

Figure 5: Comparison of probability of track detection. — the modified Hough transform initiation; - - the standard Hough transform initiation.

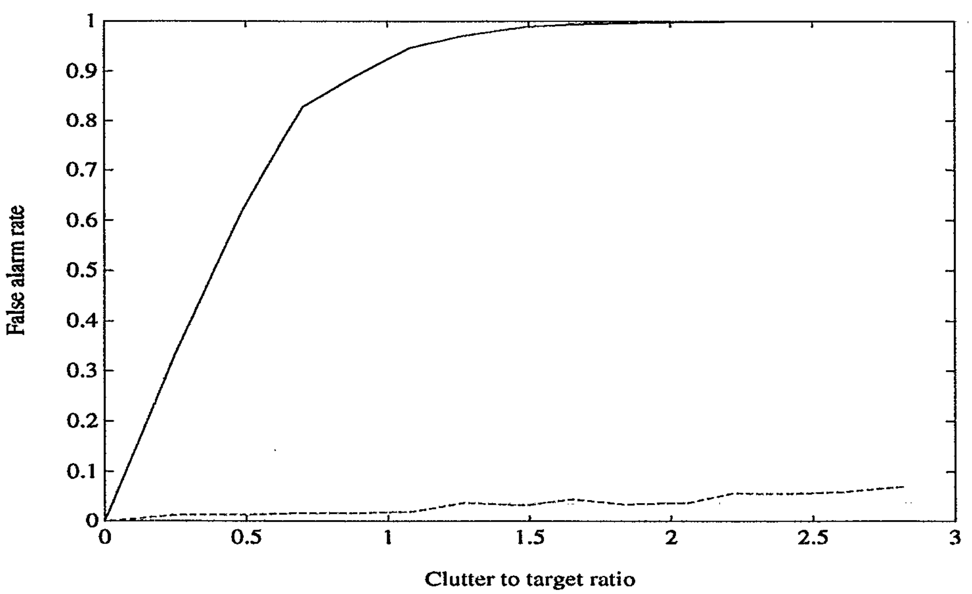

Figure 6: Comparison of false track rate. - - the modified Hough transform initiation; — the standard Hough Transform initiation.

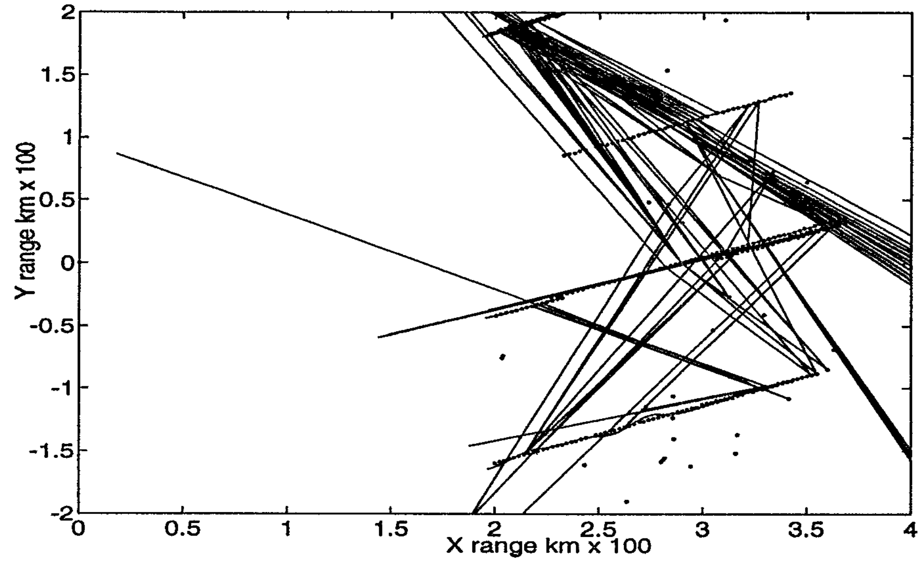

Figure 7: Tracking results based on real data using the conventional Hough transform.

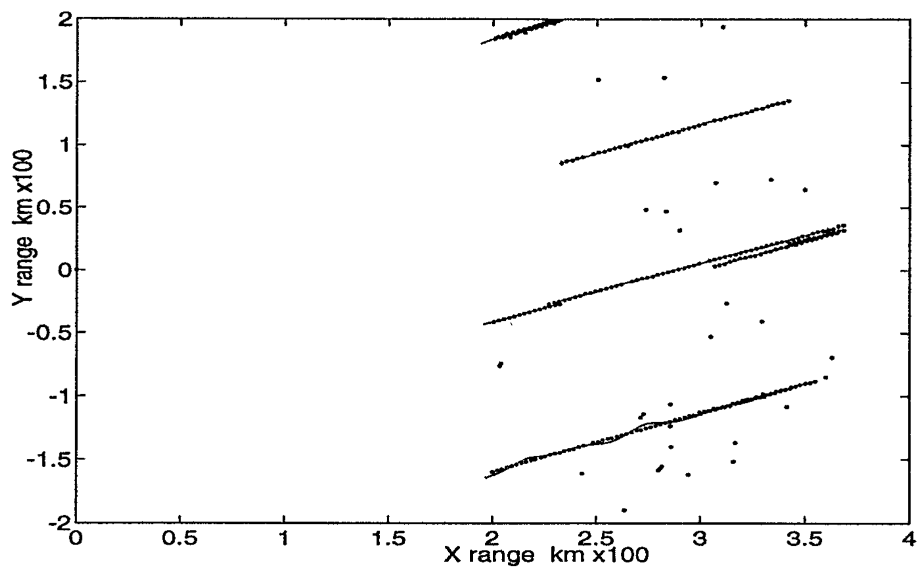

Figure 8: Tracking results based on real data using the modified Hough transform.