ROBUST TRACK & MODE IDENTITY MAINTENANCE SCHEME FOR IFF OPERATIONS

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Abstract:
Maintaining the identity of target tracks intact during garbling and code swapping is a challenging task for the radar data processing (RDP) unit of Identification of friend or foe (IFF) radar. The IFF target tracks are maintained in RDP with a unique track number and associated IFF codes. The scheme developed here for IFF track code maintenance follows novel consistency checks for track initiation and maintenance so that the IFF track codes will be maintained for occasional updating with valid wrong IFF codes. For better estimation accuracy the proposed IFF tracker uses interacting multiple model based target tracking approach. The performance of the proposed scheme is compared with instantaneous code update scheme and verified the advantage.

Key words: imm, IFF tracker, maneuvering, target tracking

I. INTRODUCTION

The majority of IFF target report may come from interference free circumstance and direct updation of plots to tracks is possible. However a portion of IFF reports may have one or the other type of errors associated with it and in such cases IFF tracker will be capable of identifying the associated errors and even be able to correct it. The first task in plot association module of IFF tracker is to match the target report with the established air target track. This process is straightforward if the codes are fully matching and are unique in a given area. If the IFF code of either the target or the track is incomplete then the association of target with the track is less obvious and it is required to follow a consistency check before updating the track with the IFF plot report.

The proposed consistency check is developed for handling three types of errors, they are 1) IFF code error due to garbling 2) IFF code error due to code swapping and 3) IFF code error due to ring around targets produced by sidelobe replies which were not suppressed. The developed IFF tracker can handle four types of IFF modes namely, i) Mode 1, ii) Mode 2 iii) Mode 3/Mode A and Mode C for height information. Because the IFF radar can operate in any of the four modes the IFF tracker is capable to initiate tracks and maintain the IFF codes with any one or with any combination of multiple reply modes. The challenge involved with IFF track initiation and maintenance are the errors in IFF plots and the possibility of IFF code change on the fly and the existence of multiple aircrafts having same Mode 3/Mode A code. These challenges are circumvented in the RDP using plot association module and the consistency check module.

Apart from track identity maintenance the other major objective of RDP is to obtain accurate positional and kinematic parameters of the target track and to achieve this Interacting Multiple model (IMM) estimator is used in this paper for target state estimation. In Multiple Model estimation, it is assumed that the possible system behavior patterns or structures, called system modes, can be represented by a set of models; a bank of filters runs in parallel at every time, each based on a particular model, to obtain the model-conditional estimates. The overall state estimate is a certain combination of these model-conditional estimates. The present paper considers an IMM filter with two models, they are :

1. Constant acceleration model (CA)
2. A nearly "Coordinated Turn" (CT) model for to handle maneuvers.

The turning of an aircraft usually follows a pattern known as "coordinated turn"- a turn with a constant turn rate and a constant speed. Although the actual turning of an aircraft is not exactly "coordinated" since the ground speed is the air speed plus the wind speed, it can be suitably described by the coordinated turn model plus a fairly small noise representing the modeling error, resulting in a nearly coordinated turn model. With the help of above two models it is possible to track most of the maneuvering targets using IMM estimation technique under the presence of moderate measurement noise.

This paper shows the performance of IMM estimator when applied to IFF radar measurements. The smoothening effect of IMM estimator is improved by robust data association scheme developed in this paper for multi mode IFF operations. The robust track and mode identity maintenance scheme with IMM technique, gives better estimation accuracy by proper model switching on the onset and offset of maneuvers.

II. TARGET TRACKING USING IMM ALGORITHM

In target tracking literature, a moving target is usually modeled by the stochastic system [2 3]

$$x_{(k+1)} = F_{(k)}x_{(k)} + G_{(k)}U_{(k)} + v_{(k)} \tag{1}$$

where $x_{(k)}$ is the n_x dimensional state vector, $u_{(k)}$ is an n_u dimension acceleration input, and the measurement process is usually modeled by

$$y_{(k)} = H_{(k)}x_{(k)} + w_{(k)} \tag{2}$$

The process noise $v_{(k)}$ and the measurement noise $w_{(k)}$ are mutually independent zero-mean, white Gaussian random sequences with covariance matrices $Q_{(k)}$ and $R_{(k)}$

respectively. The matrices F,G,H,Q and R are assumed known and can be time varying. Most tracking algorithms compute a state estimate $\hat{x}_{k/k}$ that minimizes the mean-squared tracking error at time k based on all the measurements up to time k, Z^k.

