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Tracking a Maneuvering Target using AUV

P. Dhatri Shree, M. Ajay Kumar, M. Sai Charan, S. Koteswara Rao, Kausar Jahan

Abstract*: In this paper effort is made to track a maneuvering target using Unmanned Aerial Vehicles (UAV) with range, bearing and elevation measurements. Extended Kalman filter is preferred to processmeasurements tampered with noise. Algorithm to detect the maneuver of target is developed in this paper. This information about range, bearing and elevation is communicated to weapon guidance station by means of personal communication system between UAV and weapon guidance station. Mathematical modeling in detail and simulation results is presented.

Keywords*: Estimation, Extended Kalman Filter, Maneuvering Target Motion Analysis, Three-Dimensional tracking, Unmanned aerial vehicle.

I. INTRODUCTION

This aerial vehicle (UAV) is the safest airborne warfare system existing in the world today. UAV is a robot-like system flying in air mainly used in target tracking. It sends radio waves to track the target parameters like range, bearing and elevation. UAV now-a-days are GPS equipped so that weapon guidance system of UAV will have knowledge about position of UAV. Weapon guidance system may be a ship on the surface or an aircraft in air. Data received from UAV is sent to weapon guidance system by means of a personal communication system so that weapon guidance system will be able to know the position and motion of target and releases weapon in that direction. Target tracking is carried out using Extended Kalman filter (EKF). Target motion parameters particularly at long ranges are nonlinear. So, EKF is considered based on rapidly convergent and unbiased filter problems in Kalman Filter [9-17].

Tracking of the target is carried out by Extended Kalman filter (EKF) [3-9]. In this paper, the main contribution is tracking of a maneuvering target, as suggested in [4, 5]. Target maneuver cannot be visualized easily by observing bearing residual plot. So, zero mean chi-square distributed random sequence residuals in sliding window is used for detecting maneuver of the target. Normalized squared innovation process is used to find out whether target is maneuvering or not. To get the finest solution during target maneuver enough amount of process noise is added to the covariance. When the maneuver is completed, state noise is lowered back. Bearing and elevation measurements are non-linearly related to the state of the target parameters making the process non-linear. So, the optimal linear filters like Kalman filter is not suitable for three–dimensional tracking of target. For simplicity of the process, the target is assumed to be travelling with constant speed and maneuvers in its course. The plant noise considered is white Gaussian noise generated due to disturbance in the velocity of target.

Section II contains with mathematical modeling and implementation of the process. Section II also deals with generation of measurements in simulation environment. Sections III describe simulation and the results obtained. The paper is concluded in Section IV.

II. MATHEMATICAL MODELING

A. General Simulator model

Author Let initial position of the target and observer be (x_t, y_t, z_t) and (x_0, y_0, z_0), assuming that they move with velocities v_t and v_0. After t seconds, change in observer position is given as follows.

$$dx_0 = v_0 \sin(ocr) \sin(oph)\ t \tag{1}$$

$$dy_0 = v_0 \cos(ocr) \sin(oph)\ t \tag{2}$$

$$dz_0 = v_0 \cos(oph)\ t \tag{3}$$

Here oph and ocr are pitch and course of the observer respectively. The changed observer position is given as follows.

$$x_0 = x_0 + dx_0 \tag{4}$$

$$y_0 = y_0 + dy_0 \tag{5}$$

$$z_0 = z_0 + dz_0 \tag{6}$$

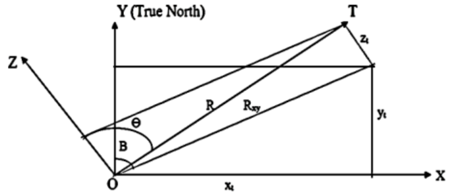

Fig.1.Target and observer positions

Similarly, from Fig.1.

$$x_t = R_{xy} \sin(B) \tag{7}$$

$$y_t = R_{xy} \cos(B) \tag{8}$$

$$\sin(\Theta) = R_{xy}/R \tag{9}$$

Substituting (35) in (33) and (34),

$$x_t = R\ \sin(\Theta)\ sin(B) \tag{10}$$

$$y_t = R\ \sin(\Theta)\ cos(B) \tag{11}$$

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* Correspondence Author

P. Dhatri Shree, B. Tech Student, Department of Electronics and Communication Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, A.P, India.

