Chapter 3

Electro-Optical Tracking System

3.1 Model-1: Prioritization of Electro-Optic Sensors to Track and Improve Accuracy of Moving Object Position

Overview

Electro-optic sensors are essential for surveillance, target acquisition and monitoring the position of a flying object in the battlefield but it is a very difficult task due to many degrees of freedom underlying in the aircraft with a limited field view of electro-optic sensors (EOS). We have improved the accuracy of measured position when more than one EOS has been utilized to measure the position of an object. Proposed method successfully identifies the erroneous EOS and discards that. Then the triangulation method applied again to get an accurate position of the object. The accuracy of the measured position has been verified by calculating the perpendicular distance and prioritizes all the EOS. To achieve accurate object position, high priority EOS results are adopted and low priority EOS results are discarded for triangulation method. Hence, Prioritizing the EOS and improvement of the object position measurement is a novel approach in the field of current research. The experimental results and analysis demonstrate the originality of this investigation.

3.1.1 Introduction

To test the flight behavior of any flying object, it is very necessary to track its motion, whether it is moving on the desired path (or planned motion) or not. There are different systems that can track and measure the location of a moving object like Radar, EOS, and Telemetry, etc. Electro-Optic Sensors (EOS) is one of the popular tracking instruments. EOSs are able to find the object of its range and produce the direction of the object but not the actual position. A minimum of two numbers of EOS is required to find the object position. The triangulation method can be applied to get the position of the object with the measurements of direction by at least two EOS. EOS returns the direction of the flying object i.e. azimuth and elevation angles with respect to its own position and local axis. One cannot use this data directly for the triangulation method as each sensor has its own local axis. So all these EOS measurements should be aligned to a common reference axis before applying the triangulation method. The accuracy of position measurements by the triangulation method directly depends upon the direction measurement accuracy and alignment accuracy of EOS. One of the erroneous EOS may contribute a huge shift in position measurements. We are trying to find out a method of finding EOS measurement accuracy hence improving the accuracy of flying object position measurement. We have explained the triangulation method and method of finding out the criteria for prioritizing EOS measurement accuracy in the succeeding section.

Motivation and Objective

The main motivation and objectives of this investigation are mentioned below:

To improve the position measurement of the flying object through multiple EOS.

Find out the erroneous EOS which is not able to focus the same object of interest due to bird or other flying object come into the view of EOS.

For more than one erroneous EOS, we are able to prioritize the EOS to measure the position of the flying object.

To achieve good accuracy, it is possible to discard the least priorities EOS measurement results.

3.1.2 Proposed Scheme

A. Position of EOS and Reference Point

It is advised to use a reference axis (which is parallel to the Geographic coordinate system) to track the position of the flying object. The origin of the axis will be the reference point. This reference point may be the starting point of the target or any point towards which the target is moving and measure the position with respect to the reference axis.

For the measurement, we consider the position of EOS with respective to the reference point as the object's position is also measured with respect to the reference point.

For this, we have to convert the geodetic coordinates to ECEF (Earth-Centered Earth Fixed). Let X, Y, and Z are the coordinates in ECEF coordinate system.

$X = (N(\Phi)+h) \times cos\Phi \times cos\lambda$

$Y = (N(\Phi)+h) \times cos\Phi \times sin\lambda$

$Z = (\frac{b^2}{c^2}N(\Phi)+h) \times sin\Phi$

where, Φ is latitude, λ is longitude, h is altitude.

$N(\Phi) = \frac{a^2}{\sqrt{\left(a^2cos^2\Phi + b^2sin^2\Phi\right)}}$

$N(\Phi) = \frac{a^3}{\sqrt{\left(1-e^2sin^2\Phi\right)}}$

Where a and b are the equatorial radius (semi-major axis) and the polar radius (semi-minor axis), respectively.

$e = 1 - \frac{b^2}{c^2}$ is the square of the first numerical eccentricity of the ellipsoid. The prime vertical radius of curvature N(Φ) is the distance from the surface to the Z-axis along the ellipsoid.

$X' = Xe - Xr$

$Y' = Ye - Yr$

$Z' = Ze - Zr$

Where, 'e' is EOS position and 'r' is reference axis origin's position and there after multiplying them with the rotational matrix to get the position coordinates with respective to reference axis.

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} -sin\lambda & cos\lambda & 0 \\ -sin\Phi\cos\lambda & -sin\Phi\sin\lambda & cos\Phi \\ cos\Phi\cos\lambda & cos\Phi\sin\lambda & sin\Phi \end{pmatrix} \begin{pmatrix} X' \\ Y' \\ Z' \end{pmatrix}$$

Rotational Matrix-1

Steps for finding position of EOS with respect to the reference point

Step-1: Input Position of EOS in latitude, longitude and altitude (*LLA*) format.

Step-2: Conversion of *LLA* to XYZ format

Step-3: Input position of reference point in *LLA* format

Step-4: Apply Rotational Matrix-1 to align EOS local XYZ axis with reference point local XYZ axis.

Step-5: Position of EOS with respect to reference point.

B. Position of object by EOS and its rotation

To keep track of the object, one should measure the position with suitable time intervals and track the path too. For measuring the position, we can use a different kinds of machines like Radar, Electro-Optic sensors and Telemetry systems. Angle based tracking system uses only Azimuth Elevation angles which may be produced either from Electro-optical sensors or antenna of Telemetry systems in which case minimum of any two such systems is required for position calculation. The radar-based tracking system provides Azimuth, Elevation and Range information of the target so that a single Radar can provide position information of the target with respect to its own position.

Here, we have considered Electro-Optic sensors, which measure the position of an object, with respect to its position by, returning the Azimuth and Elevation angles.

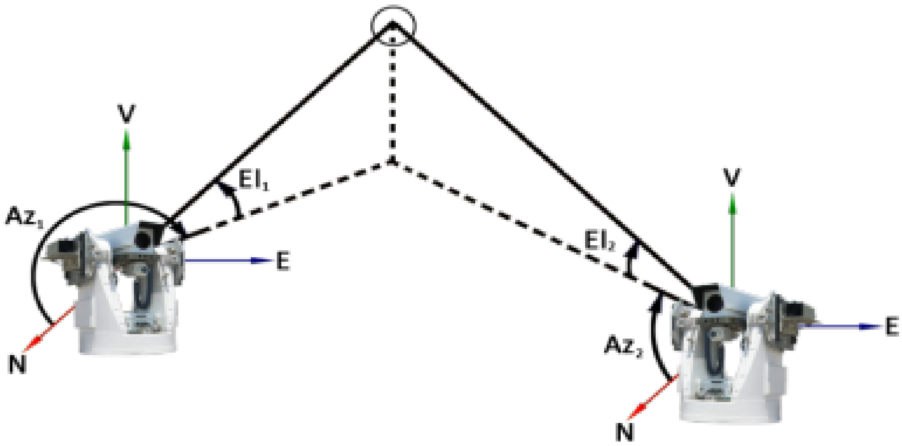

Figure 3.1: Triangulation method measuring the position.