It is well known that the state estimate that minimizes the minimum mean squared error (MMSE) is given by the conditional mean

$$\hat{x}_{k/k} = E\left(x_k / Z^k\right) \tag{3}$$

If $u_{(k)}$ is a known constant, as in the case of a non-maneuvering target where $u_{(k)}$ = 0, the conditional mean estimate can be calculated using the Kalman filter. However, when $u_{(k)}$ is unknown, possibly random and jumping from one value to another, as in the case of maneuvering targets, the standard kalman filter cannot provide good estimates. It is necessary for the tracking filter to adapt itself to the new model structure when tracking a maneuvering target. The problem thus becomes one of adaptive estimation [4].

Using interacting multiple model (IMM) approach, at time k the state estimate is computed under each possible current model using r filters, with each filter using a different combination of the previous model – conditioned estimates – mixed initial condition [5].

The input to the filter matched to model j is obtained from an interaction of the r filters, which consists of the mixing of the estimates $\hat{x}^i(k-1/k-1)$ and the associated covariance $\hat{p}^i(k-1/k-1)$ with the weightings (probabilities) $\mu_{i/j}(k-1/k-1)$, called the mixing probabilities.

A brief description of one cycle of the algorithm is as follows:

Step1: Calculation of the mixing probabilities. The probability that mode M_i was in effect at k-1 given that M_j is in effect at k conditioned on Z^{k-1} is,

$$\mu_{i/j}(k-1/k-1) = P\{M_i(k-1)/M_j(k), Z^{k-1}\} \tag{4}$$

The above are the mixing probabilities, which can be written as

$$\mu_{i/j}(k-1/k-1) = \frac{1}{c_j} p_{ij}\mu_i(k-1) \tag{5}$$

Where the normalizing constants are

$$\bar{c}_j = \sum_{i=1}^{r} p_{ij}\mu_i(k-1) \quad \text{j = 1,…,r.}$$

Step2: Mixing:

Starting with $\hat{x}^i(k-1/k-1)$ one computes the mixed initial condition for the filter matched to $M_j(k)$

$$\hat{x}^{0j}(k-1/k-1) = \sum_{i=1}^{r} \hat{x}^i(k-1/k-1)\mu_{i/j}(k-1/k-1), \quad \text{j = 1,…,r} \tag{6}$$

$$P^{0j}(k-1/k-1) = \sum_{i=1}^{r}\mu_{i/j}(k-1/k-1) \times \left\{ \begin{array}{l} P^i(k-1/k-1) \\ +[\hat{x}^i(k-1/k-1) - \hat{x}^{0j}(k-1/k-1)] \\ .[\hat{x}^i(k-1/k-1) - \hat{x}^{0j}(k-1/k-1)]' \end{array} \right\} \tag{7}$$

j = 1,…,r

Step3: Mode-matched filtering.

The estimate (6) and covariance (7) are used as input to the filter matched to $M_j(k)$ which uses z(k) to yield

$$\hat{x}^j(k/k) \text{ and } \hat{P}^j(k/k) \tag{8}$$

The likelihood functions corresponding to r filters are computed using the mixed initial conditions and the associated covariance as

$$\Lambda_j(k) = p[z(k)/M_j(k), \hat{x}^{0j}(k-1/k-1), \hat{P}^{0j}(k-1/k-1)]$$

j = 1,… r

Step4: Mode probability update: This is done as follows

$$\begin{aligned} \mu_j(k) &= P\{M_j(k)/Z^k\} \\ &= \frac{1}{c} p[z(k)/M_j(k), Z^{k-1}]P\{M_j(k)/Z^{k-1}\} \\ &= \frac{1}{c}\Lambda_j(k)\sum_{i=1}^{r} p_{ij}\mu_i(k-1) \quad \text{, j=1,…,r} \end{aligned} \tag{9}$$

Step5: Estimate and covariance combination

Combination of the model-conditioned estimates and covariance is done according to the mixture equations

$$\hat{x}(k/k) = \sum_{j=1}^{r} \hat{x}^j(k/k)\mu_j(k) \tag{10}$$

$$P(k/k) = \sum_{j=1}^{r}\mu_j(k)\left\{ \begin{array}{l} P^j(k/k) + \\ [\hat{x}^j(k/k) - \hat{x}(k/k)][\hat{x}^j(k/k) - \hat{x}(k/k)]' \end{array} \right\} \tag{11}$$

This combination is only for output purposes- it is not part of the algorithm.

