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Review Article

UNDERWATER TARGET TRACKING SYSTEM USING ACTIVE SONOBUOYS

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Abstract

Surveillance of the targets done in two phases, one is radar (which is operated in air), another is sonar (which is operated underwater). These are operated in active mode. Sonar's range and bearing measurements are used to estimate the target position and velocity. In this paper by using Sonobuoy, observer tracks a target in underwater environment. Sonobuoy operates in active mode where it emits sound energy (pings) into the water and listen back echo before transmitting another pulse. The simulation is carried out in Matlab environment using Monte-Carlo statistical process. For smoothing of measurements and reduction of error in the predicted target motion parameters, extended Kalman filter algorithm is utilized.

Keywords: Sonobuoy, Extended Kalman Filter, Bearing Angle, Estimation, Monte-Carlo method**.**

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INTRODUCTION

Sonobuoy is one of the equipment with expendable sonar system that is dropped from the aircraft or from surface of water by ships for conducting an underwater acoustic research. Sonobuoy provides the most effective airborne warfare in today's world. It is used to detect the target with help of floating sensor system. It contains a float-bag quite assembly because the higher unit supporting the equipment submerged in water. Sonobuoy is integrated with Global positioning system to work out the correct position of target path. Sonar systems use sound waves of propagation to navigate, communicate with targets or detect targets on or under the surface of the water. Sonobuoy is a sonar system, used to send and receive the sound waves.

Basically, Sonobuoys are of two types: passive Sonobuoys and Active Sonobuoys [2]. Passive Sonobuoy receives the signals from the moving targets and, Active Sonobuoy emits sound energy (pings) into the water and listen back echo before transmitting next ping. If the echo is received, using beamforming at the receiver [3], it will be considered that there is a target. The Sonobuoys will be dropped from the air or from on the water, after that it will reach to a steady state and that co-ordinates where taken as origin.

If the system is having multiple transmitters, then it is known as multi-static. The performances of these three systems are explained in [4]. Data received by the Sonobuoy is processed and sent to the aircraft by means of an ultra-high frequency.

The study of methods and mathematical modelling proposed in this paper are utilized to predict the target future position and to reduce the errors using statistical filtering algorithms. The working of Kalman filter can be described in two steps. One is estimating the present state of the variables using their uncertainties [5-6]. Other is updating these estimates using the weighted averages based on the measurements obtained. Kalman filter is a recursive filter and is optimal filter only for linear systems [7-9].

The tracking of target in underwater scenario is a nonlinear process, so extended Kalman filter (EKF) is chosen to find out target motion parameters. In this paper, estimation process is carried out using the suboptimal nonlinear filter, EKF. It linearizes the nonlinearities in the state and measurement models using Taylor-series before applying Kalman filter algorithm[10-14]. In other words, the Kalman filter uses the linearized state and measurement models of the nonlinear system.

In sonobuoy, propeller creates a random noise in water. This combines with the received signal decreasing the signal strength. As, noise cannot be eliminated, EKF tries to reduce this noise.

In this paper, the simulator is developed to generate true range, measured range, true bearing, measured bearing with time tagged. The true values are corrupted with noise such that these measurements can be treated as output measurements of sonobuoy. The purpose of this research work is to smooth the measurements and at the same time to estimate the target path.

Mathematical Modeling

Simulator:
It is assumed that the observer (Sonobuoy) is at origin which is fixed stationary as shown in

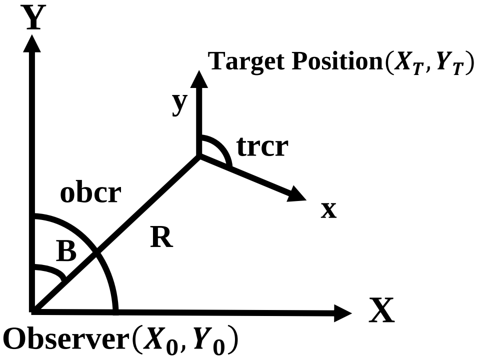

Fig 1. Observer and target scenario

The target moves with speed, V_t and at course, trcr. Initially, the target is assumed to be at a distance of R meters from the observer. An imaginary line joining observer and target positions is called line of sight and it makes an angle (bearing) with respect to Y-axis as shown in Fig.1. It is assumed that target and observer are in the same plane. The measurements are made in active mode for every t seconds.

