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Localization Algorithm for Multilateration System Using Hyperbolic Localizations

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***Abstract*— This paper is focused on localization algorithm for multilateration (MLAT) system for aircraft traffic control (ATC) operations. MLAT is a proven technology that has been in use for many decades. The multilateration system was developed for military purposes to locate the aircraft accurately. The provided localization algorithm locates a source based on intersections of hyperbolic curves, which is defined by TDOA (time difference of arrival) of a signal received by a number of sensors. The main objective of this paper is to locate the accurate position of the target and analyse its error, performance study, compare the given method with other methods, and show that how this method works better than other methods. In addition, the TOA (Time of arrival) estimation method is explained. Provided localization algorithm addresses the problem accuracy of position of the target .The mathematical equations of this method, is introduced. Furthermore, the provided hyperbolic localization method performs better than Chan and Taylor series method. In this context, some simulations are performed. Error estimations are also done where we have applied AWGN noise. In this paper, the hyperbolic localization performance analysis is done by GDOP (Geometric dilution of precision), HDOP (Horizontal dilution of precision) and MSE.These performance analysis parameters are calculated for each method .Finally, the results are compared and it is observed that the provided hyperbolic localization methods accuracy is better. It gives an explicit solution .This method is simple, efficient and non-iterative. The solution is in closed form, which is valid for both close and distant sources. Moreover, the multilateration system overcomes several issues like; it requires no additional avionics equipment, as it uses replies from modes A, C and S.**

Keywords: Multilateration(MLAT), Time of arrival(TOA),Time difference of arrival(TDOA), Localization, Air traffic control(ATC), Geometric dilution of precision(GDOP) ,Horizontal dilution of precision(HDOP).

I. INTRODUCTION

Several different position location (PL) technologies present themselves as candidates for a mobile radio PL system. However, radio frequency (RF) PL systems have dominated the field because they offer advantages of relatively low cost, ease of integration and potentially high accuracy. Radio frequency PL techniques also work with the existing cellular/PCS infrastructure, eliminating the need for external network implementations. Furthermore, radio frequency systems may operate, to a limited extent, in cases where other PL methods completely fail, such as when the line-of-sight (LOS) to the source is not available. Radio frequency PL systems attempt to locate a source by direct measurements on radio signals traveling between the transmitter and receiver. The hyperbolic PL technique, also known as the time difference of arrival (TDOA) PL technique, utilizes cross-correlation techniques to estimate the TDOA of a propagating signal received at two receivers. This delay measurement defines a hyperbola of constant range difference from the receivers, which are located at the foci. When multiple receiving stations are used, multiple hyperbolas are formed, and the intersection of the set of hyperbolas 1 2 provides the PL estimate of the source. The hyperbolic position location technique offers the advantages of not requiring additional hardware or software within the mobile unit, ability to resolve ambiguities in the PL estimate and minimizing the effect of noise within the mobile radio channel. Many organizations are developing competing products to comply with the FCC's E-911 mandate, which requires U.S. cellular carriers to provide location information of phone calls, effective October 2001. The accuracy required is 100 meters or better. Many of these products will implement the above-mentioned time difference of arrival technique for locating a mobile with varying degrees of accuracy. Methods for calculating the TDOA and mobile position have been reviewed previously [1][2]. Some methods calculate the two dimensional position and others the three-dimensional position depending on the degree of simplicity desired.

II. LITERATURE REVIEW

Multilateration is a surveillance technique that is based on the measurement of the difference in distance between two stations at known locations by broadcasting the signals at known times. The measurements of absolute distance or angle, measuring the difference in distance between two stations results in an infinite number of locations that satisfy the measurement. When these possible location are plotted, they form a hyperbolic curve. For locating the exact location along that curve, it relies upon multiple measurements, therefore a second measurement taken from a different pair of stations, which will produce a second curve. This second curve will intersect with the first one. When these two curves intersect, a small number of possible locations will be seen.