In this paper IMM estimator uses Coordinated turn (CT) and constant acceleration (CA) model.

1 CT Models with known/unknown Turn Rate:

The models used in IMM estimation technique presume that the target moves with (nearly) constant speed v and (nearly) constant angular turn rate ω. Assuming ω known leads to state vector, e.g., $x = [x, \dot{x}, y, \dot{y}]'$, in the Cartesian coordinates. This CT model is linear since ω is known. Its discrete time equivalent assuming period T can be found to be

$$x(k)=\begin{bmatrix}1 & \frac{\sin\omega T}{\omega} & 0 & \frac{-(1-\cos\omega T)}{\omega}\\ 0 & \cos\omega T & 0 & -\sin\omega T\\ 0 & \frac{1-\cos\omega T}{\omega} & 1 & \frac{\sin\omega T}{\omega}\\ 0 & \sin\omega T & 0 & \cos\omega T\end{bmatrix}x(k-1)$$

In the rare cases where the constant (approximately) turn rate is known a priori, the above CT model gives good tracking performance. The necessity of an exact knowledge about the value of the turn rate makes the direct use of this model unrealistic for most practical applications. A natural idea is to replace the above ω by its estimate, based on the latest velocity estimates.

2 Constant acceleration (CA) Model

Constant acceleration model assumes target is moving with constant acceleration over the given period of time. The target state vector in this case is $x=[x,\dot{x},\ddot{x},y,\dot{y},\ddot{y}]'$ and the state transition model follows the recursion

$$x(k)=\begin{bmatrix}F1 & 0\\ 0 & F1\end{bmatrix}x(k-1),\ \text{where}\ F1=\begin{bmatrix}1 & T & \frac{T^2}{2}\\ 0 & 1 & T\\ 0 & 0 & 1\end{bmatrix}.$$

III. IFF TRACKER MODULES

The developed IFF tracker consists of three major modules. The first module is the track initiation, second one is the measurement-to-track association and the third one is the consistency check. The tracker is designed to drop the track after six consecutive miss of IFF plot reports. Brief descriptions about these three modules are given in this section along with flow chart.

Track initiation: Track is initiated if there is a consistent (correlated IFF reports falling inside the gate) IFF plot report for more than two scans. The flow chart of the implementation is given in Fig. 1. The plots used for initiation are those plots which are not used for association and also not used for updating any other valid track.

Plot-to-track association: The target report parameters used to associate IFF plots to the track data are,

a) Measured range
b) Measured azimuth
c) IFF codes (Mode 1, Mode 2, Mode 3/Mode A and Mode C)
d) Height

If there is a perfect code match the corresponding IFF plot report can be used for updating the track provided the position of the plot falls inside the gate area of the track. If the code matched plot is falling outside the gate there is a possibility of aircraft maneuver or there is another aircraft having same IFF code. The aircraft maneuver can be tested by increasing the gate to find out still the plot falls inside the gate or not. The limit to which the gate size is increased is limited with the maneuver capabilities. The new target confirmation will be done by consistent observation of the plot having same valid IFF code. The flow chart of the plot-to-track association scheme is given in Fig. 2.

If there is no valid code matched plot for a track the track will not be updated with any other plot having valid IFF code, but will be allowed to update with any invalid plot or allowed to coast.