Here AZ_1, EL_1, AZ_2 and EL_2 are Azimuth and Elevation angles of two different EOS. These angles can not be used directly for the triangulation method as all the EOS have different local axis. Hence, it is advised to convert by rotating them to make the angles of all EOS with respect to the reference axis.

EOS returns the azimuth and elevation angles with respect to its own position. Let l', m', n' be the direction cosines of Line of Sight (LOS). Where, these direction cosines are with respect to local axis of particular EOS. Direction cosine is computed from its measured azimuth (AZ) and elevation (EL) values as follows.

$l' = cos(EL) * sin(AZ)$

$m' = cos(EL) * cos(AZ)$

$n' = sin(EL)$

Now, new direction cosines of the new LOS parallel to local axis of common reference point is

$$\begin{pmatrix} l \\ m \\ n \end{pmatrix} = (Matrix-2) * (Matrix-3) * \begin{pmatrix} l' \\ m' \\ n' \end{pmatrix}$$

Matrix-2 =

$$\begin{pmatrix} -sin\lambda & cos\lambda & 0 \\ -sin\Phi\cos\lambda & -sin\Phi\sin\lambda & cos\Phi \\ cos\Phi\cos\lambda & cos\Phi\sin\lambda & sin\Phi \end{pmatrix}$$

Matrix-3 =

$$\begin{pmatrix} -sin\lambda' & -sin\Phi'\cos\lambda' & cos\Phi'\cos\lambda' \\ cos\lambda' & -sin\Phi'\sin\lambda' & cos\Phi'\sin\lambda' \\ 0 & cos\Phi' & sin\Phi' \end{pmatrix}$$

Where Matrix-2 is the ECEF to local alignment matrix of reference point where, λ and ϕ are the Geodetic Longitude and Latitude of reference point respectively and Matrix-3 is local to ECEF alignment matrix of EOS position where, λ'

and Φ' are the Geodetic Longitude and Latitude of position of EOS respectively.

Now, we can calculate the new (i.e., rotated values with respective to the reference point) azimuth and elevation angles from the new direction cosines and this data is used in Triangulation method in measuring the position of object.

The new direction cosines are also used in calculating the perpendicular distances from the measured position to the new LOS of each EOS.

C. Position measurement

For better position measurement, we can't simply trust a single sensor because of various factors like environmental conditions, calibration, erroneous nature etc. So, it is essential to consider more than one sensor and for the Triangulation method, at least two sensors are required for the position measurement calculation.

We are measuring the position with the rotated azimuth and elevation angles returned by seven Electro-Optic Sensors and the data considered here is real track data in ideal case, where no noise, calibration factors and erroneous nature of EOS are involved. Using this, one can acquire the information about ideal behavior of accuracy levels in measuring the position which helps us in finding the corrupted EOS when the non-ideal data is provided.

As, we are considering the ideal data, every EOS is valid by default. But, when we add some noise or bias to study the accuracy then, we make particular EOS as invalid by this we do not consider the particular EOS for Triangulation because of its erroneous nature, which will have bad impact on the position measurement.

D. Calculating The Perpendicular Distance

It is a general norm that if we keep on increasing the Electro-Optic Sensors, we will get the accurate measurement of position with the help of Triangulation method. But, it is only possible when the case is ideal. Because of noise, calibration factors and erroneous nature of particular EOS which effects the measurement and which results decrements in accuracy factor according to the noise. The decision of eliminating such erroneous sensor(s) can be done by prioritizing the EOS by their performance and contribution towards the measurement of the position. As, we are measuring the position with the help of Triangulation method, we get the most accurate position with respective to the reference point. We cannot take help of triangulation for measuring the accuracy levels. Hence, we can implement a new method to find accuracy levels of each EOS by calculating the perpendicular distance from the measured position (by Triangulation) to the new LOS of each EOS.

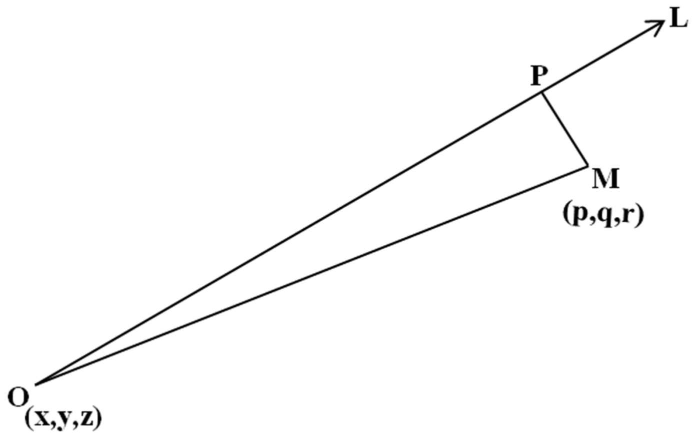

Figure 3.2: Calculating perpendicular distances

Where, 'O' is the position of particular EOS, OL is Line of Sight and (p, q, r) is the measured position of object M with the help of triangulation and the rotated azimuth and elevation angle values returned by that particular EOS as the position of object, lie on the line OL. Projection of OM on OL is OP and l, m, n are direction cosines of line OL.

We can rotate the position of object with respect to the position of EOS. But, already we rotated the azimuth and elevation angles with respect to the reference point. Hence, to reduce the computation we can calculate the perpendicular distance in the following manner.

$$OP = (p-x)l + (q-y)m + (r-z)n$$

$$MP^2 = OM^2 - OP^2$$

$$= (p-x)^2 + (q-y)^2 + (r-z)^2 - [(p-x)l + (q-y)m + (r-z)n]^2$$

After calculating the perpendicular distances for each LOS of EOS to the measured position, one can calculate accuracy levels contributed by each EOS to the position measurement of object.

3.1.3 Result and Analysis

In all the plots, time is considered in seconds (sec) and all distance are considered in meters(m).

Case I: Ideal case where all sensors are non-erroneous and do not have any noise and alignment errors.

