Toward Adaptive Initialization of New Tracks in MTT Systems

Nemanja Mitrović[1] and Zeljko Djurović[2]

***Abstract* – Environment topology in multiple target tracking (MTT) systems has important influence on initialization of new tracks. This paper presents functional analysis of MTT system block responsible for initialization of new sources. Having in mind relief topology as a static radar environment, the aim of presented analysis is to reduce false targets tracks with simultaneous preserving of real tracks confirmation. This goal is achieved by estimation of new source density and adjusting the initialization procedure based on this estimate. The efficiency of proposed procedure is demonstrated through computer simulations. The obtained results may be used to improve the efficiency of radar or sonar systems or any other sensors network that performs multiple target tracking.**

***Keywords* – Multi Target Tracking (MTT), Radar System, Digital Signal Processing.**

I. INTRODUCTION

Multi target tracking (MTT) is essential requirement for surveillance systems employing one or more sensors together with computer subsystem to interpret the environment [1]. Sensors systems are radars, sonar, infrared thermal cameras, and etc [2]. Mainly, MTT has two tasks - to interpret the targets of interest and to interpret the background noise sources such as radar ground clutter, internal error sources (thermal noise), environment topology, and etc. Environment topology in MTT systems has important influence on initialization of new tracks. This paper presents functional analysis of MTT system block responsible for initialization of new sources. Having in mind relief topology as a static radar environment, the aim of presented analysis is to reduce false targets tracks with simultaneous preserving of real tracks confirmation.

Basically, sequential MTT consists of five components: sensor data processing and measurement formation, data association (correlation), track initialization, confirmation, and deletion, filtering and prediction, and gating [3]. Connections between components are very strong so there is no clear distinction between the boundaries. Sequential MTT as any other realization type of MTT require a lot of calculations and memory space [7]. Next section gives short description of each specific MTT component.

Reducing false targets tracks is achieved by estimation of new source density and adjusting the initialization procedure based on this estimate. The efficiency of proposed procedure is demonstrated through computer simulations. The obtained results may be used to improve the efficiency of radar or sonar systems or any other sensors network that performs multiple target tracking.

II. MTT ARCHITECTURE (STRUCTURE)

Basic MTT architecture could be distributed to five functional blocks presented on Fig. 1.:

1) Sensor data processing and measurement formation
2) Data association (correlation)
3) Track initialization, confirmation, and deletion
4) Filtering and prediction
5) Gating.

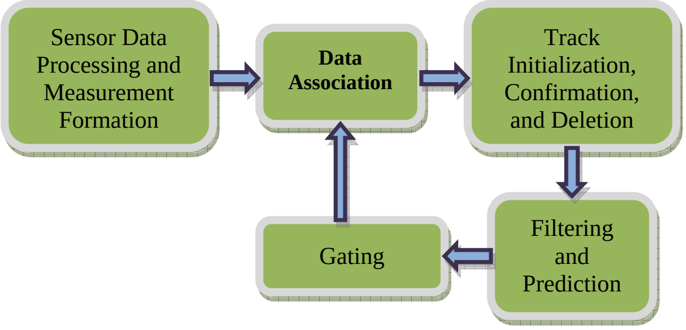

Fig. 1. Sequential MTT block diagram

Once confirmed observation initiated new track. MTT predicts new positions of observations for all active tracks and create gates around new positions. Correlation process performs association between new observation and existing track according to norm *d* as:

$$d = \left| y_i - \overline{y_i} \right|, \tag{1}$$

where y_i measured observation position at i^{th} sample time and $\overline{y_i}$ predicted observation position at i^{th} sample time. For 2D case relation (1) could be defined as:

$$d^2 = \frac{(R_0 - R_p)^2}{\sigma_R^2} - \frac{(\theta_0 - \theta_p)^2}{\sigma_\theta^2}, \tag{2}$$

where R_0 and Rp are existing and predicted target radial components, θ_0 and θp are existing and predicted target azimuths, and σ_R and σ_θ are residual variance of target radial component and azimuth. Also, it is useful to define residual standard deviation σ_r as:

$$\sigma_r = \sqrt{\sigma_0^2 + \sigma_p^2}, \tag{3}$$

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where σ_0 and σ_p are standard deviation of existing target position and prediction error.

