Improving Height Estimation of Primary Surveillance Radars using Secondary Surveillance Radar

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***Abstract*: Height Information of air target is necessary for generating accurate air surveillance picture in multi sensor environment. The height information provided by the Primary Surveillance Radars (PSR) is not very accurate. In the multi sensor environment height from the different sensors have huge variations due to which it is not possible to estimate correct height of the air target. A secondary surveillance radar (SSR) is normally used to interrogate the Mode C and other transponders to obtain height information of the air target. The height information provided by SSR are relatively more accurate. This paper proposes an algorithm to efficiently use the height information provided by the PSR based on a decision matrix which is calculated with the help of height provided by SSR. We enhance our proposition by simulations. The proposed methodology has potential to be used in Real time multi sensor environment.**

Keywords—Primary radar, Secondar Surveillance radar, Friendly targets, Height Estimation

I. INTRODUCTION

The incorporation of radar technology to detect targets is not new and has been in operation since World War II. All the sections of defence forces use radars to detect the enemy position and enemy tracks. Targets tracking is an important area of research and development for defence sectors as well as civilian applications [1]. The air space situational awareness is an important part of surveillance of air tracks. Multi radar tracking (MRT) is an extensively used technique for naval-based target tracking applications. In multi-platform and multi sensor data fusion systems [2], the information obtained from multiple radars located at different places are fused to get crisp track estimates.

Various types of radars are used in operations for estimating the target positions. These radars comprise of 2-D, 3-D and are utilised in the MRT process to estimate the target positions in 3-D. Particularly 2-D radars provide range and azimuth information of a target that is used for ship-based tracking. As the plot data supplied by the 2-D radar contains only range and azimuth information, it is not possible to estimate target height with a single sensor due to observability problem, so that there is a need to combine the information (range and azimuth) obtained from multi 2-D radars. If an aircraft is detected by only two primary radars, it is not possible to use multi-lateration techniques to determine its altitude in an air traffic control system. A primary surveillance radar (PSR) provides only slant range and azimuth measurements of an aircraft, and hence, an air traffic control (ATC) system usually uses the altitude information obtained from the aircraft's on-board mode C transponder to estimate aircraft’s three dimensional position and velocity. A secondary surveillance radar (SSR) is normally used to interrogate the mode C and other transponders and obtain altitude and other information about the aircraft.

The height information provided by the PSR is not very accurate due to high level of inaccuracy. In the multi sensor environment height from the radars have huge variations due to which estimation of height has some discrepancies. The fusion of height information from more than one sensor is also not possible due to inaccuracy and variation of height. SSR is normally used to interrogate the mode C and other transponders for obtaining height and other information about the air target. The height information provided by SSR is relatively more accurate. The problem with SSR is that it does not provide height information for longer duration. Only friendly air target reply to the interrogation by SSR. The enemy air target either do not reply to the SSR interrogation or provide wrong information. Due to high level of inaccuracy of primary radars a single track is shown at different height from different radar. The behavior of the radars is also not consistent throughout the life of a track. In some sector particular Primary radar may give correct height and in some other sector it may perform badly. We cannot completely rely on a particular primary radar from given pool of radars for getting the height information of a track. The height provided by Primary radars cannot be used for further estimation of correct height of the air target.

Fusion of the height from more than one primary radars is also not possible.

This inconsistency in the height estimation is to be solved by using the secondary surveillance radars. This present paper proposes an algorithm to efficiently use the height provided by the PSR on the basis of a decision matrix which is calculated with the help of height provided by SSR. All the PSR detect the height of the target and deliver them to a decision center. The decision center is responsible for prioritizing the primary radars based on their accuracy. The decision matrix is prepared by calculating the statistical distance with the help of height provided by PSR and SSR. The decision matrix is created in the random environment and the whole process is stochastic and dynamic in nature. This decision matrix is updated iteratively whenever the SSR height is available.