In this case, in Fig 3.3 it is clearly shown that, very small deviation in measured positions of the path and actual positions of planned path of the object. Here, Ground Range is calculated by X and Y coordinates of the motion.

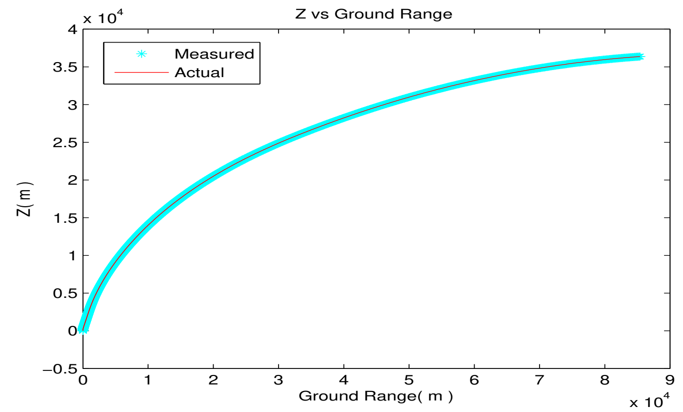

Figure 3.3: Plot of Z coordinates of motion vs Ground Range.

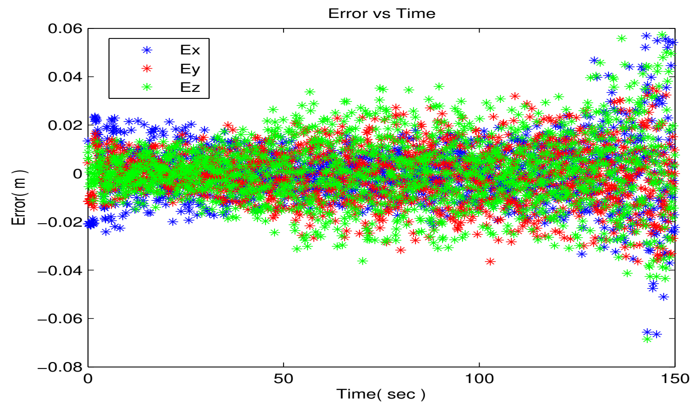

Figure 3.4: Plot of error in X, Y and Z coordinates vs Time.

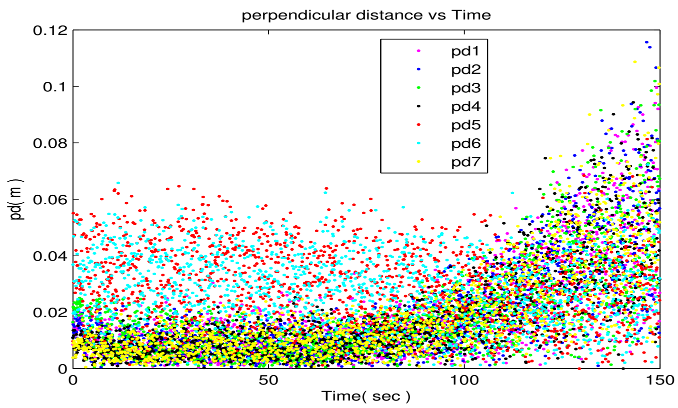

Figure 3.5: Plot of perpendicular distances of seven EOS vs Time.

Fig 3.4 is the study of deviations of coordinates of measured path from the actual planned path i.e., error of difference between actual and calculated or measured and it is very small in the range of ±0.06m.

Fig 3.5 is the plot of seven perpendicular distances from the measured position (with the help of Triangulation) to LOS of each EOS respectively. As, it is ideal case the distance is very small in the range of 0.12m. In real scenario, we only have measured position and not the actual position. So, this perpendicular distance is the way to calculate the measurement of accuracy as, it has correlation with the error of coordinates of measured position.

Case II: Non-Ideal case where alignment error of 1 degree has been added in the EOS 1 and all other sensors are error free.

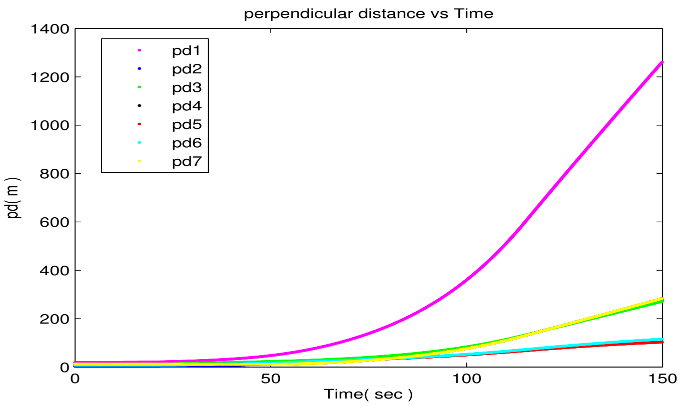

Figure 3.6: Plot of perpendicular distances of 7 EOS vs Time.

In this case, alignment error of 1 degree has been added in the azimuth of EOS 1. In Fig 3.6 it is clearly shown that, very high values of perpendicular distances compared to the case I which are in the range of 0 to 1250 m for EOS1.

In Fig 3.7 the deviations of coordinates of measured path from the actual planned path i.e., error of difference between actual and calculated or measured

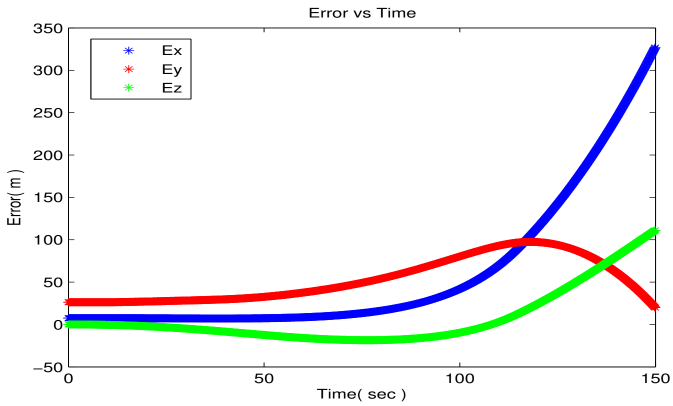

Figure 3.7: Plot of error in X, Y and Z coordinates vs Time.

became very high due to the error and its maximum value is 350m.

Here, one can clearly observe the effect of alignment error of EOS 1 in perpendicular distance measurement of all sensors. Now, we will show the improvement in measurement if we do not consider EOS 1 for the measurement as shown in case III in succeeding paragraphs.

Case III: Erroneous EOS 1 is not considered for measurement and all other sensors are non-erroneous and do not have any noise and alignment errors.