The observer positions are calculated as follows

$dx_0 = v_0\ \sin(obcr)\ t$ (1)

$dy_0 = v_0\ \cos(obcr)\ t$ (2)

where obcr is observer course.

Now the new observer position becomes

$x_0 = x_0 + dx_0$ (3)

$y_0 = y_0 + dy_0$ (4)

The target position (x_t, y_t) with respect to origin is given by

$x_t = R\ \sin(B)$ (5)

$y_t = R\cos(B)$ (6)

After t seconds,

$dx_t = v_t\ \sin(trcr)\ t$ (7)

$dy_t = v_t\ \cos(trcr)\ t$ (8)

Now the new target position after time t is given as

$x_t = dx_t + x_t$ (9)

$y_t = dy_t + y_t$ (10)

True bearing and range are calculated as follows

Bearing, $B = \tan^{-1}\frac{x_t - x_0}{y_t - y_0}$ (11)

Range, $R = \sqrt{(x_t - x_0)^2 + (y_t - y_0)^2}$ (12)

Measurements:

Let $X_S(e)$ be state vector.

$X_S(e) = [\dot{x}(e) \quad \dot{y}(e) \quad R_x(e) \quad R_y(e)]^T$ (13)

Here $\dot{x}(e)$ and $\dot{y}(e)$ are target velocity in x and y directions and $R_x(e)$ and $R_y(e)$ are target range in x and y directions.

The State equation of the target is

$X_S(e+1) = \emptyset(e+1/e)X_s(e) + b(e+1) + \omega(e)$ (14)

where $\omega(e)$ is noise having zero mean white Gaussian power spectral density and $\emptyset(e+1|e)$ is transient matrix and it is

$$\emptyset(e+1|e) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ t & 1 & 1 & 0 \\ 0 & t & 0 & 1 \end{bmatrix} \quad (15)$$

where t is measurement interval and $b(e+1)$ is deterministic matrix

$$b(e+1) = \\ \begin{bmatrix} 0 & 0 & -(x_0(e+1) + x_0(e)) & -(y_0(e+1) + y_0(e)) \end{bmatrix}^T \quad (16)$$

where $x_0(e)$ and $y_0(e)$ are observer position components.

To reduce the mathematical complexity, all angles are measured with respect to Y-axis.

Z(e) is measurement vector

$$Z(e) = \begin{bmatrix} B_m(e) \\ R_m(e) \end{bmatrix} \quad (17)$$

Here $B_m(e)$ and $R_m(e)$ are measurements and they are defined as

$B_m(e) = B(e) + \gamma(e)$ (18)

$R_m(e) = R(e) + \eta(e)$ (19)

where B(e) and R(e) are true bearing angle and range

$B(e) = \tan^{-1}(R_x(e)/R_y(e))$ (20)

$R(e) = \sqrt{R_x^2(e) + R_y^2(e)}$ (21)

The noises $\eta(e)$ and $\gamma(e)$ are uncorrelated.

Extended Kalman Filter:
EKF can be formulated as follows

$x_e = f(x_{e-1}, u_e) + w_e$ (22)

$z_e = h(x_e) + v_e$ (23)

Here w_e and v_e are the process and measurement noises, x_e and z_e are the state and measurement vectors respectively. The noises are assumed to be multi-variate Gaussian noises with zero mean. The function ' f ' is used to compute the state estimate from the previous state and the function 'h' gives the mathematical computation of the measurement estimate from the estimated state. The Measurement equation is as follows

$Z(e) = H(e)X_s(e) + v(e)$ (24)

Here $v(e) = \begin{bmatrix} \gamma(e) \\ \eta(e) \end{bmatrix}$ (25)

$$H(e) = \begin{bmatrix} 0 & 0 & \frac{\cos\hat{B}(e)}{\hat{R}(e)} & \frac{-\sin\hat{B}(e)}{\hat{R}(e)} \\ 0 & 0 & \sin\hat{B}(e) & \cos\hat{B}(k) \end{bmatrix} \quad (26)$$

$\hat{B}(e)$ and $\hat{R}(e)$ are estimated values of bearing and range respectively. EKF algorithms is as follows.

i) $X(0|0)$ and $P(0|0)$ are initial state vector and its covariance matrix.