The basic premise of the works is to priorities the primary radars on the basis of their relative accuracy using SSR. To the best of our knowledge this is a novel idea that has come up. Usage of SSR height makes it possible to use height information provided by the best available PSR. The proposed algorithm takes input from PSR and SSR and suggest a decision matrix which is having the priority list of all the radars. This matrix can be further used to estimate the correct height information based on the accuracy level of PSR. The decision matrix shows the priority of the PSR based on their accuracy level. The proposed methodology has potential to be used in Real time multi sensor environment. The paper is organized as follows. Section II presents the literature survey of altitude estimation. Section III discuss the proposed solution using our proposed approach with algorithms. Section IV discusses the experimental setup and simulation results supporting our claim of improved height estimation using secondary radars. Finally, concluding remarks are presented in section V.

II. LITERATURE REVIEW

The current literature regarding height estimation restricts itself to computations involving two or more 2D radars where the height can be completely determined by simple geometric computations. It suggests a mathematical method to infer aircraft altitude from two updates given by a single 2D radar [3]. A single 2D radar source cannot directly determine the altitude of aircraft, thus naturally, the method presented here is either coupled with a number of assumptions and limitations or is a mere approximation. The terms height and altitude are often used interchangeably. Height refers to the height of an aircraft above ground level, and altitude the height of the aircraft above mean sea level [4]. Triangulation [5], [6] can be used to better estimate the altitude. But if the aircraft is under the coverage of only two PSRs, trilateration or triangulation is no longer possible. There has been some related work on altitude estimation using primary radar and non-linear filtering [7, 8]. Due to poor observability of the altitude, given only the slant range and azimuth measurement, the filtering schemes require multiple nonlinear filters, such as extended Kalman filter (EKF) and unscented Kalman filter (UKF). Meanwhile, the feasibility of a solution depends on whether the aircraft trajectory provides enough observability. Thus, the estimation method in [7, 8] is not necessarily a practical solution. However, the analysis in [7,8] is informative in helping to understand the challenge in altitude estimation using PSRs only.

In [5], a method to estimate the altitude using single 2-D radar by fitting the range curve from a few range measurement data is proposed, but the altitude estimation errors are large [6]. This is caused by the low observability of the target states from single radar, which suggests that we use more radar. In [7], 3-D tracking approach using measurements from two or more 2-D radars in World Geodetic system (WGS-84) coordinates is proposed. However, the root mean square error (RMSE) of three dimensional positions therein makes it not very attractive for practical applications. In [8], an algorithm referred to as the height-parameterized extended Kalman filtering (HPEKF), which incorporates the autonomous multiple model (AMM) method [9], is presented. In particular, the altitude interval of interest is first partitioned into subintervals, an independent extended Kalman filter (EKF) is run for each of the intervals, and finally the overall target's state estimate is obtained by combining the EKF models' state estimates. In [10], another altitude estimation method using a 2-D radar network is proposed. This method considers the earth surface's curvature and employs the maximum likelihood (ML) estimator to find the target's altitude using the measurements obtained from synchronous multiple radars. Recently, an approach for altitude estimation and mitigation of slant range errors on 3-D target tracking with 2-D radars has been proposed in [11], where it uses measurements in polar coordinates and state vectors in geodetic coordinates.

III. PROPOSED SOLUTION

The setup for the problem statement is shown in Fig. 1. Three PSRs (PSR1, PSR2, and PSR3) are used to detect the height of the hostile target whose true height is h1. Height of the target detected by three PSRs (PSR1, PSR2, and PSR3) are h11, h12, h13 respectively. First, we show the comparison of the inaccuracy associated with the height provided by the three PSR for same track. The actual height of the friendly target (h2) is detected by the SSR and h21, h22, h23 are the heights detected by the three PSRs.