After getting highly deviated results of position measurement and in perpendicular distances, the erroneous EOS 1 is not considered for measurement of position and now, all other six sensors are non-erroneous. In this case, in Fig 3.8, it is clearly observed that the perpendicular distances are very similar, with compared to the observations in case I with the range of 0.12m and the Error between measured positions and actual positions are also very small in the range of

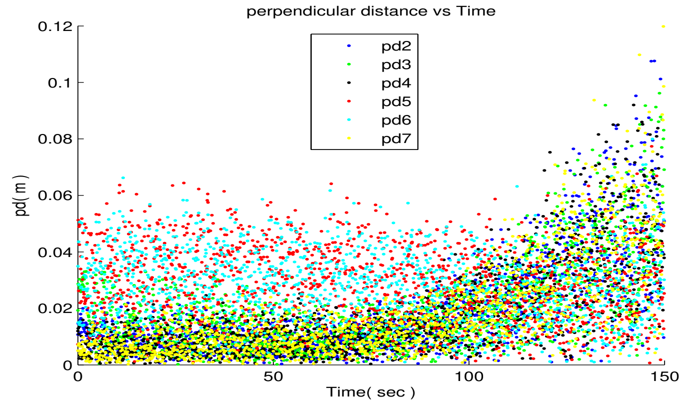

Figure 3.8: Plot of perpendicular distances of Six EOS vs Time.

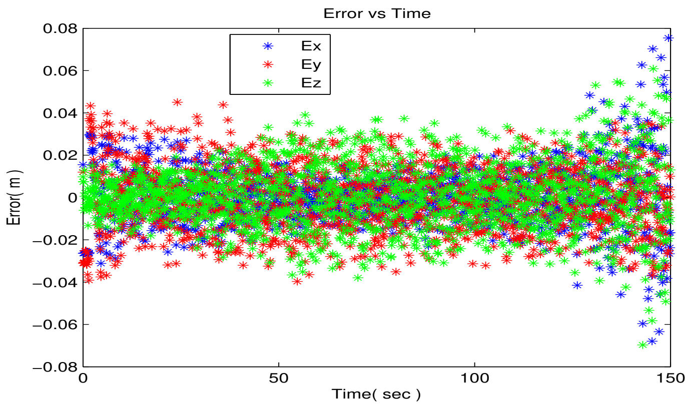

Figure 3.9: Plot of error in X, Y and Z coordinates vs Time.

±0.08min Fig 3.9. Whereas, in case I, it is ±0.06m which is because of removal of one EOS 1 and this leads to decreased number of EOS for the measurement.

Case IV: Non-Ideal case where alignment error of 1 degree has been added in both EOS 1 and EOS 2 and all other sensors are error free.

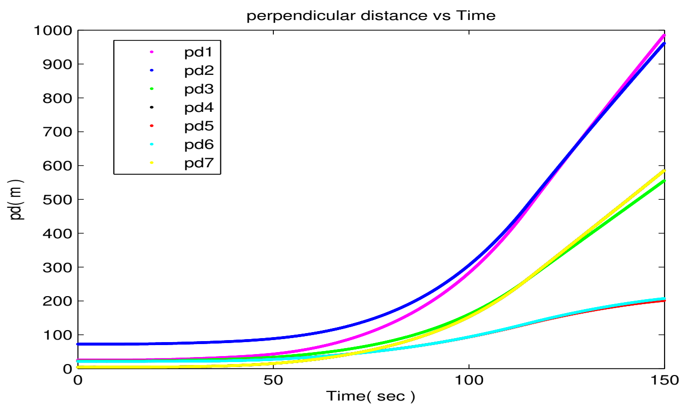

Figure 3.10: Plot of perpendicular distances of 7 EOS vs Time.

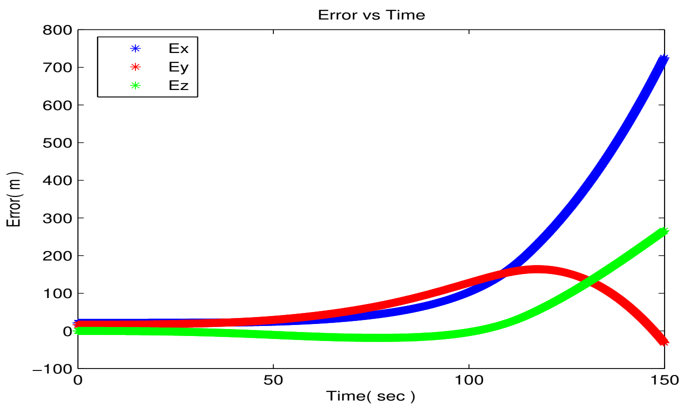

Figure 3.11: Plot of error in X, Y and Z coordinates vs Time.

In this case, alignment error of 1 degree has been added in the azimuth of both EOS 1 and EOS2. In Fig 3.10 it is shown even more high deviation from the case III. As two EOS become erroneous, by which the values observed in the range of 0 to 1000m. In Fig 3.11 the deviations of coordinates of measured path from the actual planned path i.e., error of difference between actual and calculated or measured became very high due to the erroneous EOS 1and EOS 2 with the range of 0 to 800m. Now, it is the time for removing the most erroneous EOS with the help of perpendicular distances by prioritizing them and in case V, we will study the perpendicular distances after removing the Low Priority EOS, i.e., EOS 2 in current case.

Case V: Most erroneous EOS ie EOS2 is not considered for measurement and all other sensors except EOS1 are non-erroneous and do not have any noise and alignment errors.

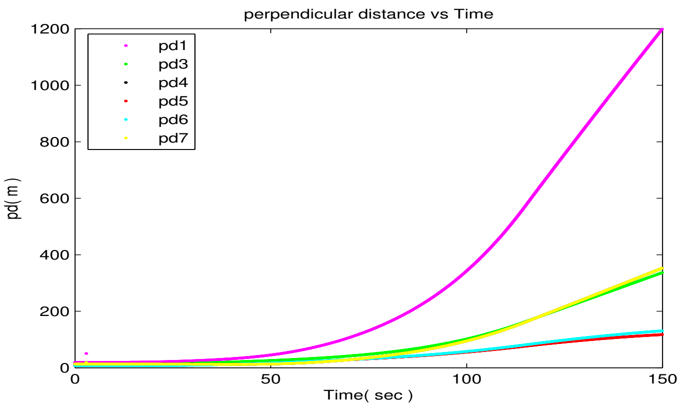

Figure 3.12: Plot of perpendicular distances of six EOS vs Time.