A. Data Association (Correlation)

Most sensitive part of MTT is data association – correlation [8]. The correlation function takes the inputs from of the gating function and makes final observation-to-track data assignment. Basically, data association problem has two approaches: all neighbors (AN) and nearest neighbor (NN). For each approach there are many techniques dedicated to improve performance data association. It is very difficult to obtain optimal solution for this problem, so most of techniques are suboptimal. Here, is presented one technique of NN approach, in [1] called suboptimal solution one.

Data association process starts with formation of assignment matrix. Assignment matrix fields are norms *d* of observations to centers of predicted gates of existing tracks, according to the relation (1). This way, one dimension of assignment matrix is equal to number of observation and other to number of tracks. Next step in data association is association matrix search and association by six rules.

1) An observation that validates with a singly validated track is rejected by multiply validated track.
2) A multiply validated observation is rejected by any track that validates with singly validated observation.
3) Whether or not a track is multiply validated is determined again after each application of Rule 1 affecting it. A track that becomes singly validated is again subject to Rule 1.
4) Whether or not an observation is multiply validated is determined again after each application of Rule 2 affecting it. An observation that becomes singly validated is again subject to Rule 2.
5) For each remaining multiply validated track, choose the observation with minimum distance.
6) For each remaining multiply validated observation, choose the track with minimum distance.

B. Track Initialization, Confirmation, and Deletion

The second step in MTT processing is track initialization, confirmation and deletion. One of many techniques that obtain it is sequential probability ratio test (SPRT). SPRT propose two hypotheses:

H_0 – no true target is present, so return is from false alarms or clutter.

H_1 – a true target is present.

SPRT accept one of three possible choices: (1) accept H_0 (2) accept H_1 (3) defer decision for some next sampling period. The likelihood functions of H_0 and H_1 after k subsequent scans with particular sequence of m detections are:

$$\begin{aligned} P_{0,k} &= P_F^m \cdot \left(1-P_F\right)^{k-m}, \\ P_{1,k} &= P_D^m \cdot \left(1-P_D\right)^{k-m}, \end{aligned} \tag{4}$$

where P_F and P_D are detection probabilities of false and true targets. Now, likelihood ratio U_k is defined as:

$$U_k = \frac{P_{1,k}}{P_{0,k}}, \tag{5}$$

SPRT test U_k likelihood ratio respect to C_1 и C_2 thresholds:

$$C_1 = \frac{1-\beta}{\alpha}, C_2 = \frac{\beta}{1-\alpha}, \tag{6}$$

where α is probability of accepting H_1 when H_0 is true and β is probability of accepting H_0 when H_1 is true. Formulation of SPRT is:

1) If $U_k \le C_1$ accept H_0.
2) If $U_k \ge C_2$ accept H_1.
3) If $C_1 \le U_k \le C_2$ continue testing.

C. Filtering and Prediction

Idea of reducing false targets tracks with simultaneous preserving of real tracks confirmation is achieved by estimation of new source density β_{NS} and adjusting the initialization procedure based on this estimate. This improvement of MTT is embedded in *α-β-γ* tracker. Standard target parameters that are subject of *α-β-γ* tracker estimation are position, speed, and acceleration are extended with estimation of new source density. Equations that describe extended α-β-γ tracker are:

$$\begin{aligned} x_s(k) &= x_p(k) + \alpha \cdot \left(x_0(k) - x_p(k)\right), \\ v_s(k) &= v_s(k-1) + T \cdot a_s(k-1) + \frac{\beta}{qT} \cdot \left(x_0(k) - x_p(k)\right), \\ a_s(k) &= a_s(k-1) + \frac{\gamma}{(qT)^2} \cdot \left(x_0(k) - x_p(k)\right), \\ x_p(k+1) &= x_s(k) + T \cdot v_s(k) + \frac{T^2}{2} \cdot a_s(k), \\ \beta_{NS,s}(k) &= \beta_{NS,p}(k) + \delta \cdot \left(\beta_{NS,0}(k) - \beta_{NS,p}(k)\right), \\ \beta_{NS,p}(k+1) &= \beta_{NS,0}(k), \end{aligned} \tag{7}$$

where T=1s is sampling period, α, β, and γ filter fixed coefficients, q parameter which value is 1 when at least one observation pass gating test, or value of number scans without target presents, x target position, v target speed, a target acceleration, and β_{NS} new source density. Indexes *s* indicate estimated state of vector, indexes *p* indicate predicted state of vector, and indexes *0* indicate measured state of vector.

Standard set of initialization parameters is:

$$\begin{aligned} & x_s(1) = x_p(2) = x_0(1), \\ & v_s(1) = a_s(1) = \alpha_s(2) = 0, \\ & v_s(2) = \frac{x_0(2) - x_0(1)}{T}, \\ & a_s(3) = \frac{x_0(3) + x_0(1) - 2 \cdot x_0(2)}{T^2}, \\ & \beta_{NS}(0) = 0. \end{aligned} \tag{8}$$

All calculations in this paper are performed for standard set of filter coefficients [1]:

$$\begin{aligned} &\alpha \le 0.6, \\ &\beta = 2\cdot\left(2-\alpha\right) - 4\cdot\sqrt{1-\alpha}, \\ &\gamma = \frac{\beta^2}{2\cdot\alpha}. \end{aligned} \qquad (9)$$

D. Gating

The gates are forming around the predicted tracks positions. One simple gating technique is rectangular technique that is defining as:

$$d = \left|y_i - \overline{y_i}\right| \le K_{Gi}\cdot\sigma_r\,, \qquad (10)$$

where σ_r target residual standard deviation given with relation (3), K_{Gi} the gating constant of i^{th} track. Assuming the Gaussian error model, it is possible to adopt same gating constant K_G for all tracks.

Define probability of correct decision P_{CD} as:

$$P_{CD} = P_D\cdot P_{CC/D} + \left(1-P_D\right)\cdot P_{NE/D}\,, \qquad (11)$$

where P_D is detection probability, $P_{CC/D}$ is probability of correct correlation, $P_{NE/D}$ is probability of no correlation.

Probability of correct correlation $P_{CC/D}$ refers to state of detection when the true target occurs:

$$P_{CC/D} = \left[C\cdot erf\left(\frac{K_G}{\sqrt{2\cdot C}}\right)\right]^2, \qquad (12)$$

where constant C is defined by next relation:

$$C = \frac{1}{\sqrt{1+\frac{\pi}{2}\cdot n_{TF}}} \qquad (13)$$

Probability of no correlation $P_{NE/D}$ refers to state of detection when the false alarm satisfy gate:

$$P_{NE/D} = e^{-n_{TF}\,\square K_G^2}\,, \qquad (14)$$

where n_{TF} is dimensionless variable that represent expected number of false returns within track gates. Quantity n_{TF} defines as:

$$n_{TF} = \beta_{NS}\cdot\left(2\cdot\sigma_{r,R}\right)\cdot\left(2\cdot\sigma_{r,\theta}\right) \qquad (15)$$

Standard MTT systems assume new source density β_{NS} as a static parameter of radar system. Nature of new source density β_{NS} is more complex and except it depends on hardware platform it is also depends on relief topology. Variation of new source density respect to relief topology affects on gates that has influence on correlation and new tentative track initialization.

