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# A novel stochastic estimator using pre-processing technique for long range target tracking in heavy noise environment

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ABSTRACT

A novel stochastic algorithm using pre-processing technique is proposed in this paper to deal with the problem of underwater target tracking using passive Sonar. Pre-processing is a concept of reducing the variance of noise present in the measurements given by sensors. This key step is performed ahead of conventional estimation algorithms. Pre-processed measurements are obtained by taking weighted average of present measurements and projected previous measurements. The method is expected to bring down the variance of noise to a great deal based on the fact that the sensor errors are unbiased by nature. The most attractive feature of this algorithm is the capability to track long range targets in heavy noise environments. The algorithm is tested by running Monte Carlo simulations in Matlab R2009a environment. There, it is shown that the estimation error and the time of convergence of the pre-processing technique based algorithms like pre-processed Unscented Kalman Filter (PP-UKF) and Integrated Unscented Kalman filter (PP-IUKF) are much less compared to their non-pre-processing counterparts namely UKF and IUKF, thus indicating the importance of the proposed novel method.



## 1. Introduction

Tracking is the most essential signal processing task performed at the time of wars. It is the concept of estimating the position of a moving target using noise corrupted sensor measurements. This important task is performed with the help of a Radar when dealing with the targets which are on or above the ground and Sonar while dealing with underwater targets. Sonar primarily operates in two different modes namely active and passive. Active mode Sonar operation normally involves active transmission of signal and echo reception to find the position of a moving target while Passive mode operation is concerned with the reception of the noise generated by the propeller of the enemy's vehicle to get an idea of the targets location. The target tracking is possible with a single moving sensor as shown by Aidala [9] or by a set of stationary sensors using a concept of triangulation. This paper deals with tracking underwater targets using Towed array measurements given by a passive Sonar.

Modern era of the underwater tracking started by using the celebrated work of Kalman [1,11]. The problem with this filter when dealing with the active tracking is, the generation of undesired bias during the conversion of measurements from the available polar to the Cartesian form. This bias is properly computed and eliminated by Lerro and Bar-Shalom [7] to get considerable improvement in the results. Suchomski [16] have extended the work to make Kalman filter useful for tracking in three dimensional case. Lerro et al. [7] tried to apply Kalman filter in a different way by keeping the state and measurement equations in different coordinate systems. By doing so the measurement equation is turned to a non-linear one which creates problem to apply (KF) directly. The problem is tackled by converting the non-linear measurement equation to a linear one by Taylor series expansion. This way of implementing Kalman filter is called the Extended Kalman filter (EKF). The same procedure is followed for passive target tracking by Aidala et al. [5] and named the algorithm as Cartesian coordinate EKF. The stability problem developed by the ill conditioning of the covariance matrix is also solved in the same paper by the proper choice of the elements of the state vector. This algorithm is named as the modified polar coordinate EKF [5]. Song and Speyer [6] has introduced a time varying gain function in the EKF to get improved results in terms of stability. This filter is called Modified gain Bearings-only EKF (MGBEKF). A much simpler version of MGBEKF is derived by Galkowski and Islam [10]. Nardone et al. have applied two batch processing algorithms namely Pseudo Linear estimator (PLE) and Maximum Likelihood Estimator (MLE) to solve the problem of Bearings-only tracking

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(BOT) problem in [12]. The principles used in those algorithms are minimizing the mean square error, maximizing the log-likelihood functions respectively. The sequential processing versions of the above two algorithms are developed by Rao et al. [13,14] to make the algorithms of [12] fruitful for real time tracking problems. The nonlinear estimation problems are solved in a much efficient way after the work of Julier et al. [4] is published. The algorithm is named as the Unscented Kalman filter (UKF). The principle used is, the unscented transformation of the statistical parameters over the non-linear function. This algorithm was used for BOT problem by Rao et al. [8]. The problem of tracking objects in the order of few meters, as in case of robot tracking is solved by Zhang et al. using UKF in [3]. In [15], Rao et al. showed that the hybrid algorithms has a very important role to play for tracking applications in complicated situations. In [17] it is shown that, significant improvements in tracking problems can be achieved by considering additional inputs like Doppler along with the conventional inputs like range and bearing. A novel algorithm Integrated Unscented Kalman Filter (IUKF) [19] which work on the principle of "Collective opinion is better than the individual" is applied for BOT problem to show that the integration technique can enhance the performance of any conventional non-linear estimators. Recently the Particle filter (PF) as in [1] and [2] are introduced to solve all the nonlinear estimation problems. Their performance in terms of the estimation error is excellent but the practical implementation issue limits their usage.

