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Multi-model target tracking with fuzzy logic maneuver detector

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Abstract: Target tracking problem for vessel traffic systems with 2D radars is discussed. Conditions of small high-maneuver vessels tracking crash are shown. Algorithm for robust track-while-scan tracking based on Sugeno fuzzy logic maneuver detector is considered.

Keywords: vessel traffic system, target tracking, radar measurements, Sugeno fuzzy logic system, trace estimation.

Introduction

The most important task of vessels navigation is to ensure safety of navigation in areas of high traffic density. The solution to this problem is involved the automated vessel traffic system (VTS), which includes facilities of detection, measurement, data transmission and data processing. Analysis, interpretation and visualization of information are performed by the system too.

2D radar is the main information element of the VTS on the sea.

To prevent vessels collisions on the sea estimate extrapolated coordinates of each vessel are generated. With help of these coordinates and special target tracking algorithm we can determine the possibility of collision.

Well-known algorithms to improve the accuracy of a target tracking are based on the α - β filter and the Kalman filter.

In this paper is considered multi-model target tracking algorithm based on the α - β [2] filter with numerous measurements used to forming an assess state. The choice of the most appropriate assess state is carry out by using of fuzzy logic.

$\alpha-\beta$ Tracker

The model of target tracking is described by this formula:

$$x(k+1) = x(k) + v_x(k)\tau + q_x(k),$$
$$y(k+1) = y(k) + v_y(k)\tau + q_y(k) \quad (1)$$

k is the sequence number at time (t); $x(k), y(k)$ are target coordinates at time $(t_k); q_x(k), q_y(k)$ - random motion parameters; $\tau = t_{k+1} - t_k$.

The model can be represented by a discrete matrix equation "the state – the measurement":

$$x_{k+1} = \Phi x_k + q_k,$$
$$z_k = Hx_k + r_k. \quad (2)$$

$x_k = (x(k), v_x(k), y(k), v_y(k))^T$ - the target vector state; T – the transposition operation symbol; q_k - the vector of random motion parameter;. z_k - the measurements vector; r_k - the measurement errors vector.

The matrix coefficients are equal to:

$$\Phi = \begin{Vmatrix} 1 & \tau & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & \tau \\ 0 & 0 & 0 & 1 \end{Vmatrix}, \; H = \begin{Vmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{Vmatrix}$$

The model of the vector state estimation can be represented by the following formula:

$$\hat{x}_{k+1} = \Phi\hat{x}_k + K(z_{k+1} - H\Phi\hat{x}_k) \quad (3)$$

$\hat{x}_k$ - the vector state assessment; K - the $\alpha - \beta$ algorithm coefficient of the matrix (see formula 4).

$$K = \begin{Vmatrix} \alpha & 0 \\ \beta/\tau & 0 \\ 0 & \alpha \\ 0 & \beta/\tau \end{Vmatrix} \quad (4)$$

Relation of coefficients is optimal when the expression is used: $\beta = \alpha^2/(2-\alpha)$.

These coefficients are chosen by the following rule:

$$\alpha_k = \frac{2(2k+1)}{(k+2)(k+1)}, \; \beta_k = \frac{6}{(k+2)(k+1)}$$

Let J the number of procedure iterations of the formula 3 to estimate the vector state and let the expression $\hat{x}_i^{(J)}$ is the vector state assessment at time t_i then we will have vectors cortege of the estimate:

$$\hat{X}_i^{(J)} = \{\hat{x}_i^{(2)},\ \hat{x}_i^{(3)},\ \hat{x}_i^{(4)},\ \ldots,\ \hat{x}_i^{(J)}\} \quad (5)$$

Thus the task of target tracking comes to the choice the vector state from the cortege.

The method of solving the problem

Let the vector $\delta z_{k+1} = z_{k+1} - H\hat{x}_{k+1}$ is describing the error of the measurement assessment of the vector state and let $\|\delta z\|_i^{(J)}$ is Euclidean norm of the error vector.

Thus we have a norms cortege of errors vectors:

$$\delta_i^{(J)} = \{\|\delta z\|_i^{(2)},\ \|\delta z\|_i^{(3)},\ \|\delta z\|_i^{(4)},\ \ldots,\ \|\delta z\|_i^{(J)}\} \quad (6)$$

To analyze the target tracking quality lets to pass to a cortege of relative values:

$$\Delta_i^{(J)} = \left\{L_i^{(2)}, L_i^{(3)}, L_i^{(4)}, \ldots, L_i^{(J)}\right\} \quad (7)$$

$$L_i^{(j)} = \frac{\|\delta z\|_i^{(j)}}{\sigma};$$ σ - quantity that characterizes the roof-mean-square deviation of measurement error in the system.