M. Ajay Kumar, B. Tech Student, Department of Electronics and Communication Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, A.P, India.

M. Sai Charan, B. Tech Student, Department of Electronics and Communication Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, A.P, India.

S. Koteswara Rao, Professor, Department of Electronics and Communication Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, A.P, India.

***Kausar Jahan,** Research Scholar, Department of Electronics and Communication Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, A.P, India. Corresponding

$$z_t = R\cos(\Theta) \tag{12}$$

Fig.2.Target and observer velocities

When the target is in motion with velocity v_t, change in target position after t seconds, from Fig.2, is given as follows.

$$dx_t = v_t \sin(tcr)\sin(tph)\ t \tag{13}$$

$$dy_t = v_t \cos(tcr)\sin(tph)\ t \tag{14}$$

$$dz_t = v_t \cos(tph)\ t \tag{15}$$

Here tph and tcr are pitch and course of the target respectively.

The changed target position is as follows.

$$x_t = x_t + dx_t \tag{16}$$

$$y_t = y_t + dy_t \tag{17}$$

$$z_t = z_t + dz_t \tag{18}$$

Simulated true values of bearing, range and elevation of the target are given as follows.

$$true\ bearing = tan^{-1}((x_t - x_0)/(y_t - y_0)) \tag{19}$$

$$true\ range = \sqrt{(x_t - x_0)^2 + (y_t - y_0)^2 + (z_t - z_0)^2} \tag{20}$$

$$true\ elevation = tan^{-1}\left(R_{xy}/z_t - z_0\right) \tag{21}$$

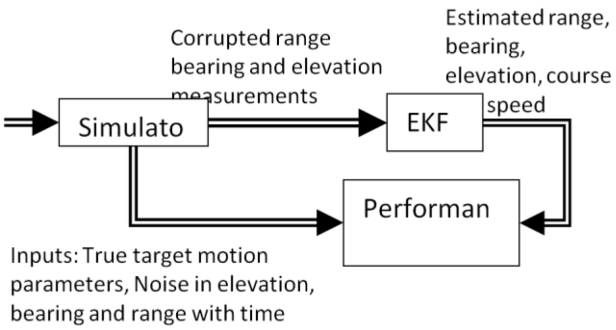

Fig:3. Block diagram of TMA in simulation mode

Block diagram of target motion analysis in simulation mode is shown in Fig.3. The measurements tampered with noise are utilized for the prediction of target parameters using EKF. The estimated target parameters are compared with that of true values.

B. System model

Consider state vector

$$X_S(kt) = \begin{bmatrix} \dot{x}(kt) \\ \dot{y}(kt) \\ \dot{z}(kt) \\ R_x(kt) \\ R_y(kt) \\ R_z(kt) \end{bmatrix} \tag{22}$$

Here $\dot{x}(kt)$, $\dot{y}(kt)$, $\dot{z}(kt)$ are speed parameters of the target and $R_x(kt)$, $R_y(kt)$, $R_z(kt)$ are its range parameters in x, y and z directions respectively. The state equation becomes

$$X_s(kt+1) = \emptyset X_s(kt) + b(kt+1) + \Gamma w(kt) \tag{23}$$

$\emptyset$ is given by

$$\emptyset = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ t & 0 & 0 & 1 & 0 & 0 \\ 0 & t & 0 & 0 & 1 & 0 \\ 0 & 0 & t & 0 & 0 & 1 \end{bmatrix} \tag{24}$$

Here t is time interval at which measurement is obtained. $b(kt+1)$ is deterministic control matrix and is given by

$$b(kt+1) = \begin{bmatrix} 0 \\ 0 \\ 0 \\ -(x_0(kt+1) + x_0(kt)) \\ -(y_0(kt+1) + y_0(kt)) \\ -(z_0(kt+1) + z_0(kt)) \end{bmatrix}^T \tag{25}$$