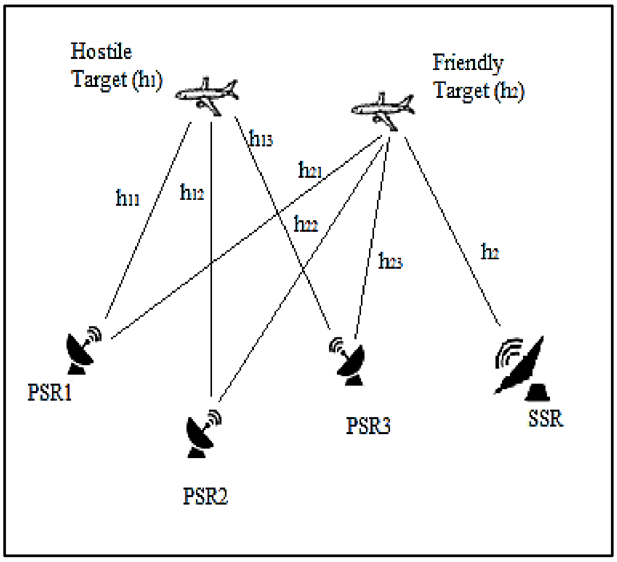

Fig. 1: Problem Statement: Three primary radars (PSR1, PSR2, PSR3) and one SSR

The Gaussian Likelihood function is described below:

$$\pounds(x_i|x_s,\sigma) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{1}{2\sigma^2}(x_i - x_s)^2} \; where \; i = 1, \ldots 3 \qquad (1)$$

where x_i is the height of the target detected by PSRs and x_s is the height of the target detected by SSR. σ is the standard deviation and is defined as

$$\sigma = \sqrt{\sigma_i^{\,2} + \sigma_s^{\,2}} \qquad (2)$$

A dynamic matrix of Gaussian likelihood is formed by using equation (1) for all the PSRs for the same track. The accuracy of the PSRs shall be validated by its likelihood score. The elements of the matrix shall be arranged as per the respective likelihood score as shown in equation (3).

$$\begin{bmatrix} PSR_1 \\ PSR_2 \\ PSR_3 \end{bmatrix} = \begin{bmatrix} \pounds_1 \\ \pounds_2 \\ \pounds_3 \end{bmatrix} \qquad (3)$$

where $\pounds_1$ is the maximum likelihood score and $\pounds_3$ is the minimum likelihood score. When all the PSRs are available we will use the PSR_1 corresponding to $\pounds_1$. In case the data from the PSR_1 having maximum likelihood is not available data of the PSR_2 having second best likelihood score ($\pounds_2$) shall be used and so on. Every time the data from SSR is available the likelihood matrix in equation (3) shall be updated. The flow chart of our proposed algorithm is as shown in Fig. 2.