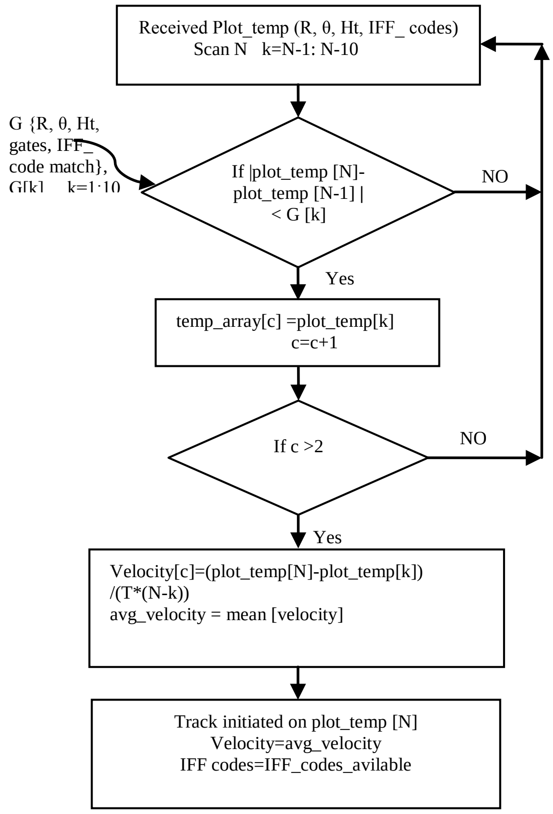

Figure 1. IFF Track initiation by checking code matched IFF reports.

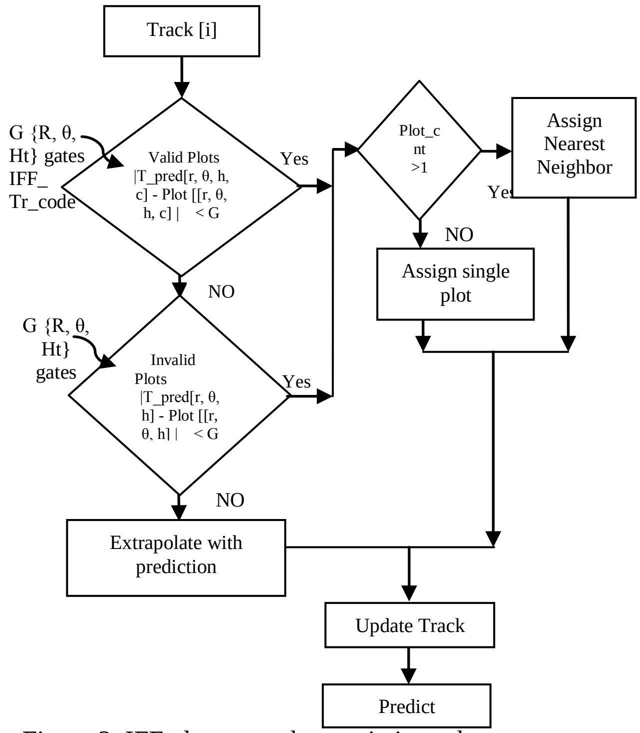

Figure 2. IFF plot-to-track association scheme.

This restriction in data association gives robustness to the proposed approach against code swapping. More over the

IFF track will be maintained with correct IFF code in garbled condition.

Consistency check: On the fly, aircrafts may be allowed to change the IFF code [1] or the query can be to answer in a new mode. In the first case an established IFF code attached with a track has to be changed and in the second case IFF code for a new mode has to be identified. The developed approach assumes the IFF codes in a particular mode will not change rapidly or at least a minimum number of stay is guaranteed. With this assumption the proposed approach is flexible to IFF code change on the fly and capable to handle multiple modes of IFF operation.

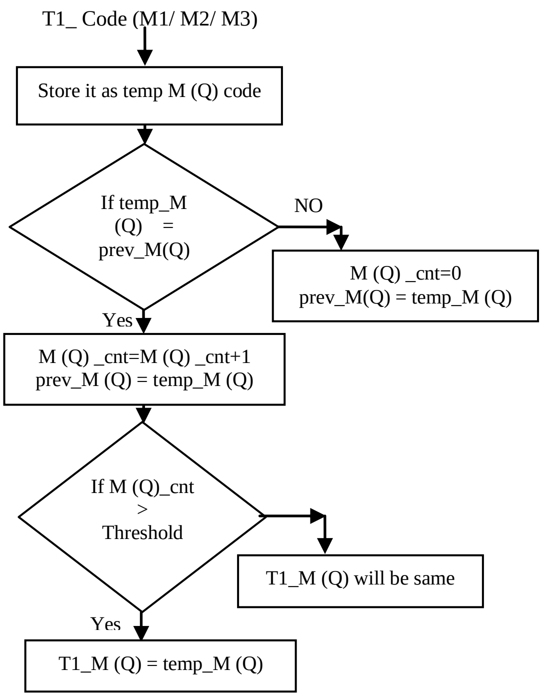

Figure 3. IFF code consistency checking scheme.

