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Advanced Submarine Integrated Weapon Control System

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Abstract

Background/Objectives: In underwater, a single submarine processes noisy sonar bearings from a radiating target (ship/submarine/torpedo) in passive listening mode. **Methods/Statistical Analysis:** The target is assumed to be at constant velocity or maneuvering in its course/speed/course and speed. An adaptive Kalman filter estimates target motion parameters. **Findings:** Data fusion and data association in multi target and multi sensor scenario are carried out, using Chi-squared innovation process. **Applications/Improvements:** Finally improved torpedo intercept guidance algorithm with homing capabilities is developed for attacking the target.

Keywords: Data Fusion, Doppler, Fire Control System, Towed Array

1. Introduction

In the ocean environment, two-dimensional bearing's only TMA is generally used. An observer monitors noisy sonar bearings from a radiating target in passive listening mode. An observer processes these measurements and find out target motion parameters viz: range, course, bearing and speed of the target [Aidala]. The advanced submarine fire control systems should have the following capabilities.

1.1 Multi Sensor and Multi Target Tracking

With only hull-mounted sonar, submarine can carry out optimum maneuver against a single target. Effectively, optimum fire control solution is available for only one target. Ownship maneuver can be avoided by using (a) Towed array with statistical (like maximum likelyhood estimator etc.) beam formation so that the bearing accuracy remains same in the region 0 to 180° (b) Narrow band signal processing to obtain Doppler frequency (tonal) measurements along with bearing measurements of the target or (c) Elevation measurements of the target.

1.2 Data Association

In multi sensor scenario, two or more sensors may be tracking same target. So, it is required to find out which bearing belongs to which target (also called as Data Association). This is very much required when the targets are crossing each other.

1.3 Data Fusion

Again in multi sensor scenario, single target may be assigned to many sensors for the purpose of tracking. A set of target motion parameters, estimated by different sensor outputs is available. By using Kalman filter; a better and more accurate solution can be obtained by fusing all the estimated data of each sensor.

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1.4 Limitation of Tracking of Target to Constant Velocity Motion

The least square or the maximum likelihood estimator algorithm is used in present submarines for tracking the target while it is at constant velocity. Kalman filter can track the maneuvering ships/submarines[1-3]. If the target (like torpedo) is in continuous proportional navigation or circular/sector search, then Kalman filter requires one more set of bearing measurements from another sensor (like towed array) or Doppler frequency or elevation measurements.

1.5 Integration of Sonar and Contact Motion Analysis

So far sonar signal processing and contact motion analysis are available at different places. The fire control system should be split into Contact Motion Analysis (CMA) process and weapon control process. The CMA process is to be clubbed with sonar signal processing, and weapon control process which takes care of firing sequence of weapons, launching of weapons and calculation of pre set parameters, is to be in weapon control system[4,5]. If sonar signal processing and CMA are available in the same console, the advanced techniques like data association, data fusion etc., in multi sensor and multi target tracking can be implemented easily.

1.6 Advanced Intercept Guidance and Search Algorithms

The CMA used in present fire control systems, do not calculate the range error uncertainty ellipse zone or Circular Error Probability (CEP). Hence two homing torpedoes are to be fired against a single target. Using advanced Kalman filter, the author has developed CMA, which generates range error uncertainty ellipse zone. This zone will be superimposed on to the estimated range and accordingly preset parameters will be found out. Hence, a single homing torpedo is sufficient to attack a target.

After the end of straight run, if homing contact is not obtained, inbuilt FCS calculates the parameters for torpedo spiral search. Several types of search algorithms can be incorporated depending on the environment like shallow/deep waters and so on[3,5,6].

2. Simulation and Results

Modified gain bearings only extended Kalman filter is developed. A simulation environment is also developed to evaluate the filter performance. It is assumed that the submarine uses a hull-mounted sonar. Monte Carlo simulation is carried out and the results are shown for various scenarios.

Case 1: The target is assumed to be at 20000 meters at an initial bearing of zero degrees and moving at 140˚ at a constant speed of 10 meters/sec. Observer is at a speed of 3 meters/sec and making S-maneuver as line of sight at a turning rate of 1˚ /sec. The results are shown in Figure 2 (a) to (d). The solution is said to be converged when the range estimate is 8 %, in course estimate 5˚, and speed estimate is 1 meters /sec. The required accuracy is obtained from sixth minute onwards.