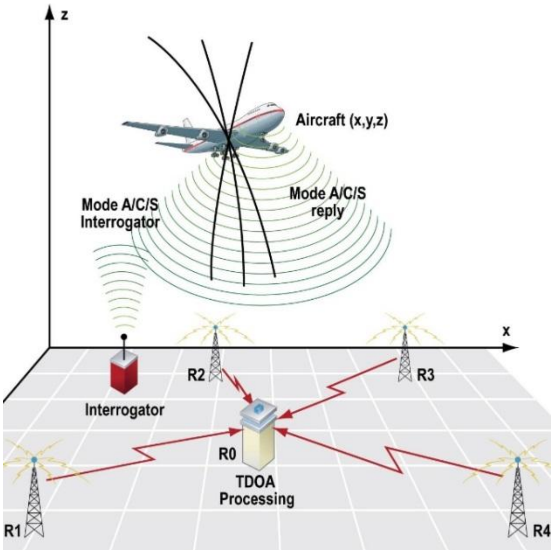

Figure 1 Multilateration System using in the aircraft

Here,we see a transmitter on the aircraft. Four receiver R1,R2,R3 and R4 .It uses modes A/C orMode S signal for interrogation . R1,R2,R3 and R4 are receiving signal from the aircraft and a TDOA processing unit(central processing unit) calculates the aircraft position from the TDOA(Time difference of arrival) of the signal at different receivers. When the four receiver detect the aircrafts signal, then it will estimate the 3D position of aircraft location by calculating the intersections of the resulting hyperbolas. MLAT application provides a source of airport surveillance information for safer and more efficient ground movement management at airports. Relevant airport ground vehicles need to be equipped and displayed, together with aircraft, on a situational display. MLAT supports ground conflict detection by providing frequent updates of aircraft's position. The MLAT system used by different organizations as commercial , general ,and Military Aviation.[35] Multilateration System is becoming an important surveillance and identification system for large airports. The advantages of MLAT over conventional SSR (Secondary surveillance radar) is that, it is cheap to install and easy to maintain. It is more accurate than others are and it works better, where other conventional radar has problems with large rotating.antenna

2.1 Multilateration Principle:

Multilateration system consists of a number antennas and these antennas receive signal from the aircraft and a central processing unit and calculates the aircrafts position from the time difference of arrival (TDOA) of the signal at the different antennas. Mathematically, TDOA between two antennas corresponds, with a hyperboloid in three-dimensional on which the aircraft is located. When four antennas detect the aircrafts signal, then we can estimate the aircrafts three-dimensional location by the intersections of resulting hyperbolas. When three antennas are available, a 3D position cannot be estimated directly, but if the target altitude is known from other source (like-Mode C) then the target can be located. This is actually referred as a 2D solution. With more than four antennas,extra information can be used .Verifying the correctness of the other measurements or calculating an average position from all measurements, which should have an overall small error.[5]

Position location systems can be classified into two broad categories: direction finding (DF) and range-based PL systems [4]. Each of these systems can be classified as a satellite or terrestrial based system, indicating whether the base station is located on the surface of the earth or on orbit around the earth. Direction finding systems estimate the position location of a source by measuring the direction of arrival (DOA), or angle of arrival (AOA), of the source's signal. The DOA measurement restricts the location of the source along a line in the estimated DOA. When multiple DOA measurements from multiple base stations are used in a triangulation configuration, the location estimate of the source is obtained at the intersection of these lines. Consequently, direction finding PL systems are also known as direction of arrival or angle of arrival PL systems. Range-based PL systems can be categorized as a ranging, range sum, or range difference PL system [6]. The type of measurement used in each of these systems defines a unique geometry, or configuration, of the position location solution. Ranging PL systems locate the source by measuring the absolute distance between a source and the receiver. Range measurements are determined by estimating the time-of-arrival (TOA) of the signal propagating between the source and receiver. The TOA estimate defines a sphere of constant range around the receiver. The intersection of multiple spheres produced by multiple range measurements from multiple base stations pro- vides the 5 6 position location estimate of the user. Consequently, ranging systems are also known as TOA or spherical PL systems. Most practical ranging systems are unable to measure the range between the user and a base station directly, and as a result, measurement of the range and a bias term is commonly performed. This bias term can be calculated using an additional range measurement by an additional base station. Ranging systems of this type are often called pseudo-range systems. Range sum PL systems measure the relative sum of ranges between the source and receiver respectively. These systems measure the time sum of arrival (TSOA) of the propagating signal between two base stations to produce a range sum measurement. The range sum estimate defines an ellipsoid around the receiver, and when multiple range sum measurements are obtained, the position location estimate of the user is at the intersection of the ellipsoids [7]. Consequently, range sum PL systems are also known as TSOA or elliptical PL systems. Range difference PL systems measure the relative difference in ranges between the source and receiver respectively. These systems measure the time difference of arrival (TDOA) of the propagating signal between two base stations to produce a range difference measurement. The range difference measurement defines a hyperboloid of constant range difference with the base stations at the foci. When multiple range difference measurements are obtained, producing multiple hyperboloids, the position location estimate of the user is at the intersection of the hyperboloids [8]. Consequently, range difference PL systems are also known as TDOA or hyperbolic PL systems.

