Multilateration Techniques for a Multistatic Hitch-hiker radar for Anti-Stealth application

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Abstract:

Multistatic radars use the single transmitter and multiple receivers or vice versa and jointly process the signals to improve the detection, localisation and tracking. When the transmitter of opportunity of multistatic radar is another radar; it is referred as hitch-hiker. This paper presents a mulilataration localisation technique for a hitch hiker multistatic radar. A multisatic radar comprises of one transmitter and three receive stations geographically distributed is considered here for analysis. In this work, elliptic, hyperbolic mutilateration along with bistatic radar localisation techniques is proposed to improve the localisation accuracy. After extensive simulation and analysis it is concluded that multilateration in its direct form such elliptic and/or hyperbolic method cannot used in multistatic radar. Multilateration along with triangulation and superior signal processing and tracking algorithms will results in a practical multistatic radar.

I. INTRODUCTION

The basic principle of bistatic radar[1][2] and its extension to multistatic radar [3] offers enormous benefits compared to monostatic radar. But it brings in so many complexities and design challenges. One of the major challenges is the localisation of the target. In this work, multilateration technique to address the localisation problem of a hitch-hiker multistatic radar is investigated. The hitch-hiker multistatic radar consists of transmit station i.e a monostatic mechanically rotating radar, receiver station is a multi-channel receiver which is realised through digital beamforming. The bistatic receiver measures the delay transmitter to target and target to receiver. This delay sum results in ambiguity of ellipsoid in range whose foci are transmitters and receivers. Due to the wide beamwidth of the receiver, there will be a crude initial estimate of azimuth and range. A new localisation technique, multilateration[4][5] both elliptic and hyperbolic along with triangulation is promising for multistatic radar. It is found that the elliptic method is naturally well suitable for multistatic radar. However, it suffers from geometry dependant error and solution of large numbers of nonlinear simultaneous equations in real time. Similarly, the hyperbolic method works on the Time Difference of Arrival (TDOA) among receive stations. Constant TDOA results in hyperboloid whose foci are two receiving stations. When the numbers of targets are large, clutter false alarms more, multilateration needs to solve large numbers of equations in real-time. So, the combination of both elliptic, hyperbolic and triangulation methods are used for practical application. Further, the judicious choice of the bistatic nodes in terms of SNR and geometry is relation with the localisation techniques to get the best estimate of locations play a major role in detecting and tracking targets, especially stealth targets such as UAV and fighter aircrafts.

The paper is organised in the following manner. Section-II introduces the multistatic radar. It also explains about the interference and multipath clutter scenario in a bistatic station of a multistatic radar. In section-III the signal processing aspect of multistatic radar is discussed. Theory of multilateration technique is covered in section-IV. Section-V details out the simulation and analysis of both elliptic, hyperbolic method. Finally the paper in concluded in section-VI.

II. MULTISTATIC RADAR

A multistatic radar system is one where multiple independent spatially diverse (monostatic or bistatic) radars are networked, each radar performs some local processing, and the outcomes of this processing are made available to a central processor through communication links. A Passive multistatic RADAR is a radar that does not emit any RF signal of its own to detect targets. It utilizes already existing RF energy in the environment or a transmission from a different location. Examples of such sources of RF energy are Broadcast FM stations, Global Positioning Satellites, Cellular Telephones, and Commercial Television or our own Transmission. When the radar transmitter of opportunity is radar, the terms such as: Hitchhiker or parasitic radar are often used. When the transmitter of opportunity is from a non-radar transmission, such as broadcast communications, terms such as: Passive multistatic radar, Passive coherent locator, or multistatic bistatic radar are used. The Fig.1 shows the configuration of multistatic radar system with one transmitter and multiple receivers.