After prioritizing the sensors and finding the lowest priority EOS i.e., EOS 2, we removed it for the betterment of measurement and accuracy. In Fig 3.12 it is still showing the higher perpendicular distance for EOS 1 but, the perpendicular distances of other sensors are improved as, EOS 2 is removed. In Fig 3.13 also, it shows the improvement in deviation errors of position measurement. Hence, we are going correctly, by prioritizing the EOS with the help of perpendicular dis-

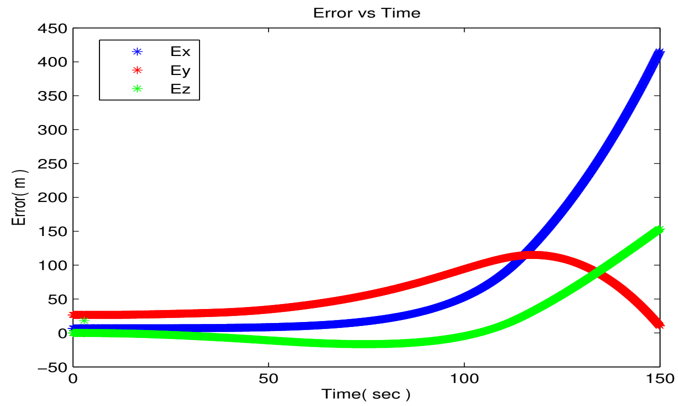

Figure 3.13: Plot of error in X, Y and Z coordinates vs Time.

tances and now, by prioritizing again, we found EOS 1 as the low priority EOS. We will study the perpendicular distances after removing EOS 1 in next case, i.e., case VI.

Case VI: Erroneous EOS 1and EOS 2 both are not considered for measurement and all other sensors are non-erroneous and do not have any noise and alignment errors.

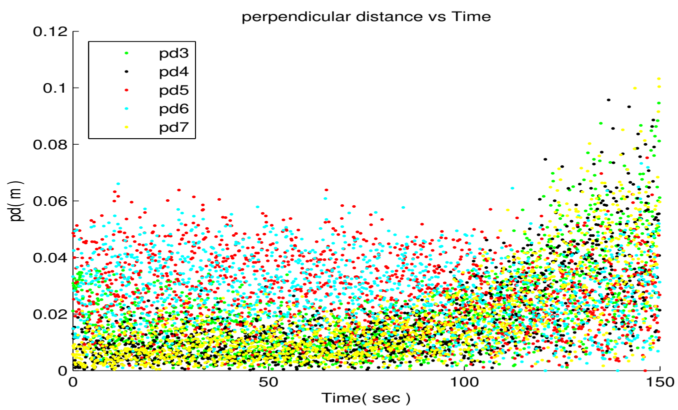

Figure 3.14: Plot of perpendicular distances of 5 EOS vs Time.

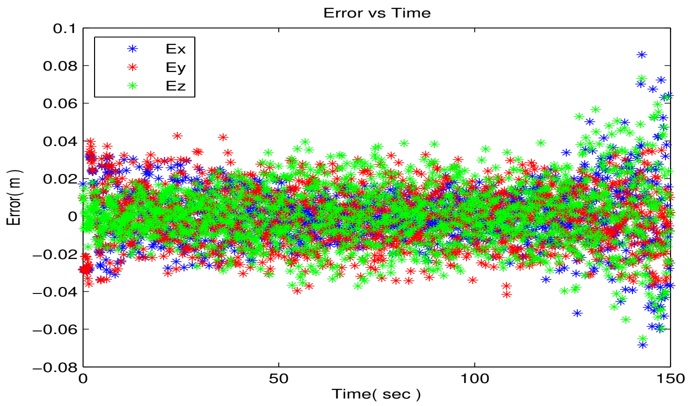

Figure 3.15: Plot of error in X, Y and Z coordinates vs Time.

After observing highly deviated results in position measurement and in perpendicular distances, the low priority EOS 1 is removed from case V and it is not considered for measurement of position and all other five sensors are non-erroneous. In this case, in Fig 3.14, it is clearly shown that the perpendicular distances are almost similar with compared to the observations in case I with the range of 0.12m and the error between measured positions and actual positions are also very small in the range of ±0.1m in Fig 3.15, whereas in case I, it is ±0.06m. This is because of two number of EOS are decreased (for the measurement) from the case 1.

Case VII: Non-Ideal case where noise of 5 seconds has been added in the EOS 1 and all other sensors are non-erroneous and do not have any noise and alignment errors.

In this particular case noise of 5 seconds has been added in Azimuth angle of EOS 1, one can observe Fig 3.16 where, the perpendicular distances are little

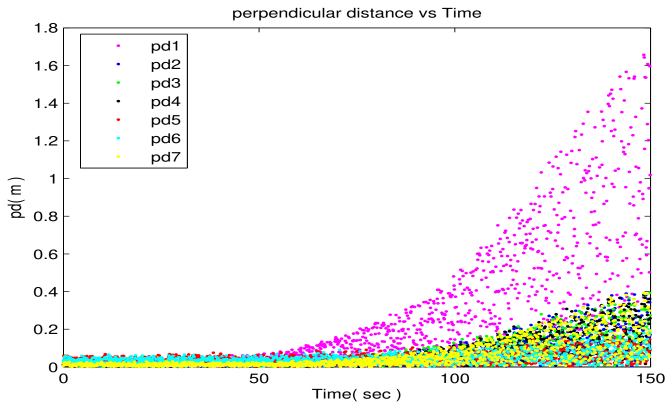

Figure 3.16: Plot of perpendicular distances of 7 EOS vs Time.

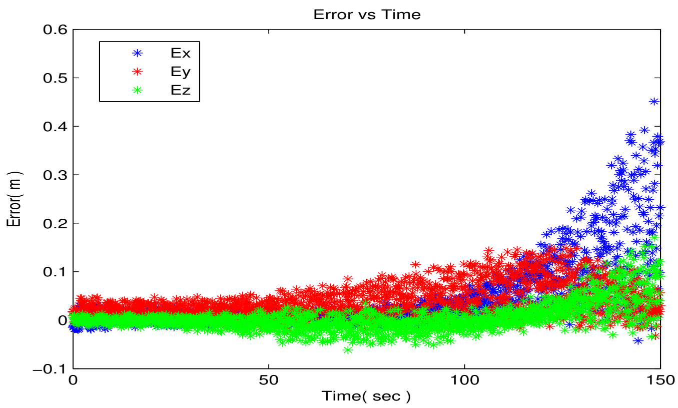

Figure 3.17: Plot of error in X, Y and Z coordinates vs Time.

higher than the case I. It clearly shows the little erroneous results in EOS 1 than other EOS. Similar observation can be seen in the deviation error of position in Fig 3.17 as both perpendicular distances and deviation error of position are correlated. Here, one can observe noise factor in one EOS does not contribute much towards the erroneous results. Let's see what happens if noise factor is added in one more EOS in case VIII.