The accuracy of target localization is mostly determined by TOA measurement errors and multilateration solving algorithm. TOA is defined as the time of signal from the transmitter to the receiver which is composed with two parts: time from transmitter to target and time from target to receiver. Target position is obtained through the solution of the TOA equations [9]. There are T □ R path between transmitters and receivers, whereT is number of transmitters and R is number of receivers. Therefore the number of equation is T □ R and far more than the unknown variable, target coordinates. So TOA is redundant comparing with target localization. Accumulation of TOA measurements errors may lead to worse accuracy than a single TOA measurements error. On the contrary, offset of TOA measurements errors may obtain better accuracy. Besides, the TOA equations are nonlinear and over determined. To solve the nonlinear equations, a simple way is to substitute them with approximate linear equations. Taylor expansion is a classical method to solve nonlinear equations and was used in[10]-[14]. Since target location is unknown at the beginning, the point of Taylor expansion is uncertain too. So the initial target position should be estimated by other method or used in tracking. After target coordinate is calculated from TOAs, other parameters, e.g. distance, direction angle, elevator angle, speed, .etc can be drawn from coordinates. In [15], parallel factor analysis is used to solve detection and location of multi-target. In [15], the phase errors in coherent processing and the Cramer–Rao lower bound (CRLB) are discussed. Doppler-shift and angle information are exploited in [16] and target position is found by searching the desired area using the grid search method. In this paper, we observe the path from a receiver, as shown in 0, and then set a transmitter as reference station. Letting TOA from any transmitter subtract the TOA to reference station, the TOA equations are change to TDOA equations. Since all paths from transmitters to a receiver share same path between the receiver and the object, the localization is same as passive localization after the subtraction. Then some classic localization methods can be This work was supported by the China National Science Foundation under Grant 61079006. used. Each receiver can obtain similar equations in same way. Averaging these equations on all receivers leads to averaging on TDOA measurement errors which can decrease the variance of TOA measurement errors.[17]-[20]

III. RESEARCH GAP

In this age of advancement in technology, communication, more particularly position location technique is of great importance in both military and civilian applications. There is inability in determining actual positions of the sources and chances of not getting the accurate location of the aircraft. Accessibility of accurate information from basic and manual system is difficult. Sometimes data is mismatched. So, estimation of the position of different moving sources is difficult. Estimation of the position of the target depends upon the measurement of TDOA (Time difference of arrival).This research, therefore, seeks to find a suitable and efficient localization algorithm for Multilasteration system. It provides extensive studies on hyperbolic localization algorithm in Multilateration system, where several concerns are investigated. A detailed analysis of its performance study, which is based on GDOP, HDOP, MSE along with a comparison with other two-localization algorithm.

IV. METHADOLOGY

Here we present an comparative study and analysis about Chan ,Taylor and Hyperbolic approach.

4.1 Hyperbolic location estimator with equations

For getting accurate position of a source an efficient hyperbolic location estimation algorithm is required. For that hyperbolic location algorithm, TDOA is very important. These TDOA will be responsible for hyperbolic curves and the curves will be responsible for producing an accurate and unambiguous solution for position localization problem. Our provided algorithm is based on TDOA estimation. The position localization of a target is determined from the intersection of hyperbolic curves, which are produced from TDOA estimation. The hyperbolic curves equations are a set of non-liner equation. It is not easy to solve non-linear equation.

If the set of hyperbolic equations are equal to the number of unknown co-ordinates of the source, then that system is consistent and a unique solution is obtained. If the system is inconsistent system, in which the redundant range difference measurements are made, the solving of this problem becomes more difficult as no unique solution exists. Direct non-linear solution to inconsistent system can give accurate results where they tend to be computationally intensive. Linearization of these equations is used to simplify the computation of the position localization solution.

4.2Simulation Analysis and Comparison

The TDOA (Time difference of arrival) estimates are converted into range difference measurements. These measurements can be converted into hyperbolic equations. These hyperbolic equations are non-linear. To solve nonlinear hyperbolic equations is not an easy task. Several algorithms have been provided for solving these equations .All algorithm have different complexities. Here, three methods are discussed which is related to this research.

4.2.1 Hyperbolic Location Algorithm

This is the provided hyperbolic estimator method which is very efficient method. This is the new approach for localizing a source from set of hyperbolic curves, which is defined by TDOA measurements.