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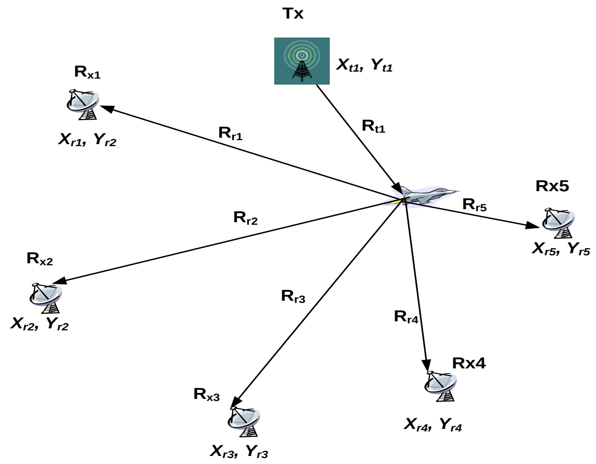

Figure 1 Multistatic Radar Configuration

In this paper a passive multstatic hitch-hiker radar where the transmitter is an radar is considered for study and simulation. Hereafter, for the sake of simplicity we use the term multistatic radar in stead of multistatic hitch hiker radar.

Multistatic radar has numerous advantages over conventional monostatic radar.

Merits:

i) The receiver is entirely passive and is undetectable by the opponent radars.
ii) Multistatic radar requires no spectrum allocation and has minimal impact on the environment.
iii) Stealth technology is less effective on multistatic radar. Since stealth aircraft are designed to have low RCS towards the emitter, the target reflects electromagnetic energy in other directions. Hence it might reflect maximum energy at places where passive receivers are placed.

Some of the demerits and challenges of multistatic radar systems include complex geometry and processing, communication and data fusion between sites, reduced line of sight because of needed line of sight from several locations.The Fig. 2 explains about the multipath clutter, target echo and indirect reference signal in multistatic scenario

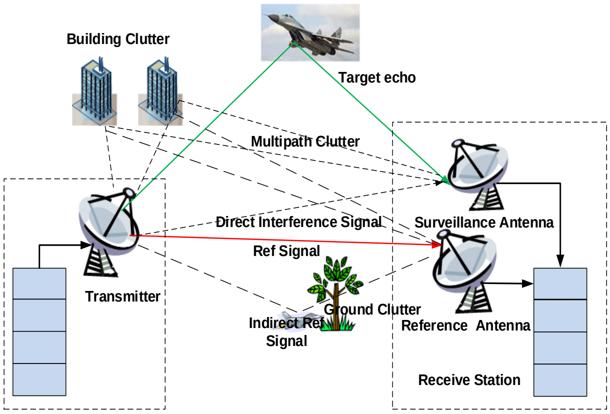

Figure 2 Passive bistatic radar operational scenario

II. MULTISTATIC RADAR SIGNAL PROCESSING, LOCALISATION AND TRACKING

The detction and localisation process in MSADR follows two stage processing. The first stage processing is done is at each bistatic receive station. Bistatic signal processing comprises of digital beamforming is to supress the inteference, cross-correlation for pulse compression and doppler procesing followed by CFAR for detection and range doppler and azimuth estimation. For 360 degree coverage six to eight receivers are used. The each receive beam width is in the order of 45^0 for eight receiver and 60^0 for six receiver configuration. The ambiguity of range will be the ellipsoid with foci at transmitter and receiver location.

The first stage of processing coarse co-ordinates of target is estimated with respect to each pair of bistatic station. The measurement generally ambigous and inaccurate. In the second stage the global co-ordinate of the target is estimated by processing across the receive stations. The multistatic signal processing include the distributed detection to reduce the false alarm (P_{fa}) and improve the probality of detection (P_d). The multilateration scheme localises the position of the target by solving at least three or four simultaneous equation in 2D/3D to locate the target.