Case 2: The previous scenario is extended to a maneuvering target, as shown in fig 2.Detection of target maneuver is

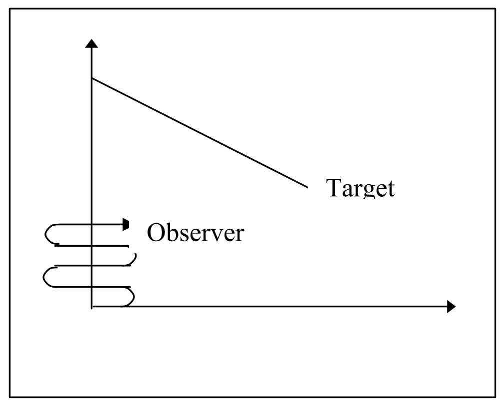

Figure 1. TMA with single observation platform in S – maneuver.

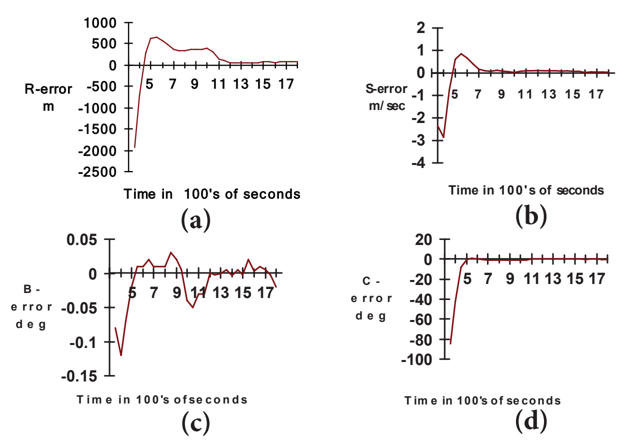

Figure 2. **(a)** Error in range estimates. **(b)** Error in Speed estimate. **(c)** Error in bearing estimate. **(d)** Error in course estimate.

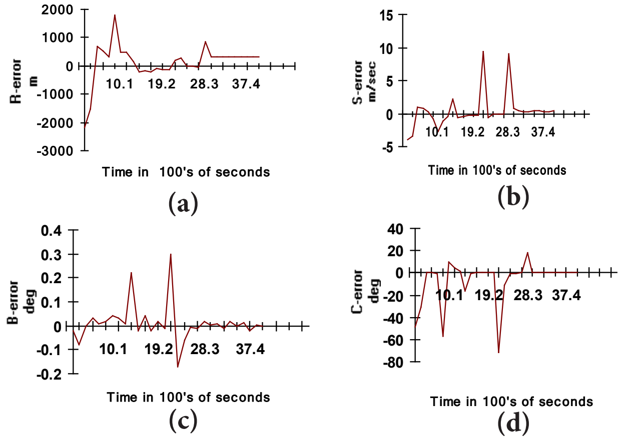

Figure 3. **(a)** Error in range estimates. **(b)** Error in Speed estimate. **(c)** Error in bearing estimate. **(d)** Error in course estimate.

carried out using normalized and squared innovation process and the target state vector is adjusted accordingly. The results are shown in Figure 3 (a) to (d).

Case 3: Let the submarine is under a torpedo attack. With single hull mounted sonar it is not possible to track a torpedo, which is pursuing the submarine under homing. The torpedo is assumed to be initially at constant velocity and changes to pursuit guidance on to the submarine once it obtains homing contact. The problem is solved using towed array bearings along with hull mounted array bearings.

Case 4: Many times it is not possible to have a towed array due to operating constraints. If hull mounted sonar uses narrow band signal processing, Doppler frequency measurements are available. Using these measurements along with hull-mounted sonar bearing measurement, submarine maneuver (to obtain the Observability of the process) can be avoided. This algorithm can be easily extended to track a maneuvering target.

Case 5: The torpedo intercept guidance algorithm as mentioned above is developed.

3. Conclusion

The author has developed tracking of target (torpedo/ship/submarine) using bearings only measurements using MGBEKF algorithm. Mathematical modeling of the algorithms & results of data fusion, data association and intercept guidance algorithm are not included in this paper due to space constraint. Importing of submarine Fire Control System is not required. NSTL has developed the algorithms to meet the state of art of technology in this field.

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