Here x_0, y_0, z_0 are the observer position components. To reduce the mathematical complexity, Y–axis is taken as reference while measuring all the angles. Let $w(kt)$ be plant noise

$$w(kt) = [w_x \quad w_y \quad w_z]^T \tag{26}$$

Variance of $w(kt)$ is given by

$$E[\Gamma(kt)w(kt)w^T(kt)\Gamma^T(kt)] = Q\delta_{ij} \tag{27}$$

$$\text{Where } \delta_{ij} = \sigma_w^2(i = kt) \tag{28}$$

= 0 otherwise

$$Q = \begin{bmatrix} ts^2 & 0 & 0 & ts^3/2 & 0 & 0 \\ 0 & ts^2 & 0 & 0 & ts^3/2 & 0 \\ 0 & 0 & ts^2 & 0 & 0 & ts^3/2 \\ ts^3/2 & 0 & 0 & ts^3/4 & 0 & 0 \\ 0 & ts^2/2 & 0 & 0 & ts^3/4 & 0 \\ 0 & 0 & ts^2/2 & 0 & 0 & ts^3/4 \end{bmatrix} \tag{29}$$

$$\Gamma(kt) = \begin{bmatrix} t & 0 & 0 \\ 0 & t & 0 \\ 0 & 0 & t \\ t^2/2 & 0 & 0 \\ 0 & t^2/2 & 0 \\ 0 & 0 & t^2/2 \end{bmatrix} \tag{30}$$

$Z(kt)$ represents the matrix of all measurements and is given by

$$Z(kt) = [R_m(kt) \quad B_m(kt) \quad \Theta_m(kt)]^T \tag{31}$$

Here $R_m(kt)$, $B_m(kt)$ and $\Theta_m(kt)$ are measured range, bearing and elevation

$$R_m(kt) = R(kt) + \xi_R(kt) \tag{32}$$

$$B_m(kt) = B(kt) + \xi_B(kt) \tag{33}$$

$$\Theta_m(kt) = \Theta(kt) + \xi_\Theta(kt) \tag{34}$$

where $R(kt)$, $B(kt)$ and $\Theta(kt)$ are simulated range, simulated bearing and simulated elevation.

$$R(kt) = \sqrt{R_x^2(kt) + R_y^2(kt) + R_z^2(kt)} \tag{35}$$

$$B(kt) = tan^{-1}\left(R_x(kt)/R_y(kt)\right) \tag{36}$$

$$\Theta(kt) = tan^{-1}\left(R_{xy}(kt)/R_z(kt)\right) \tag{37}$$

$$\text{Where } R_{xy} = \sqrt{R_x^2 + R_y^2} \tag{38}$$

Measurement vector is given by

$$Z(kt) = H(kt)X_s(kt) + \xi(kt) \tag{39}$$

$$H(kt) = \begin{bmatrix} 0 & 0 & 0 & \sin(B)\sin(\Theta) & \sin(\Theta)\cos(B) & \cos(\Theta) \\ 0 & 0 & 0 & \dfrac{\cos(B)}{R_{xy}} & \dfrac{-\sin(B)}{R_{xy}} & 0 \\ 0 & 0 & 0 & \dfrac{\sin(B)\cos(\Theta)}{R} & \dfrac{\cos(\Theta)\cos(B)}{R} & \dfrac{-\sin(\Theta)}{R} \end{bmatrix} \tag{40}$$

$$\text{And } \xi(kt) = [\xi_R \quad \xi_B \quad \xi_\Theta]^T \tag{41}$$

C. EKF Algorithm

All EKF implementation is as

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follows.

i). Initially the estimation of state and its covariance be$X(0|0)$ and $P(0|0)$.

ii). State vector at the next time period is predicted as$X_s(kt+1)$:

$$X_s(kt+1) = \emptyset(kt+1|kt)X_{kt}(kt) + b(kt+1) + \omega(kt) \quad (42)$$

iii). The predicted covariance matrix of the state vector is given as follows.

$$P(kt+1|kt) = \emptyset(kt+1|kt)P(kt)\emptyset^T(kt+1|kt) + Q(kt+1) \quad (43)$$

iv). The gain of the Kalman filter is calculated as given in eq. (44).