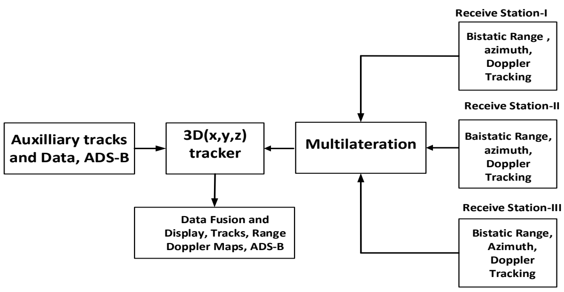

Figure 3 Signal processing block diagram of a multistatic radar

The resolved targets are used in the tracker to estimate the state. The Kalman filter both linear and non-linear forms is used to handle geometric dependent measurement error along with white guassian measurement noise.

IV. MULILATERATION TECHNIQUES

Multilateration technique uses the Time of Arrival (TOA) and Time Difference of Arrival (TDOA) at different stations. The localisation accuracy is a function of error time measuremet, geometry of the tx/rx station with respect to taregt and of course the signal-to-noise-ratio. The targets that are detected by the respective receiver sites gives the range, doppler data or plot level data to the centralised station where the final target tracking takes place. As discussed earlier, the target detected by each Tx-Rx pair lies on an elliptic contour with Tx-Rx as the foci. For a given target, each Tx-Rx pair has its own elliptic contour and the intersection of the multiple ellipses gives the location of actual target position. Fig.5 shows the basic diagram of possible target ellipses and target localisation with a multistatic radar system. It consists of one transmitter at the centre and receivers surrounding it. Each Tx-Rx pair is by itself a bistatic radar system with Tx-Rx as foci. The detail explaination of both elliptic and hyperbolic method is given below.

Elliptic Method:

The constant sum of transmitter to target (R_T)and target to receiver(R_R) range for each bistatic pair is forms a ambiguity on ellipse i.e the constant range sum (Sum of time of arrival "TSOA"). The elliptic multilataration is explained in the following set of three equations of ellipsoid. The tramsmitters, receivers and target locations, transmitter T_i (x_i,y_i,z_i), receiver R_j (x_j,y_j,z_j) receiver R_k (x_k,y_k,z_k), receiver R_l (x_l,y_l,z_l) and target *(x,y,z)*.

$$T_i + R_j = \sqrt{(x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2} + \sqrt{(x_j - x)^2 + (y_j - y)^2 + (z_j - z)^2} \quad (1)$$

$$T_i + R_k = \sqrt{(x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2} + \sqrt{(x_k - x)^2 + (y_k - y)^2 + (z_k - z)^2} \quad (2)$$

$$T_i + R_l = \sqrt{(x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2} + \sqrt{(x_l - x)^2 + (y_l - y)^2 + (z_l - z)^2} \quad (3$$

Where, T_i + R_j is the sum of distances from transmitter T_i and receiver R_j , T_i + R_k is the sum of distances from transmitter T_i and receiver R_k , T_i + R_l is the sum of distances from transmitter T_i and receiver R_l. The resultant ellipsoid expression for each pair of transmitter and receiver pair is given in equation (1,2,3). The above equations are for the single target, simillarly for more numbers targets that many numbers of ellipsoid equations and the intersection of ellipsoid equations gives the true location of the target.

Hyperbolic Method:

Another method of multilateration is the hyperbolic method which use Time Difference of Arrival (TDOA) among two receivers to locate the target. Constant TDOA of taregt at two receivers results in surface of points as hyperboloid. This method is polpularly used in passive localisation of radiating sources, especially for Electronic Warfare (EW) application. However, this method is simpler and it does not require the timing information about the transmitter. Linearization of simultaneous equations is easier in hyperbolic method. The following four equations of hyperboloid for single target localisation.