A different way for localizing a source from a set of hyperbolic curves defined by TDOA measurement, is provided. This approach is non-iterative and gives an explicit solution. This solution is in closed form, which is valid for both distant and close sources. This method is better than Chan, Taylor and Fang method.

Method for simulation:

Basically, in this method one transmitter and four receivers are used.At first, the position for receiver and transmitter has been set. Based on that, we got one position for transmitter and four receiver. Now, after setting the positions for receivers and transmitter, have to apply cross correlation for calculation of TDOA and TOA.

According to Cross correlation, we will calculate the signal spectral using FFT(Fast Fourier transform).So we have to apply FFT on both receiver and transmitter positions. And at last we will conjugate the complex functions both in receiver and transmitter and have to multiply with both of them.

At last, we have to take the inverse FFT covert into frequency domain. After doing this, we will get the difference time for all positions. After that have to take 1st receiver position as a reference and get our difference of time and we will get TOA .After that calculation of overall TOA performed. And after getting TOA, we can easily get the TDOA. Which we will get by the difference of TOA2 –TOA1.Like this; we got TOA for transmitter and receiver by using cross correlation approach.

After that, we inserted noise, firstly we add AWGN noise with TOA. Additive white Gaussian noise (AWGN) is a basic noise model, which is used in information theory to mimic the effect of many random processes that occur in nature. It is Additive because it is added to any noise, which might be intrinsic to the information system. . And after getting noisy TOA,we can easily get the noisy TDOA. Which will get by the difference of TOA2 –TOA1.Like this. We got TOA for transmitter and receiver by using cross correlation approach.

To get an accurate position location estimation of a source requires an efficient hyperbolic position location algorithm. When the TDOA information is obtained, the hyperbolic PL location algorithm will be responsible for producing an accurate and clear solution to the position location problem.

4.3 Performance analysis measuring parameter

In this research for performance analysis of the algorithms, we calculate GDOP, HDOP and MSE. For better understanding, we will describe these parameters first and discuss the calculation method.

4.3.1 GDOP

The performance of multilateration surveillance system is affected by the geometry of remote stations and also the error of equivalent range of each station.Basically,the errors range are considered independent and this is approximately zero mean Gaussiasn random variance and where the variance is determined by the sum of the variance of its each components.

Geometric dilution of precision (GDOP) describes error which is caused by the relative position of the receivers. are spread apart . If the baseline is larger than the distance between target and receiver then the accuracy is higher.

GDOP Calculation:

According to Hyperbolic Localization Method, we can calculate GDOP from the following equation,

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$$\text{GDOP}=\sqrt{\frac{\sigma_x{}^2+\sigma_y{}^2}{c^2\sigma_\varepsilon{}^2}} \quad (1)$$

Where, c is the range error variance. is the TDOA Variance.

4.3.2 HDOP

Horizontal dilution of precision (HDOP) is the measurement of the geometric quality of a GPS satellite configuration in the sky. The relative accuracy of a horizontal position of the GPS satellite is determined by HDOP. The smaller the DOP number, the better the geometry.

HDOP Calculation:

For calculation of HDOP we use this equation.

$$\text{HDOP}=\sqrt{\sigma_{xx}{}^2+\sigma_{yy}{}^2} \quad (2)$$

Where, $\sigma_{xx}{}^2 = \sigma_{yy}{}^2 = TDOAvaric$

Table 4-1 Dilution of Precision Rating table according to its value

DOP Value	Rating
<1	Ideal
1-2	Excellent
2-5	Good
5-10	Moderate
10-20	Fair
20>	Poor

4.3.3 MSE

Mean square error (MSE) is a term used in statistics, which measures the performance of an estimator. It is used mainly during statistical estimation for relaying the concepts of accuracy and precision

To measure the mean square error, target of prediction or estimation along with predictor or estimator is required. MSE is defined as the average of square of the errors. In MSE, error is defined as the difference between the attribute which is to be estimated and the estimator. It can also refer as a risk function, which corresponds to the expected value of the loss of squared error.

MSE calculation: For calculating MSE we take the difference of original and estimated location and divide with the total number of size.

For MSE calculation, we use the following equation,

$$\text{MSE} = \sqrt{E[(x-x^\wedge)^2+(y-y^\wedge)^2]} \quad (3)$$

Where (x,y) is the co-ordinate of the source and (x^,y^) is the coordinate if the estimated position of the source.