Case VIII: Non-Ideal case where noise of 5 seconds has been added in both EOS 1 and EOS 2and all other sensors are non-erroneous and do not have any noise and alignment errors.

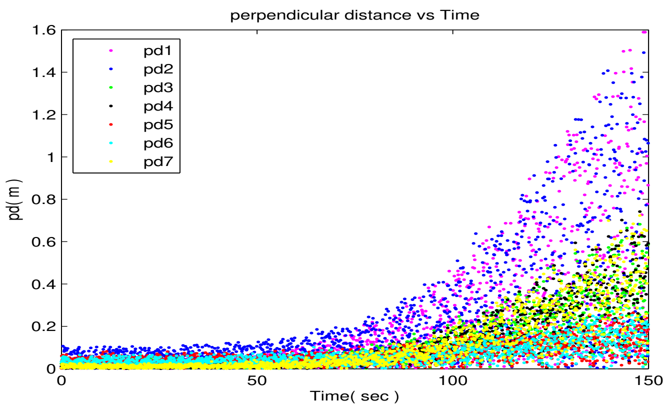

Figure 3.18: Plot of Perpendicular distances of 7 EOS vs Time.

In current case noise factor of 5 seconds is added in both azimuth angles of EOS 1 and EOS 2. Fig 3.18 clearly shows the erroneous behavior in both EOS 1 and EOS 2 and it is very low, as noise factor does not affect much. In Fig 3.19 the error in deviation of position is little higher than in case VII due to one more EOS affected little with noise factor. From these observations one can clearly state that, the noise have very less contribution towards decreasing accuracy levels and it is almost negligible and whereas, alignment error contributes very much in giving

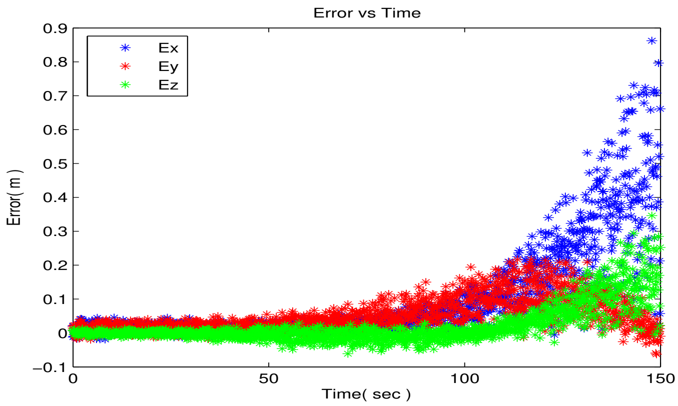

Figure 3.19: Plot of Error in X, Y and Z coordinates vs Time.

the erroneous position while measuring.

Observations of various cases discussed is shown in following table.

Table 3.1: Average Perpendicular distance (pd) in each case.

Average values	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
pd1	**0.019**	**327.0**	**–**	**260.1**	**311.3**	**–**	**0.23**	**0.194**
pd2	**0.019**	**72.27**	**0.018**	**288.0**	**–**	**–**	**0.055**	**0.203**
pd3	**0.019**	**77.16**	**0.02**	**151.1**	**93.7**	**0.02**	**0.059**	**0.107**
pd4	**0.018**	**73.38**	**0.017**	**143.1**	**90.4**	**0.017**	**0.055**	**0.101**
pd5	**0.03**	**40.09**	**0.029**	**76.8**	**43.9**	**0.028**	**0.045**	**0.064**
pd6	**0.028**	**42.65**	**0.028**	**77.5**	**46.6**	**0.027**	**0.046**	**0.065**
pd7	**0.018**	**73.36**	**0.018**	**143.2**	**90.4**	**0.017**	**0.056**	**0.103**

3.1.4 Findings and Discussion

Improved accurate position measurement of a flying object has been proposed when more erroneous EOS has been utilized. The proposed scheme used the triangulation method to get an accurate position. In this approach, it has successfully prioritized all EOS and identified the erroneous EOS with the help of priority. High priority EOS can be used to improve the object position and the least priority EOS measurement need to remove from the resultant measurement.

Experiments were carried out with the help of real track data as well as simulated track data. Simulation covers zero error ideal data, noise added data and alignment error introduced in one or more sensor azimuth and/or elevation data.

A thorough study concludes the correlation between deviation of position measurement and perpendicular distances. And the study covers the impacts of added alignment error in some EOS azimuth and/or elevation on the position measurement accuracy and perpendicular distances. From the impacts and correlation, it is clear that the noise has very little contribution towards decreasing accuracy levels and it is almost negligible and whereas, alignment error contributes very much in giving the erroneous position while measuring.

In real scenario, we can only have the measured values of position and not actual values of position. By the value of perpendicular distances, erroneous EOS can be prioritized.

Hence, the accurate position of the flying object can be obtained by discarding erroneous EOS by prioritizing them with the help of perpendicular distances from the direction by each EOS.

More numbers of erroneous EOS can be eliminated and perpendicular distance may be modified to improve the scheme in the future.

3.2 Model-2: Improvement in the Accuracy of the Moving Object Position by Eliminating Erroneous Sensors using Clustering Approach

Overview

Clustering is the process of grouping objects that have similar features. The integration of data from multiple sensors can improve the accuracy of measurement than using a single sensor. Electro-Optic sensor can provide the azimuth and elevation angles with respect to itself about the position of the moving object at each time instance. It can give the direction of the moving object, so if we have at least two EO sensors then the actual position of the object can be calculated with the help of the triangulation method. As we increase the number of sensors then the accuracy of the moving objects position increases. But meanwhile, if any of the sensors has erroneous measurement then the final position measurement will be erroneous. To overcome this problem we have to eliminate the effect of this erroneous sensor from the final measurement. We have summarized how clustering technique can be applied to identify and eliminate the erroneous sensor from the measurement. K-means clustering algorithm is applied in such a way that the erroneous measurement will be discarded on the basis of not belonging in the largest cluster. And centroid of the largest cluster will give the accurate position of the moving object.