$$R_i - R_j = \sqrt{(x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2} - \sqrt{(x_j - x)^2 + (y_j - y)^2 + (z_j - z)^2} \quad (4)$$

$$R_i - R_k = \sqrt{(x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2} - \sqrt{(x_k - x)^2 + (y_k - y)^2 + (z_k - z)^2} \quad (5)$$

$$R_k - R_j = \sqrt{(x_k - x)^2 + (y_k - y)^2 + (z_k - z)^2} - \sqrt{(x_j - x)^2 + (y_j - y)^2 + (z_j - z)^2} \quad (6)$$

$$R_k - R_l = \sqrt{(x_k - x)^2 + (y_k - y)^2 + (z_k - z)^2} - \sqrt{(x_l - x)^2 + (y_l - y)^2 + (z_l - z)^2} \quad (7)$$

Whrere, R_i - R_j is the difference of distances from receiver R_i and receiver R_j , R_i - R_k is the difference of distances from receiver R_i and receiver R_k, R_k - R_j is the difference of distances from receiver R_k and receiver R_j, R_k - R_l is the the difference of distances from receiver R_k and receiver R_l.

IV. SIMULATIONS

A simulation set up is establised with a multistatic radar as shown in Fig.4. It has one transmit station (transmitter/receiver) and three receive stations to cover 50 km x 50 km area. The transmitter is located at (0,0) location and Rx1 is at (-25,-25), Rx2 (0,-25), Rx3 (25,-25). Both types mullilateration techniques are simulated (i) elliptic method (a) single target both stationary and moving b) multiple stationary targets. It is observed that if in the elliptic method only using two receive stations are used, ghost targets get gerenated as two ellipse intersect in four points. But with the three ellipses, the target at (10,20) is located umbigousely. However, the intersection of ellipses is highly dependent on transmitter and receiver deplomements w.r.t target under surveillance. It was found that for practical application solving at least three simultaneous equation in 3D is not trivial. Further, when more number targets and false detections from clutter and noise, the mulilateration localisation scheme becomes extremely computatinally intesive to solve large numbers of simultaneous equations in real time. In addition, more numbers of ghost targets generated due to the non-linear nature of elliptic and hyperbolic equation in 3D degrades the localisation perfromance. . In hyperbolic method single target both in stationary and moving state is also simulated as shown in Fig.7 Hyperbolic method requires four minimum numbers of receivers are required, as it works on TDOA between receivers. The extra rceiver of the monosatic radar is at transmitter station is used as the fourth receiver for hyperbolic multlateration. Here for lack of space animation part of moving target could not accomodated in this paper.