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V. RESULT & ANALYSIS

We can compare the simulation results in the following table. From the table we can see that SNR changes with variance in MSE ,. We know that with less error, MSE is less and SNR is higher and higher the SNR higher is the accuracy. So we can see from the table that in hyperbolic method the SNR value is higher compared to the other two methods. Overall,, the position accuracies of two algorithm

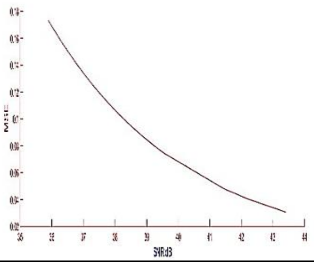
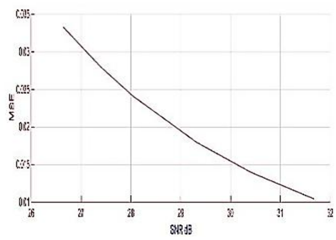
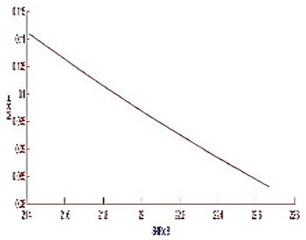
Method	Hyperbolic	Chan	Taylor
SNR VS MSE			

Table 5-1 Comparison table in the basis of SNR Vs MSE

(Chan and Taylor) are very similar and solving hyperbolic non-liner equations is not easy. Taylor LS algorithm is much more inefficient than Chan because it is iterative where Chan algorithm gives close solution . Nevertheless, Chan algorithm performs well only when the reference base station is at the origin (0, 0), otherwise large location errors are calculated.

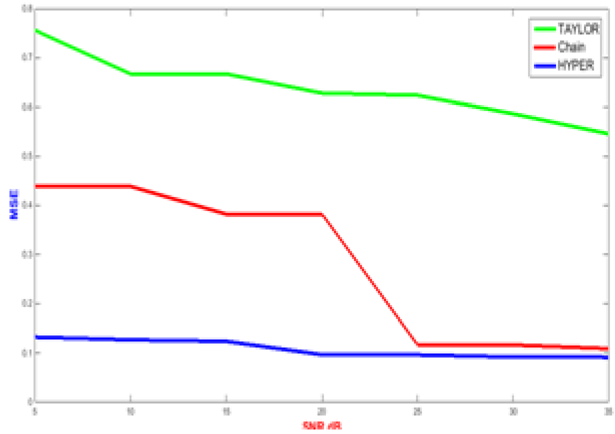


Figure 5-1 SNR Vs MSE graph for Hyperbolic, Chan and Taylor

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Table 5-2 Performance analysis table (considering both noise AWGN,RN simulations results).

Parameter	Hyperbolic	Chan	Taylor series
Error Difference Range	1.4 to 2.4 Km	2 to 4 Km	-7.4 to -6.4Km
SNR Range	Up to 43.5 dB	Up to 28.25 dB	Up to 23 dB
% Accuracy	97.6%	96 %	92.6%
GDOP	Accuracy Level High	Accuracy Level Medium	Accuracy Level Low
HDOP	Accuracy Level High	Accuracy Level Medium	Accuracy Level Low

From table 5-1, we can see that, hyperbolics SNR is far better than Chan and Taylor series method.

From the accuracy percentage we can say that in accuracy is highest in hyperbolic method followed by Chan and then Taylor series method. Although, Taylor series method can give an accurate position estimation at reasonable noise levels, but the main problem is its iterative nature whereas hyperbolic method is non-iterative. In addition, if we look upon the GDOP, HDOP chart we can say that hyperbolic accuracy level is very high than the other two methods.

From 5-1 figure, we can see that in Hyperbolic method MSE is near to zero and hence, less than other two methods.However, Chan method is better than Taylor series method. In this figure, we get the following MSE value

Table 5-3 MSE Table

Method Name	Hyperbolic	Chan	Taylor
MSE	0.15	0.45	0.95
Accuracy	Very High	High	Medium

VI. CONCLUSION

The accurate and efficient technique is provided for localizing a source using a set of hyperbolic Curves defined by TDOA. Results of hyperbolic method and Chan and Taylor series methods are simulated. A comparison of these methods was done. The comparison was established on the basis of HDOP, GDOP, SNR and Error difference in distance. After using these performance analysis parameters, we found that hyperbolic method is more efficient and result is more accurate than other two methods. Here, we discuss about TOA estimation methods. Cross correlation method and how to estimate TOA and how to convert estimated TOA into TDOA .

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