$$G(kt+1) = P(kt+1|kt)\emptyset^T(kt+1|kt)\big[H(kt+ 1Pkt+1kt\, HTkt+1+R-1 \quad (44)$$

v). The state estimation and its error covariance:

$$X_s(kt+1|(kt+1) = X_s\,(kt+1|kt) + G(kt+1)\,[Z(kt+1) - \hat{Z}(kt+1)] \quad (45)$$

$$P(kt+1|kt+1) = [1 - G(kt+1)H(kt+ 1Pkt+1kt \quad (46)$$

vi). For next iteration

$$X_s(kt|kt) = X(kt+1|kt+1) \quad (47)$$

$$P(kt|kt) = P(kt+1|kt+1) \quad (48)$$

D. Target Maneuver Detection

When target is not maneuvering, the process noise is less. When target maneuvers, the process noise increases [10, 11]. So, in simulation, the covariance matrix is multiplied by fledge factor of 10 for the time period of target maneuver. Once the target achieves its new course, i.e., completes the maneuver, process noise will be reduced. The normalized squared innovation, $\gamma_\varphi(kt)$, is calculated as follows.

$$\gamma_\varphi(kt) = \varphi^T(kt)S^{-1}(kt+1)\varphi(kt+1) \quad (49)$$

Where $\varphi(k{+}1)$ is

$$\varphi(kt+1) = Z(kt+1) - h(kt+1, X(kt+1/kt)) \quad (50)$$

Let $S(kt)$is

$$S(kt+1) = H(kt+1)P(kt+1/kt)H^T(kt+1) + \sigma^2 \quad (51)$$

Let

$$d(\xi) = \gamma^T S^{-1}\gamma \geq c \quad (52)$$

where S is $diag\{S(kt)\}$

and$\gamma = [\varphi(1) \;\; \varphi(2) \ldots\ldots \varphi(kt)]^T \quad (53)$

where c is a constant (threshold) and d is chi-square distributed statistic. This sliding window size is chosen as 5.

III. SIMULATION AND RESULTS

It is assumed that experiment is conducted at favorable environmental conditions. This simulation is carried out on a personal computer using Matlab. The scenario chosen for evaluation of algorithm is shown in Table 2. For example, scenario1 describes a target at an initial range of 3000m from the observer, travellingwith course and speeds of 170^0 and 400m/s respectively. The initial line of sight is 0^0. The bearing and range measurements are corrupted with 0.330 (1σ) and 10m (1 σ) respectively. After 300s, target changes its course to 295^0at a turning rate of 3^0 per second. The target elevation is 0^0 for simplicity. The observer is assumed to travel with constant speed of 20m/s and with a course of 90^0.

The measurements are assumed to be available continuously for every second. The true values of the target and observer are simulated in Matlab. So, the estimated values can be evaluated or validated based on the simulated values based on certain acceptance criteria.The acceptance criterion is chosen based on weapon control (this topic is not discussed here) requirement. The solutionis accepted or said to be converged when error in course estimate <= 3^0 and error in speed estimate <= 1m/s.

The estimates and true paths of target are shown in Fig.4 for scenario2.For clarity of the concepts, the simulated and predicted course and speed for scenario2 are presented in Fig.5and 6. Similarly simulated and predicted elevation of the target for scenario2 is presented in Fig.7.The solution is accepted or converged when the course and speed errors are within the acceptance criteria. The convergence time, in seconds, for the scenarios is given in Table.2.

The scenario2 chosen for evaluation of algorithm for maneuvering target has the convergence of solution for the estimated course of the target after maneuver at 460th second and 67th second before target maneuver respectively.The target does not maneuver in speed, so the convergence of speed estimate is 43 seconds for scenario 2.

Table. 1. Target to Observer Scenarios

Parameters	Scenarios	
	1	**2**
Target Range (m)	2000	3000
Target Bearing (deg)	0	0
Initial Target Course (deg)	135	170
Target Course after 300s (deg)	235	295
Target Speed (m/s)	400	400
Target Elevation (deg)	0	0
Observer speed (m/s)	20	20
Observer Course (deg)	90	90
Noise in bearing (1σ) (deg)	0.33	0.33
Noise in Range (1σ) (m)	10	10
Noise in bearing measurements (1 σ) (deg)	0.33	0.33

Table. 2. Solution convergence times in seconds

Parameters converged		Scenarios	
		1	**2**
Before Target maneuver	**Course**	54	67
	Speed	84	43
	Elevation	8	2
	Total Convergence	93	67
After Target maneuver	**Course**	385	460
	Speed	84	43
	Elevation	8	2
	Total Convergence	385	460