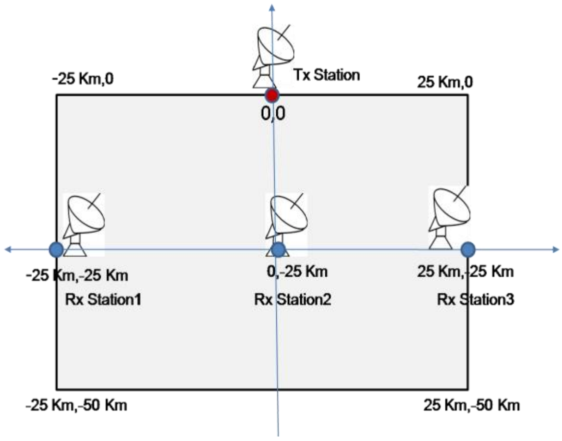

Figure 4 Multistatic radar system

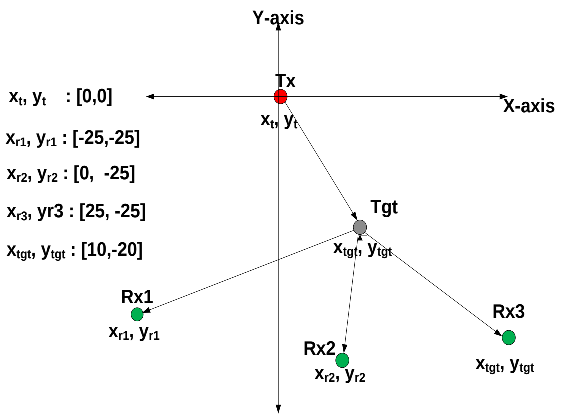

Figure 5 Geometry of transmitter, receiver and target

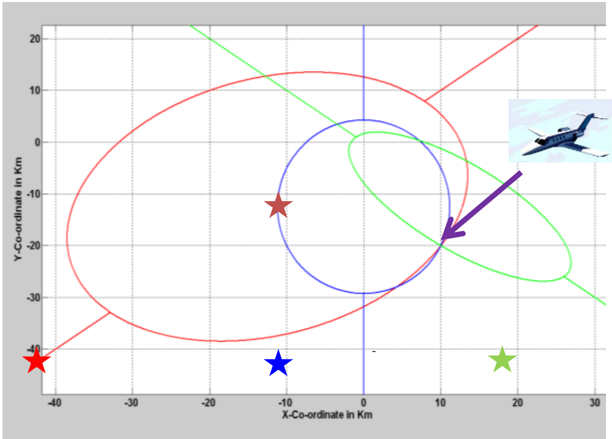

Figure 5 Elliptic multilateration method for target tracking

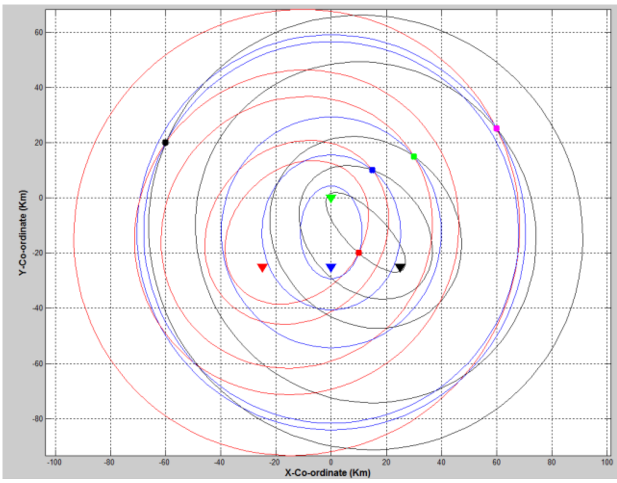

Figure 6 Elliptic multilateration method for more numbers of targets

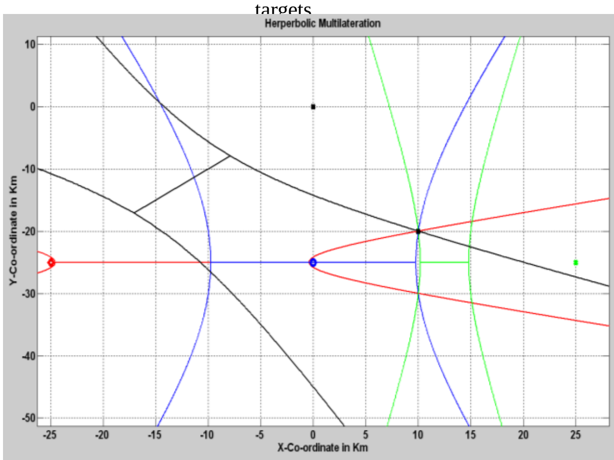

Figure 7 Hyperbolic multilateration method for target tracking

IV. CONCLUSION

Multistatic radar will be a practical reality due to the maturity of Passive Coherent Localisation

(PCL) and multilateration technique. However, for radar application standard multilateration techniques can not be directly used. The reason being that to localise large numbers of targets, solution of large numbers of simultaneous equations in real time is computationally prohibitive. Further, large numbers of ghost targets due to non-linear nature of elliptic and hyperbolic multilateration equations will results in excessive false tracks. To circumvent these aforementioned problems a combination of triangulation and multilateration is arrived. Furthermore, a need of an effective signal processing and tracking mechanism is required to enhance the signal-to-noise-ratio (SNR) to obtain reliable and unambigious detection to exploit the benefits of multilateration.

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