Let $Q_i^{(j)}$ is a linguistic variable with terms «Good» and «Bad» that are defined on the universal set $u \in [0,3]$ (see figure 1).

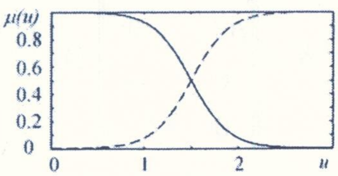

Figure 1. Membership functions of terms «Good» (solid line) and «Bad» (dash line)

$$\mu_{good}(u) = 1 - \frac{1}{1+\exp(-a(u-c))},$$

$$\mu_{bad}(u) = \frac{1}{1+\exp(-a(u-c))}.$$

Suppose that $Q_i^{(j)}$ variables are treated by Sugeno fuzzy logic engine [1]. Input parameters is the cortege of relative values (see formula 7), and the output is m_i that is the number of vector state chosen from the cortege (see formula 5). The engine operates according to a fuzzy logic inference rules system, presented in table 1.

Table 1. fuzzy logic inference rules system

The work of target tracking by Sugeno fuzzy logic algorithm is show in Figure 2.

№	$Q_i^{(2)}$	$Q_i^{(3)}$	$Q_i^{(4)}$	…	$Q_i^{(J-1)}$	$Q_i^{(J-1)}$	$Q_i^{(J)}$	m
1	G	G	G	…	G	G	G	J
2	G	G	G	…	G	G	B	$J-1$
3	G	G	G	…	G	B	B	$J-2$
…	…	…	…	…	…	…	…	…
$J-1$	G	G	B	…	B	B	B	3
J	G	B	B	…	B	B	B	2
$J+1$	B	B	B	…	B	B	B	2

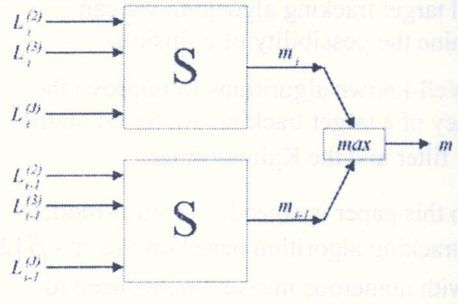

Figure 2. The diagram of the target tracking by Sugeno fuzzy logic algorithm

The modeling results

Figure 4 shows the modeling vessel track. Initially, the vessel is moving rectilinear, and then turns with a radius of 300m.

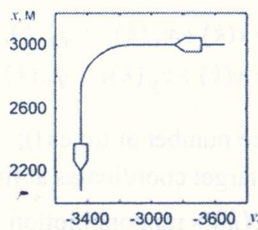

Figure 4. The vessel track

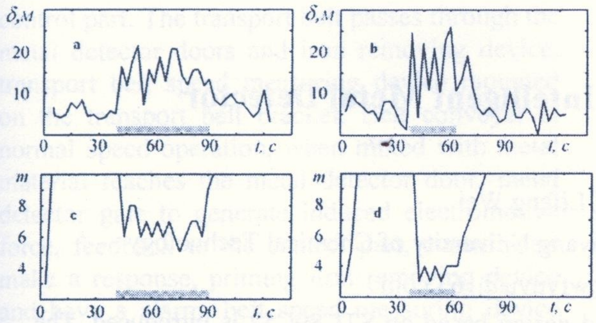

Figure 5. The tracking algorithm; dashes on the horizontal axis shows a part of the vessel maneuvering

Figure 5 shows the result of solving the problem of vessel tracking that is moving along the track at a speed of 10 m/s (the left column of figures) and 20 m/s (the right column of figures). A t symbol is a time elapsed from the beginning of the vessel tracking, δ - error of estimation the vessel moving (Figure 5a and Figure 5b).

By vessel rectilinear moving the algorithm operates with the maximum value of m, and when the vessel turn the $m = 5$ (Fig. 5c) and $m = 3$ (Figure 5d).

The algorithm responds quickly when vessel direction is changing.

Conclusion

The proposed model will significantly reduce the chance of a target tracking failure. The results of the work are focused on automating and expanding the functions of modern VTS.

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