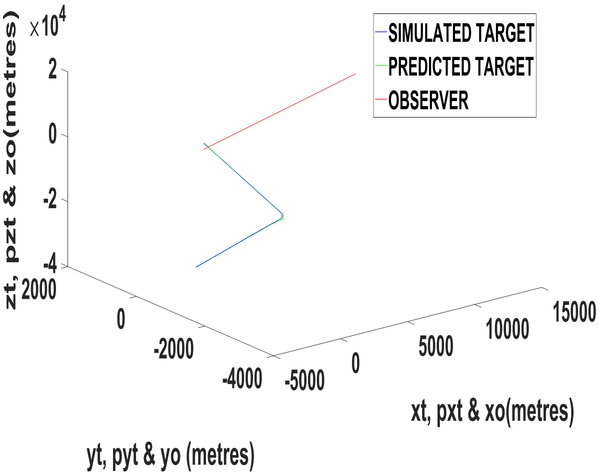

Fig.4 Target and observer coordinates for scenario 2

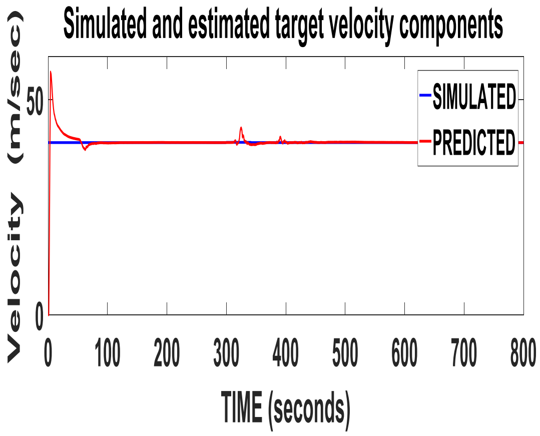

Fig.5True and predicted velocity of target for scenario 2

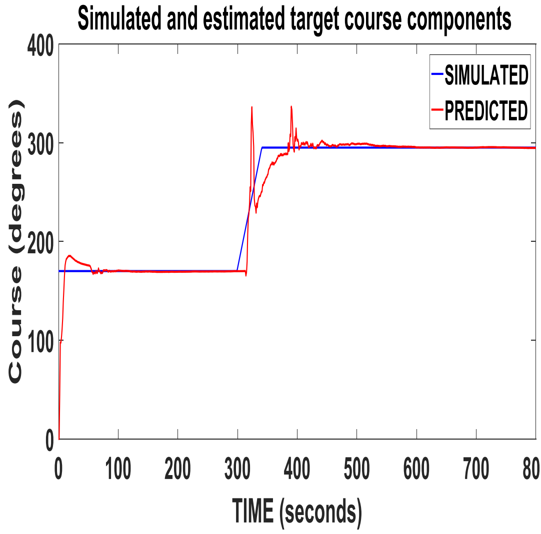

Fig.6 True and predicted course of target for scenario 2

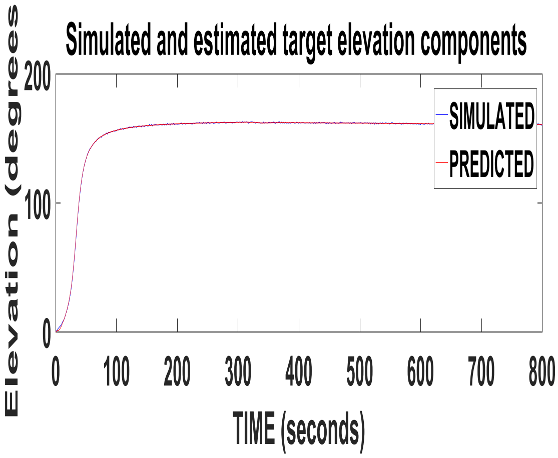

Fig.7 True and predicted elevation of target for scenario 2

IV. CONCLUSION

Based on the results obtained in simulation, Extended Kalman filter is recommended to estimate target course, speed in active target tracking from UAV systems.

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AUTHORS PROFILE

P. Dhatri Shree, studying B. Tech in Electronics and Communication Engineering in Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, AP, India.

M. Ajay Kumar, studying B. Tech in Electronics and Communication Engineering in Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, AP, India.

M. Sai Charan,studying B. Tech in Electronics and Communication Engineering in Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, AP, India.

S. Koteswara Rao, former scientist in DRDO, is currently working as Professor in KLEF, Guntur.

Kausar Jahan, research scholar in KLEF, Guntur, AP. India.