After several algebras transformations (11-15) with maximization probability of correct decision in equation (11), the gating constant is:

$$K_G = \sqrt{\frac{b^2}{4\cdot c^2} - \frac{a}{c}} - \frac{b}{2\cdot c}\,, \qquad (16)$$

where a, b, c are given as:

$$\begin{aligned} &a = \ln\left[\frac{2+n_{TF}-2\cdot P_D}{\left(2+n_{TF}\cdot\pi\right)\cdot P_D}\right], \\ &b = 0{,}14\cdot\sqrt{1+\frac{n_{TF}\cdot\pi}{2}}\cdot a + n_{TF}^2 = \frac{4}{\pi}\cdot\sqrt{1+\frac{n_{TF}\cdot\pi}{2}}, \\ &c = 0{,}07\cdot\left(1+\frac{n_{TF}\cdot\pi}{2}\right)\cdot\left(1-n_{TF}\right). \end{aligned} \qquad (17)$$

III. RESULTS AND DISCUSSION

The efficiency of toward adaptive initialization of new tracks in MTT systems is demonstrated through computer 2D simulations. It is simulated crossing maneuver condition of four targets. Further, maneuver area were distributed to four areas with different new source density that are simulated relief in real condition. Reflected signals from inhomogeneous relief structure (stones, hills, woods, and water) produce false alarm signals in MTT systems.

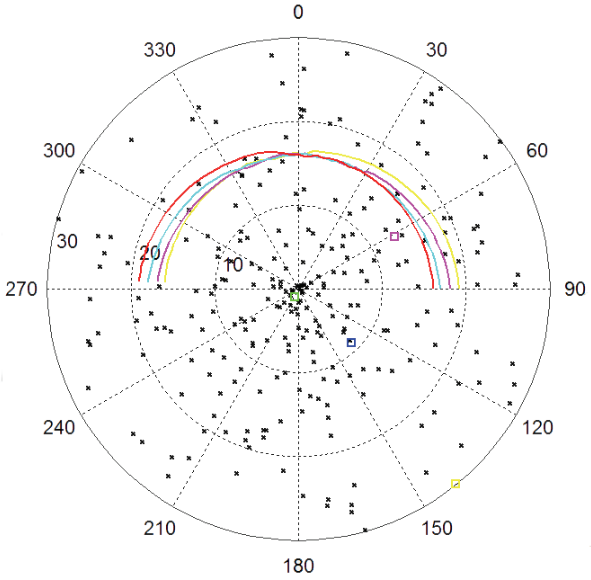

Fig. 2. Simulation of MTT tracking in homogeny field

Fig. 2. presents simulation of MTT tracking four maneuvering targets in homogeny filed. Solid lines present target tracks, rectangles new sources, and x-es present false alarms that are product of MTT clutter. Each scan results with true targets observations and false alarm observation. Large number of false alarms is consequence of large number of scans.

Initial targets positions are on 90 of azimuth and targets are moving in CCW direction. Targets are located far from the radar 15-20 km, and less than 3 m between each other. All tracking range could be divided to three areas: beginning, middle, and ending area. In the beginning area of tracking, targets are enough away from each other and allow quality tracking. The same goes for the ending area. In the middle tracking area, targets are so close and quality of tracking is not on the maximal level. It is possible to say that MTT is functioning on threshold of detection in the middle area.