In Fig. 3 Threshold is a design parameter and in the simulations done in this paper uses threshold as 5.

IV. SIMULATION RESULTS

In order to verify proposed approach we considered the two simulation scenarios. The first scenario consists of two targets crossing each other the initial range of target T1 is 20 km at an azimuth angle of 60 degrees with velocity of 150m/s with Mode 3 code as 1478 heading angle is 90 degrees. Initial Range of target T2 is 20 km at an azimuth angle of 90 degrees with velocity of 150m/s with Mode 3 code as 1500 heading angle is 60 degrees respectively. The trajectory in polar plot is shown in Fig. 4(a).

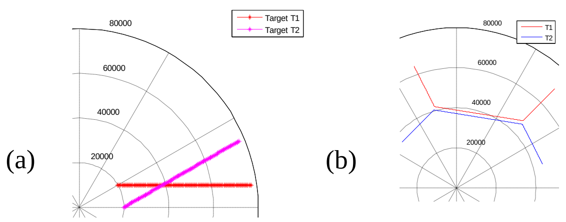

Fig 4. Input Scenarios. (a) Scenario1 (b) Scenario 2.

The second simulation scenario consists of two targets moving parallel to each other with a same speed. Initial Range of target T1 is 70 km at an azimuth angle of 45 degrees with velocity of 150km/hr with Mode 3 code as 1478 heading angle is 225 degrees. Initial Range of target T2is 45 km at an azimuth angle of 75 degrees with velocity of 150km/hr with Mode 3 code as 1500 heading angle is 333 degrees. Trajectory in polar plot is shown in Fig. 4(b).

Case 1: On the fly code change:

To simulate the on the fly code change condition the target T1 is assumed to be moving as shown in Fig. 4(a) and having a Mode 3 code as 1478, later the target stops replying through code M3 and assumed to be replying through code M1 as 1200 and further again on the fly it changes M1 code to be 1300. Figure 5 (a) shows the presence of codes during targets motion.

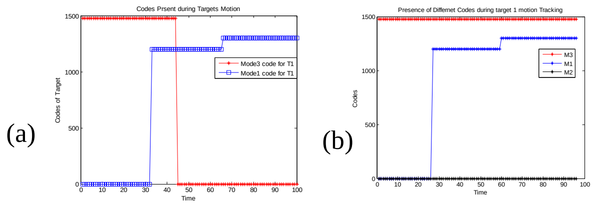

Fig 5. Input Scenario

The tracker changes gives robustness to the identity of the target track by continuously providing Mode 3 code. On the other hand the developed logic allows the Mode 1 code (M1) to change on the fly. The IFF code output is as shown in Fig. 5 (b).

Case 2: Ring around condition

In order to verify consistency check a scenario is developed where IFF code error happens due to ring around targets produced by side lobe replies which were not suppressed. For this case the target is assumed to be moving with speed of 150 m/s at an initial range of 25 km with a heading of 225 degrees at an angle of 45degree with mode 3 code as 1500. The measurements (red dots) and the estimated trajectory (blue) are shown in Fig. 6 (a).

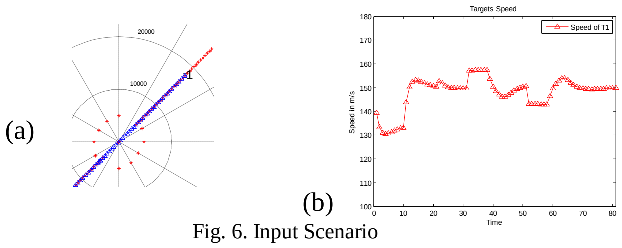

Fig. 6. Input Scenario

The velocity variations are shown in Fig. 6 (b). The error in estimated trajectory and the velocity are maintained well within the limit.

Case 3: Code Swapping

Code swap can be caused when two targets are very close in position as shown in Fig. 7 (a).

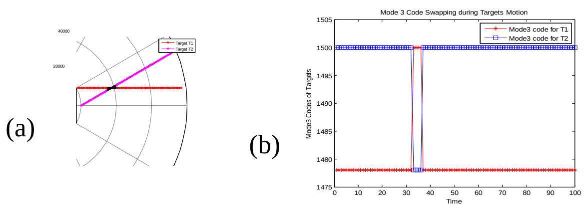

Fig 7. Variations of Range Error

In order to simulate the code swap condition the simulation scenario1 is considered where targets T1 and T2 are crossing each other as shown in figure 7(a) with code swap region in black color. The code swap is shown in Fig. 7(b). The simulation scenario2 is also simulated for IFF code error due to swapping here it is assumed that code swap has happened twice. Figure 8 (a) shows code swap for scenario 2 and Fig. 8(b) shows the tracked output code.

