Association based Feedback Aided Underwater Passive Target Tracking

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Introduction

- Passive bearing line tracking is really challenged, in situations like low Signal to Noise Ratio (SNR) scenarios and when targets are spaced close to each other [1].
- In a distributed multi-sensory systems a central system is required for associating sensor level tracking information to produce target level tracks.
- A Multiple Frequency Line Tracking system (MFLT) can track multiple frequencies of a target and in general it performs better in low SNR scenarios and when targets are spaced close to each other [2].

Contribution

- Introduced a track association system which associates sensor level tracks like passive bearing line tracks and multiple frequency line tracks, and provides feedback to sensor level tracking.
- An enhanced multiple frequency line tracking (MFLT) method is also proposed, which will make the passive bearing line tracking more robust and accurate.
- Improved the performance of passive bearing line tracking with the help of feedback from track association system.

Proposed Method

❖ MFLT System

- MFLT is a system developed to track multiple frequencies of the same target.
- Applied on Low Frequency Analyzer and Recorder (LOFAR) or Detection of Envelope Modulation on Noise (DEMON) information.
- The algorithm assumes each target is having at least one frequency component which differentiate that target from another one.
- Kalman filter based tracking on the frequency and bearing based model.

The model used for Kalman Filter is given below in (1)-(5)

state model

$$x(k) = Fx(k-1) + w(k-1) \quad (1)$$

measurement model

$$y(k) = Hx(k) + v(k) \quad (2)$$

x(k) denotes the state vector at time k, and is defined as below,

$$x(k) = \begin{bmatrix} \beta_k \\ \dot{\beta}_k \\ \ddot{\beta}_k \\ f_k \end{bmatrix} \quad (3)$$

β_k is the bearing at time k, $\dot{\beta}_k$ is the bearing rate, $\ddot{\beta}_k$ is the rate of change of bearing rate and f_k frequency.

F is the state transition matrix,

$$F = \begin{bmatrix} 1 & T & \frac{1}{2}T^2 & 0 \\ 0 & 1 & T & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4)$$

T denotes the time. $w(k-1)$ is the process noise.

$$H = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (5)$$

H is called the measurement matrix, v(k) is the measurement noise.

❖ Track Association System

- Method models track to track association problem as an assignment problem. Sensor level tracks have to be associated with existing targets.
- Well known Hungarian algorithm is used for solving the above association [3].
- The cost matrix for the Hungarian algorithm is created with the frequency and bearing information from the sensor level tracks.
- The track association system performs one additional task of analysing individual tracks and provides sufficient feedback to the trackers about the accuracy of their reported parameters, mainly bearing in this case.

Results

- The passive bearing line tracking is tested in conditions, with and without feedback from track association system.
- MFLT tracks are also assigned during the simulation scenario, by holding the assumption that each target is having at least one frequency which differentiate that target from another one.

Each simulation is carried out in N number of times, where N=50. Each simulation consists of M number of observations. Root Mean Square error (RMSE) in k^{th} observation is calculated as in (6),

$$RMSE_k = (1/N)\sqrt{\sum_{i=1}^{N}(y_k - \tilde{y}_k^{\,i})^2}\,,\ k \in [1, M] \quad (6)$$

Where y_k is the true value and $\tilde{y}_k^{\,i}$ represents observed value in the k^{th} observation in i^{th} simulation trial.

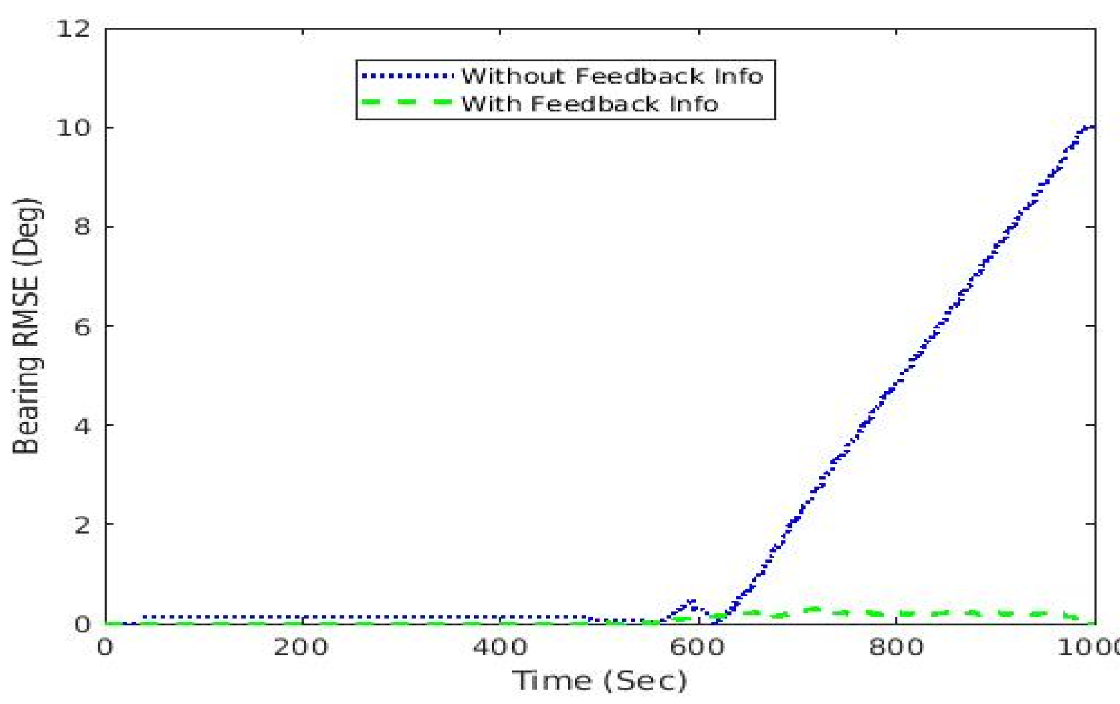

Fig.1. Bearing RMSE plot showing for a scenario in which a slow moving target crossing a stationary target. Passive bearing line tracking taken during analysis consists of energy based tracking performs in a specific window.