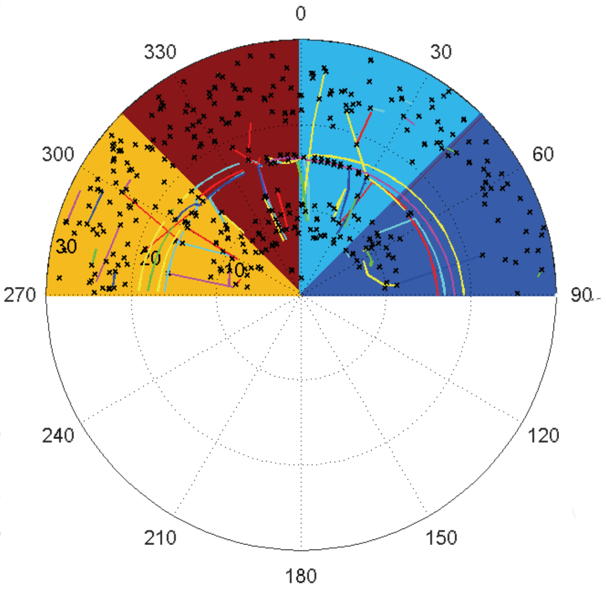

Fig. 3. Simulation of MTT tracking in inhomogeneous relief structure

Fig. 3. presents simulation of MTT tracking four maneuvering targets in inhomogeneous relief structure. Tracking area from Fig. 2. is distributed to four area with different new source density. Initially, the new source density has lowest value and slightly increasing to the end, one by one area. As it was expected, tracking is best at the first area. Number of false alarm that initiated new tracks in this area is 6. In the second area, tracking is significant disturbed and some targets could not be tracked. Reasons are increasing of new source density and closeness of targets. Number of false alarm that initiated new tracks in this area is 9. In the third area, new source density is more increased and that reflected with short losing of tracking. Number of false alarm that initiated new tracks in this area is 10. In the last area, where new source density is even more increased, short losing of tracking is again present. Number of false alarm that initiated new tracks in this area is 13.

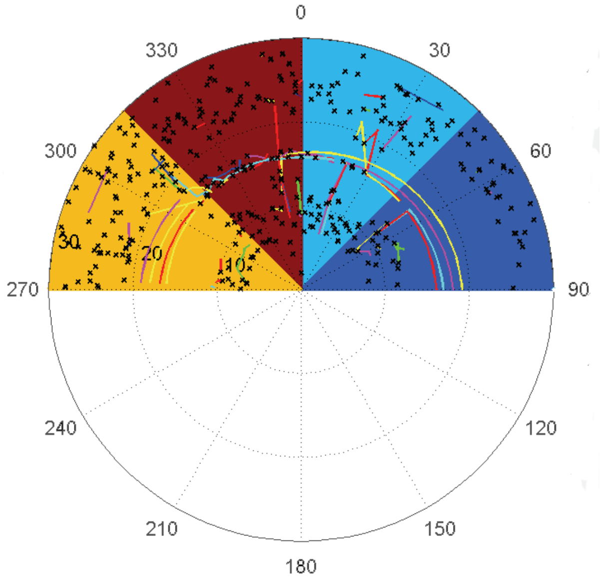

Fig. 4. Simulation of MTT tracking in inhomogeneous relief structure with estimation of new source density

Fig. 4. presents simulation of MTT tracking four maneuvering targets in inhomogeneous relief structure with estimation of new source density. Results of the new source density estimation, improves quality of true targets tracking. Number of false alarm that initiated new tracks is reduced from 6 to 4 at the first segment, from 9 to 7 at the second, from 10 to 9, and from 13 to 9 at the last. It is important to note that many of false initiated tracks are in the relief segment transient areas. With further filtering of transient areas, number of false alarm that initiated new tracks is reduced from 6 to 3 at the first segment, from 9 to 5 at the second, from 10 to 8, and from 13 to 8 at the last.

IV. CONCLUSION

General conclusion is that toward adaptive initialization of new tracks, achieved by estimation of new source density, could partial depress false targets caused by relief topology of sensor environment and improves the efficiency MTT systems. Obtained results may be applied on radar or sonar systems or any other sensors network that performs multiple target tracking.

ACKNOWLEDGEMENT

This work was supported in part by the Ministry of Science of Serbia within the Project “Research and development solutions to improve the performance of wireless communication systems in the microwave and millimeter frequency range”, project N0. TR-32052.

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