3.2.1 Introduction

The measurements obtained from a single sensor may not be accurate and reliable. To increase the accuracy of measurement, multiple sensors can be used. There are several data fusion techniques for getting an accurate measurement. Multisensor data fusion can be defined as the process of a combination of multiple sensors to provide the most precise and accurate information relates to a system. The main advantage of choosing multi-sensor data fusion over a single sensor is that it improves accuracy, improves precision and also reduces uncertainty.

Estimation of position using the measurements from the EOT sensor is necessary for the tracking of the target. Real-time target/object tracking is a well-known research area. The object is defined by its location in a single frame and at every frame that follows, the task is to determine the target's location. The measurements are affected by the noise and alignment errors that are attached to the different sensors. Accurate measurement of position of moving object can be achieved by minimizing the impact of the random noise and alignment error of sensors.

There are different tracking systems that can track the location of the moving object. The electro-optic sensor is used for tracking the moving objects in a short-range. It can provide the direction of the object in the form of azimuth and elevation. With the help of at least two sensors, the location of the moving object can be found out.

Triangulation method can be useful for finding the moving object position with at least two numbers of sensors. In the presence of any erroneous sensor, there is a huge difference between the actual position and measured position. So we have to neglect the effect of the erroneous sensor in the final measurement. K-means clustering technique is applied to identify erroneous measurement and formed a cluster having only the correct measurement. The centroid of that cluster is considered as the final position of the object and it is producing very much accurate results.

3.2.2 Proposed Scheme

Step-1: Apply triangulation algorithm by considering all the EOS and estimate the object position.

Step-2: Draw the projection on the individual EOS measured direction from the object position obtained by considering all EOS.

Step-3: Now all this projection point is considered as the object location measured by individual EOS.

Step-4: Estimated target position obtained by projection point as input for clustering by each sensor individually and assign the number of desired clusters (K).

Step-5: Assign the centroid of each cluster according to the estimated target position by the corresponding sensors.

Step-6: Calculate Euclidean distance of each measurement with the centroid of each cluster.

Step-7: Update the cluster centroid which is nearest to the measurements.

Step-8: Repeat step 6 and step 7 for each measurement and after that centroid of the largest cluster is the estimated target position.

3.2.3 Results and Analysis

Case I: Ideal case, all the sensors are noise and alignment error-free.

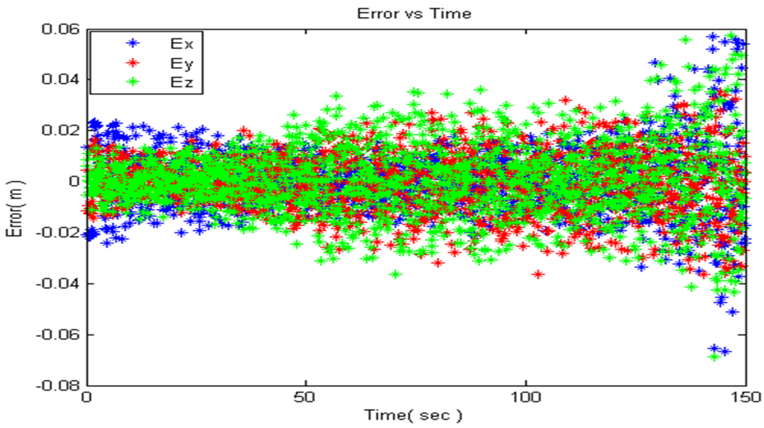

Figure 3.20: Error in X, Y and Z coordinate vs Time.

Here Fig 3.20 presents the deviation of the measured path from the actual path with respect to time.

$Ex = X - x$, $Ey = Y - y$, $Ez = Z - z$

Where X, Y, Z are the actual position coordinates and x, y, z is the measured one. Ex, Ey, and Ez represents the component wise errors.

We can clearly see that when all the sensors are non-erroneous then the error difference between actual and measured one is very less as the range of 0.06m.

Case II: All sensors having 5 sec random Gaussian noise in both azimuth

and elevation

One important thing to remember is that we cannot get the ideal case in a practical scenario. Some noise error is associated with them in general. So analysis is carried out with the consideration that each sensor has 5 sec of Gaussian random noise in azimuth as well as elevation measurement.

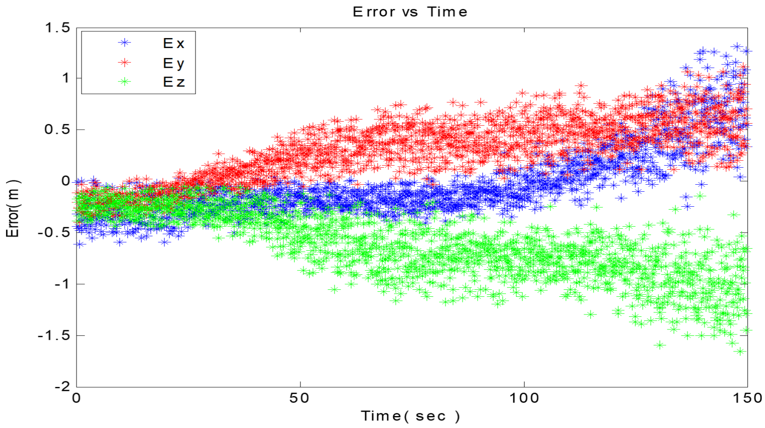

Figure 3.21: Error in X, Y and Z coordinate vs Time.

Fig 3.21 shows the actual scenario instead of the ideal scenario of Fig 3.20 when we consider noise error of 5 seconds in both azimuth and elevation of each of the sensors.

Error plot is in the range of -2m to +1.5m, which is -0.08m to +0.06m in ideal case.

When all the sensors have 5 sec of noise error in both azimuth and elevation then sensors measurement does not much vary from each other, which can be seen in Fig 3.22. Plane triangulation method is very well suited in this case to identify the actual position of the flying object.

Fig 3.23 represents the deviation of measured object position from the actual coordinate position in each of X, Y and Z direction both in the triangulation

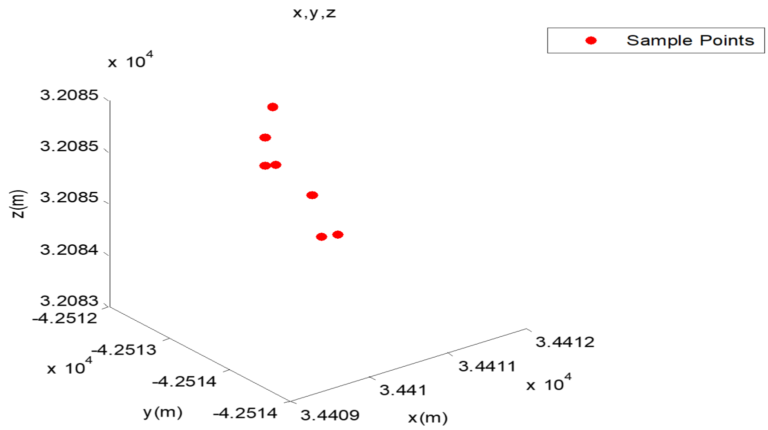

Figure 3.22: Measured positions by 7 sensors at an instance

method and in the k-means method. Here in both the methods, results are almost similar to each other. The range of error with respect to time is -2.5m to 2m in this case.