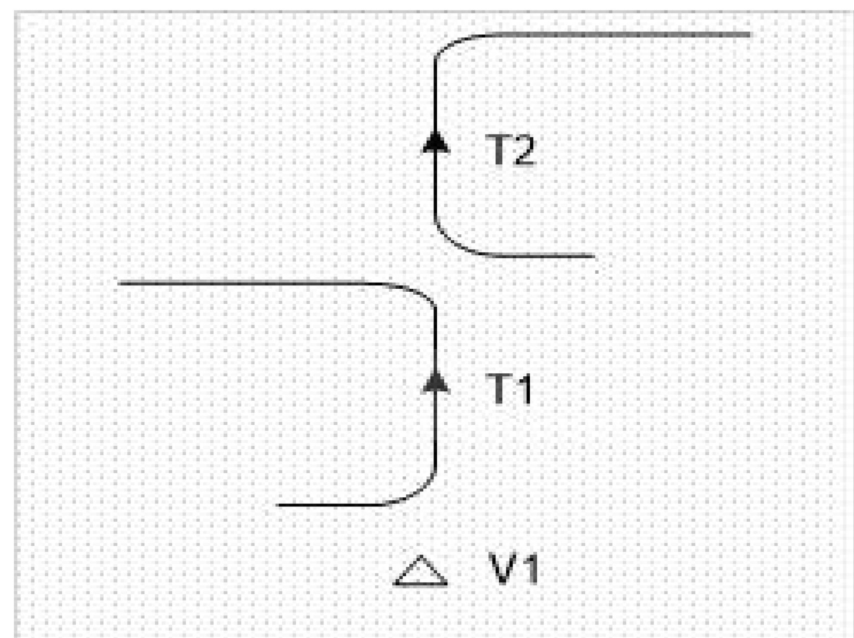

Fig.2. Scenario showing closely spaced targets for a long period of time from the perspective of own ship. T1 and T2 represents two targets and V1 represents own ship.

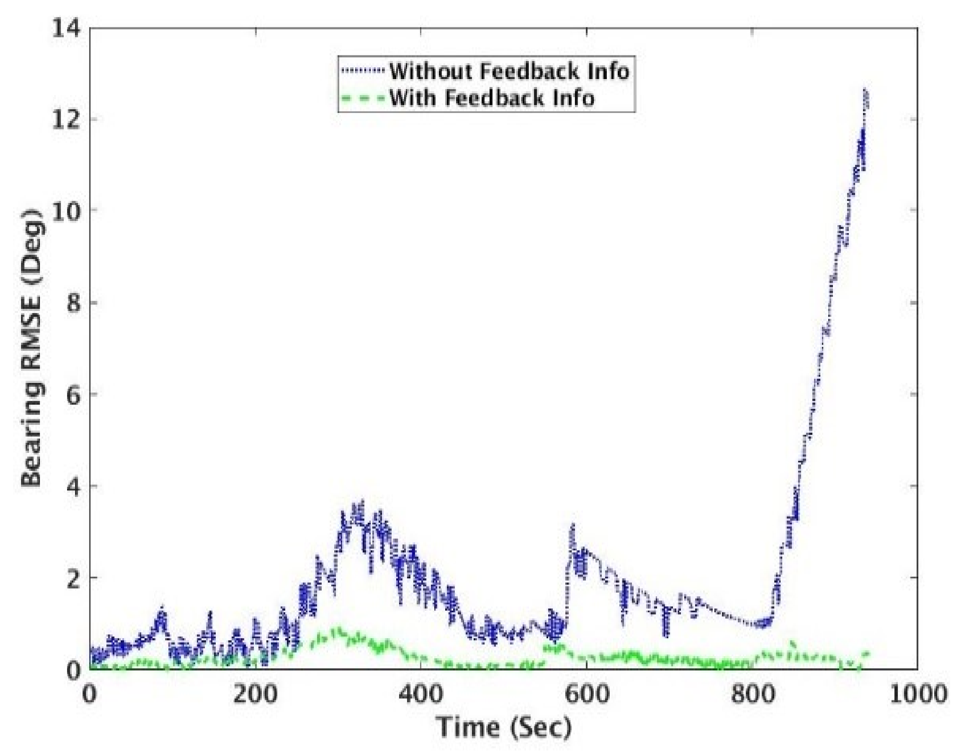

Fig.3. Bearing RMSE plot showing for the scenario having closely spaced targets for a long period of time. Passive bearing line tracking taken during analysis consists of Kalman Filter with bearing and bearing rate in the state model.

Research Impact in Defence and Conclusion

- Underwater passive target tracking with feedback from an association system and a newly developed MFLT is proposed.
- With feedback from the association system performance of passive bearing line tracking has been improved.
- Improved performance of passive bearing line tracking enhances overall performance of the association system as well as many other systems like underwater target classification system.
- The method offers robustness to the passive sonar target tracking with less manual intervention, which is essential in the areas of anti-submarine warfare.

References

[1] A.D. Waite, “SONAR for Practising Engineers”, John Wiley and Sons Ltd.
[2] R. Urick, “Principles of Underwater Sound”, McGraw Hill Inc. 1983.
[3] H. W. Kuhn, “The Hungarian method for the assignment problem”, doi:10.1002/nav.3800020109.