In the last two paragraphs we have seen, What are the basic estimation algorithms available in the literature and how they are modified to attain improved performance when dealing with the BOT problem. In this paper, a completely different way of dealing with the tracking problems is proposed. The novel pre-processing concept introduced will condition the measurements before applying them to the conventional estimators. By doing so, the performance of the estimators are improved significantly. Conditioning the measurements is done to reduce the variance of noise present in the measurements. This is achieved by using the fact that the measurement noise in unbiased i.e. mean is zero. Also this method is very much suitable for tracking targets in complicated situations of long ranges and heavy noise environments. The complexity of the algorithm is in the order of the UKF. This means that, it is much simpler than a PF. So we can say that the proposed pre-processing technique based algorithms can provide an optimal solution for tracking applications. The method is expected to work well even for the other estimation issues like the one in [18].

Section 2 deals with the concept of the proposed pre-processing technique, There the importance of pre-processing and the expressions related to pre-processing are derived. Section 3 deals with the mathematical formulations. There the dynamics of a moving target, the towed array measurements are modeled, added to this, the equations related to pre-processing, UKF, Integration technique are summarized and finally, two performance comparison metrics for estimators are defined. Section 4 is devoted to show how pre-processing is incorporated into the existing algorithms to solve BOT problem. Section 5 shows simulation, Analysis and results. Finally the paper is concluded in Section 6.

## 2. Pre-processing

### 2.1. Importance of pre-processing

In underwater scenarios hydrophones are normally used to get the bearing measurements of the targets. These measurements contain some noise. If these noise corrupted bearing or azimuth measurements are used for computation of the position of the target. Then, even small errors in bearing can cause huge errors in the Range. This is apparent from Fig. 1. There it is shown that, small errors of ΔB1 and ΔB2 in the measurements of B1 and B2 can cause an enormous Range error.

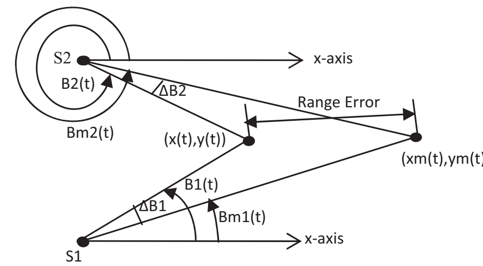


**Fig. 1.** Geometry to illustrate the effect of bearing error.

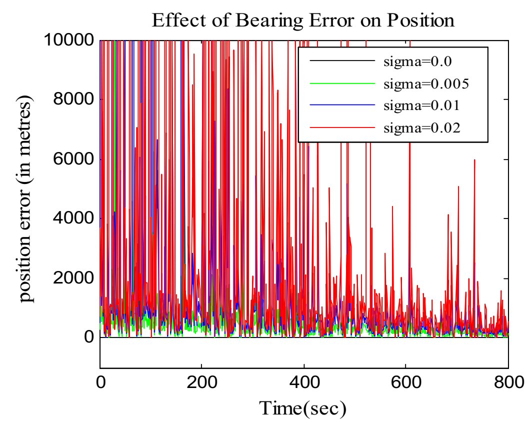


**Fig. 2.** Effect of bearing error on the position.

**Table 1**
Effect of Average range error with increasing noise.

| Sigma of bearing error (rad) | Average range error (m) |
|---|---|
| 0.00 | 0 |
| 0.005 | 139 |
| 0.01 | 3000 |
| 0.015 | 5000 |
| 0.02 | 19,000 |

The effect of the bearing error on the Range computation can be well understood by the following war time illustration. Let us consider two sensors (hydrophones) S1 and S2 located at the coordinates (0,0) and (0,500 m) respectively. A target is considered to be initially at a range of 15 km and an azimuth of 100°. It is considered to be moving with a constant course of 90° and a velocity of 10 m/s. The two hydrophones S1 and S2 capture the azimuth measurement of the target after every 1 s duration. The measurements contain noise with a Gaussian density function. The noise is unbiased i.e. the mean of the noise is zero. By using the concept of triangulation the range is computed. Now let us compare the error in the position as a function of the variance of the measurement noise.

From Fig. 2 and Table 1, it is apparent that the average range error is much more threatening for large variance of bearing errors compared to small variances.

*Observation*: Even small increments in variance of bearing error can cause a huge error in range or position. Or in other words if we can reduce the variance of the bearing error by even a small value, then we can achieve significant improvements in the position estimation. The process of reducing the variance in the angle error is called pre-processing. So we can say that the pre-processing of measurements before application of any stochastic estimator can improve the overall performance.