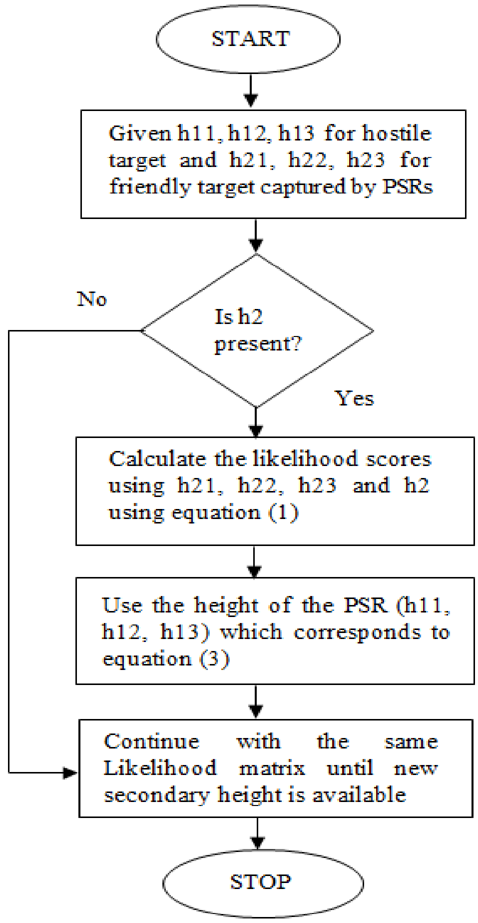

Fig. 2: Proposed Algorithm for height estimation

IV. Results and Discussions

The numerical results are produced in this section. All the simulations are carried out in MATLAB (version R2014a). The standard deviation of all the PSRs are taken as 90 meters and standard deviation of the SSR is taken as 15 meters in all the calculations performed here. Fig. 3 shows that the height reported by all the three PSRs are having large variation in comparison to the true height of the target. The figure also shows that the accuracy of the PSRs is not consistent with time.

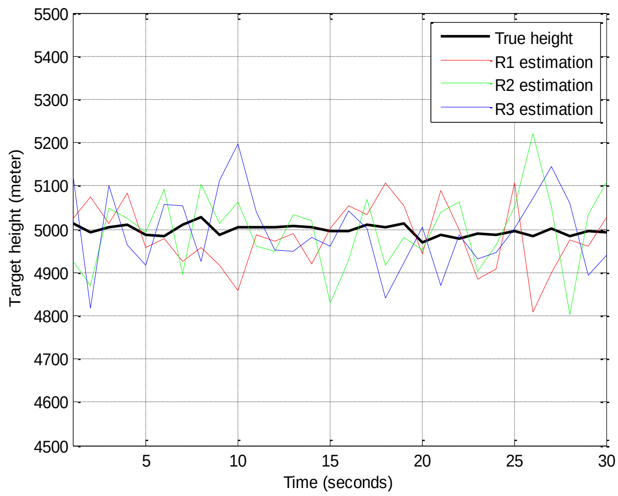

Fig. 3: Target height captured by various PSRs and the true height of the target

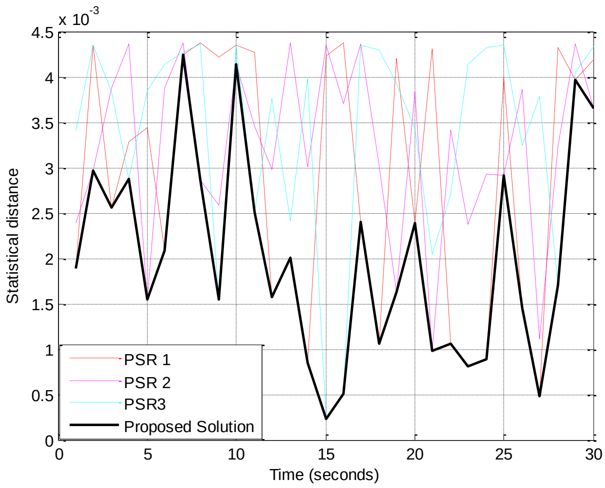

Fig. 4: Statistical Distance of various PSRs with respect to SSR and Proposed solution

Fig. 4 shows the Statistical Distance (SD) of PSRs calculated with respect to SSR at different time instance. At t=5 sec SD of PSR2 is minimum, at t=6 sec SD of PSR3 is minimum and at t=12 sec SD of PSR1 is minimum, so none of the PSRs is consistent over the whole duration of time. So it becomes difficult to rely on a particular PSR for whole duration. To overcome this problem, we have proposed the solution to effectively utilized best available PSR at any instance of time with the help of SSR. It can be clearly seen that the SD of our proposed solution is showing the best result.

V. CONCLUSION

This paper has proposed a framework to illustrate that secondary radar analysis helps us to efficiently use the height estimation of primary surveillance radar at any given instance of time. We will have enough options to choose between multiple radars for better height estimation of air tracks on the basis of decision matrix. This decision matrix is dynamic and have potential to be used in Real Time situation for multi sensor target tracking.

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