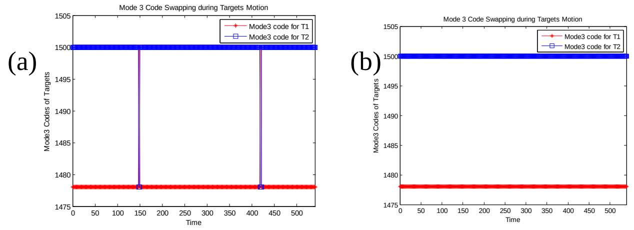

Fig 8. (a) In put to the tracker with code swap. (b) Track output with rectified codes

Improved positional and kinematics accuracies are achieved in this paper using IMM based state estimation technique. To verify the advantage the RMS value of positional error and the heading values are plotted in Fig. 9 (a) and Fig. 9(b) respectively with standard Kalman filter and IMM filter for scenario 2.

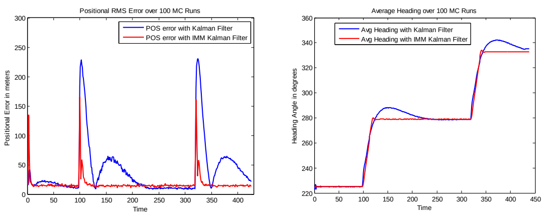

Fig 9. (a) Positional RMS error for 100 M.C runs. (b) RMS value of Heading for 100 M.C. runs.

The simulation results shows improved estimation accuracies can be achieved with the proposed IMM based technique along with IFF tracker modules developed in this paper. The IMM technique decreases the delay in estimation particularly during maneuver time and provides accurate target parameters instantaneously and the IFF tracker consistency modules ensures correct plot-to-track association.

V CONCLUSION

The IFF tracker modules developed in this paper are useful for preventing code swapping when targets are nearby. The technique is also useful for achieving robust track identity maintenance in case of garbling and ring around IFF reports. The IMM algorithm is explained with mathematical expressions and modules in IFF tracker are described with the help of flow charts. The IFF modules along with IMM estimation techniques give accurate track parameters when multiple targets maneuvers in a group. The Monte Carlo simulation results verify the advantage of the proposed approach in target crossing and target maneuver scenarios.

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REFERENCES

[1] E.Mazor, A. Averbuch, Y.Bar-Shalom and J. Dayan, "Interacting Multiple Model Methods in Target tracking: A Survey", IEEE transaction on Aerospace and Electronic Systems Vol 34, No1 January 1998.

[2] A. Houles, Y-Bar-Shalom, "Multisensor Tracking of a maneuvering Target in clutter", IEEE Transcations on Aerospace and Electronic System, March 1989.

[3] Moose R.L. "An adaptive state estimation solution to the maneuvering target problem, IEEE Transcations on Automatic Control, June 1975, 359-362.

[4] R.A. Singer, "Estimating optimal tracking performance for manned maneuvering targets", IEEE Transcations on Aerospace and Electronic System, July 1970, 473-483.

[5] Wolfgang koch," Fixed-interval retrodiction approach to Bayesian IMM-MHT for maneuvering multiple targets", IEEE Transcations on Aerospace and Electronic System, January 2000.

[6] Y.Bar-shalom, K.C. Chang, H.A.P. Blom, "Tracking a maneuvering target using input estimation versus the interacting multiple model algorithm", IEEE Transcations on Aerospace and Electronic System, March 1989.

[7] Qiao Xiangdong, Wang Baoshu, "A motion model for tracking highly maneuvering targets",IEEE 2002.

[8] X.Rog Li and Vesslin P. Jilkov. "A Survey of Maneuvering Target tracking – Part V: Multiple Model Methods", IEEE Transcations on Aerospace and Electronic System, November 2003.for tracking highly maneuvering targets", IEEE 2002.

[9] Michael C. Stevens, "Secondary surveillance radar", Artech house, 1988.

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