ii) Predict state vector $X_s(e+1)$:

$$X_s(e+1) = \emptyset(e+1|e)X_k(e) + b(e+1) + \omega(e) \quad (27)$$

iii) The Predicted state Covariance matrix:

$$P(e+1|e) = \emptyset(e+1|e)P(e)\emptyset^T(e+1|e) + Q(e+1) \quad (28)$$

iv) Kalman gain is given as:

$$G(e+1) = P(e+1|k)\emptyset^T(e+1|e)[H(e+1)P(e+1|e)\,H^T(e+1) + R]^{-1} \quad (29)$$

v) The state estimation and its error covariance:

$$X_s(e+1|(e+1) = X_s\,(e+1|e) + G(e+1)\,[Z(e+1) - \hat{Z}(e+1)] \quad (30)$$

$$P(e+1|e+1) = [1 - G(e+1)H(e+1)P(e+1|e)] \quad (31)$$

vi) For next iteration

$$X_s(e|e) = X(e+1|e+1) \quad (32)$$

$$P(e|e) = P(e+1|e+1) \quad (33)$$

Simulation and Results

Simulation is carried out using Matlab on a desktop computer.

Let us consider four scenarios for the evaluation of the algorithm. For example, in scenario 1, the range is 2000m, course is 30 deg, target speed is 20 m/s and initial bearing is 50. EKF is used and the target paths are estimated.

Table. 1. Target to Observer Scenarios

Parameters	Scenarios		
	1	2	3
Target Range	2000	500	1200
Target Bearing	50	60	45
Target Course	30	75	225
Target Speed	20	5	20

Table. 2. Solution convergence times in seconds

Parameters converged	Scenarios		
	1	2	3
Course	23	5	8
Speed	18	15	16
Total Convergence	23	15	16

Convergence time of the solution for all the scenarios is shown in Table2. Continuing the same example scenario 1, course and speed are converged at 23rd and 18 seconds respectively. Fig.2. shows the simulated and estimated paths of the target in scenario 1.

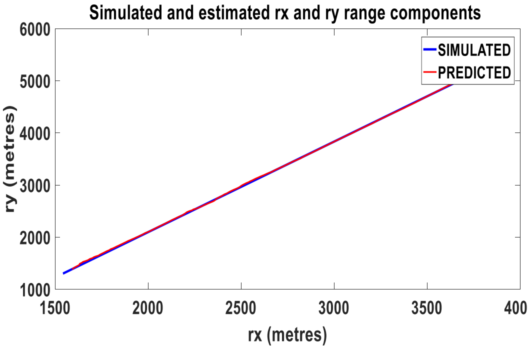

Fig.2 Simulated and estimated target position for scenario 1

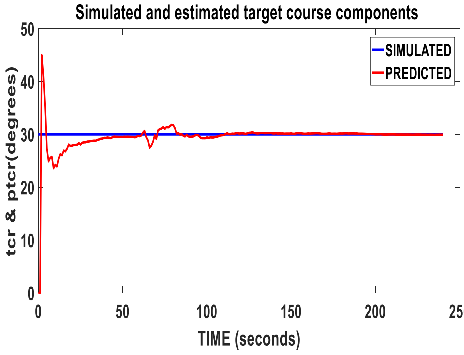

Fig.3 Simulated and estimated target course for scenario 1

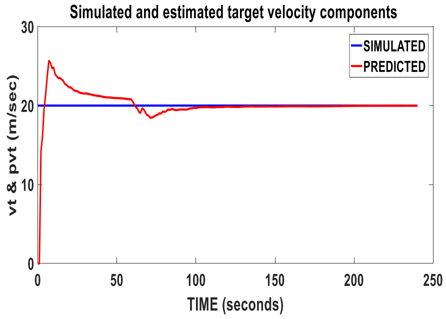

Fig.4 Simulated and estimated target speed for scenario 1

Fig. 3 and Fig. 4 show the simulated and estimated course and speed of the target for scenario 1. It can be observed from the figures that the errors in the estimated target parameters are reduced and are obtained within the acceptable values in a short time, which is less than 30 seconds.

CONCLUSION

By this paper, the target path is estimated and used the filtering algorithm to reduce the errors. Extended Kalman Filter (EKF) algorithm is explained in this paper. EKF algorithm is used to estimate target motion parameters by using Active Sonobuoys. Simulation results are carried out. Based on the results, EKF is recommended to track underwater targets by using Active Sonobuoys.

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