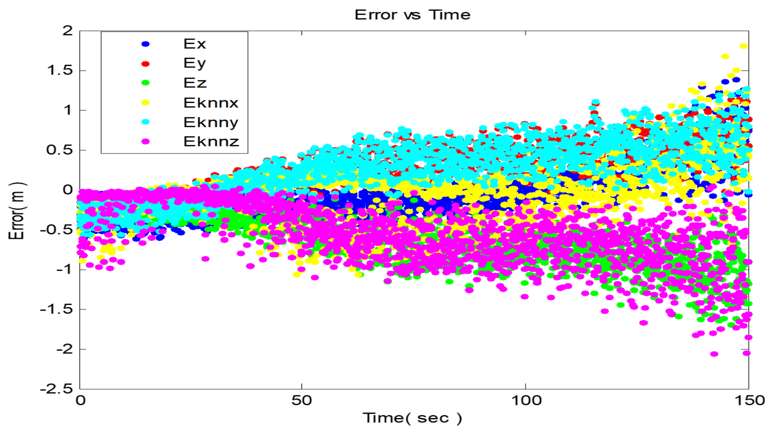

Figure 3.23: Error in X, Y and Z coordinate vs Time

In all subsequent case we have considered 5 sec random Gaussian noise in azimuth and elevation.

Case III: Allignment error has been added in the EOS 1 and all other sensors are error-free.

In this case, noise error of 5 sec has been added in both azimuth and elevation of each sensor and sensor 1 has alignment error of 1 degree and all other sensors have been considered as free from the alignment error.

In Fig 3.24, the deviation between the actual and measured coordinate position becomes very high due to the erroneous sensor and it reaches a maximum of around 180 m.

We can reduce the error in the measurement if we don't consider the erroneous sensor 1 in our measurement. In the next section, a brief idea about the elimination of erroneous measurement using clustering is given.

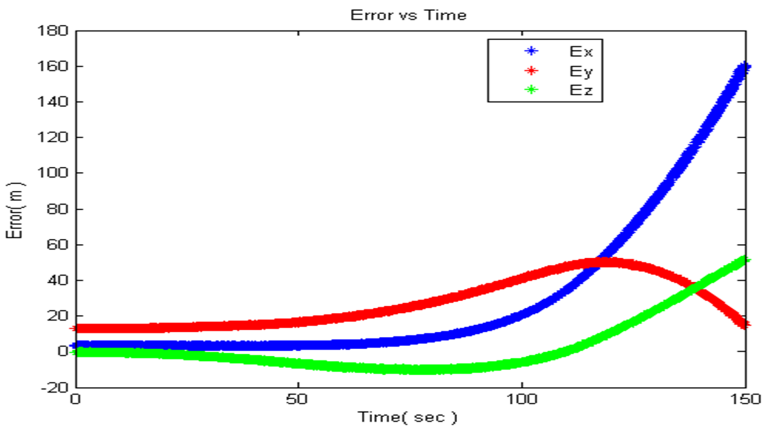

Figure 3.24: Error in X, Y and Z coordinate vs Time

Fig 3.25, shows the measurements of different sensors when the alignment error of 0.5 degrees is associated with the azimuth of sensor 1. It can be viewed that the erroneous sensor 1 measurement has been discarded by the clustering procedure.

Fig 3.26, is the deviation of the measured position from the actual position. The error boundary is quite less in the case of nearest-neighbor clustering as compared to the triangulation method.

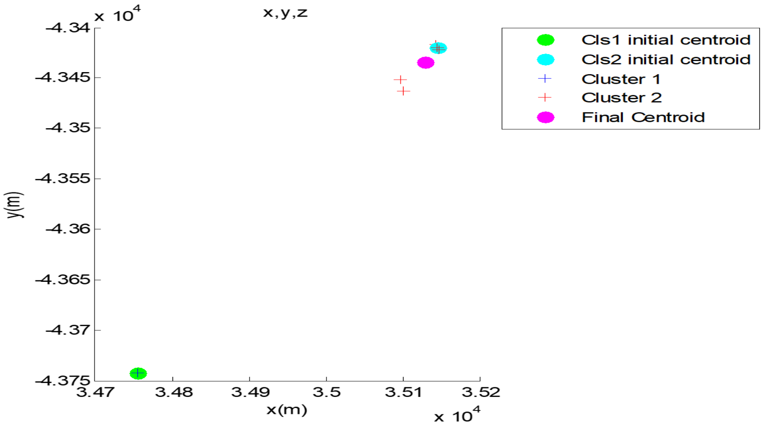

Figure 3.25: Clustering of the measured position by 7 sensors

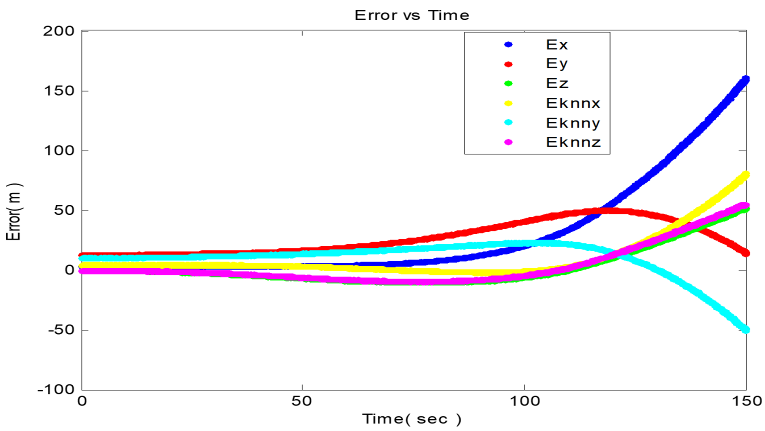

Figure 3.26: Error in X, Y and Z coordinate vs Time

Case IV: Alignment error has been added in sensor 1 elevation and all other are error free.

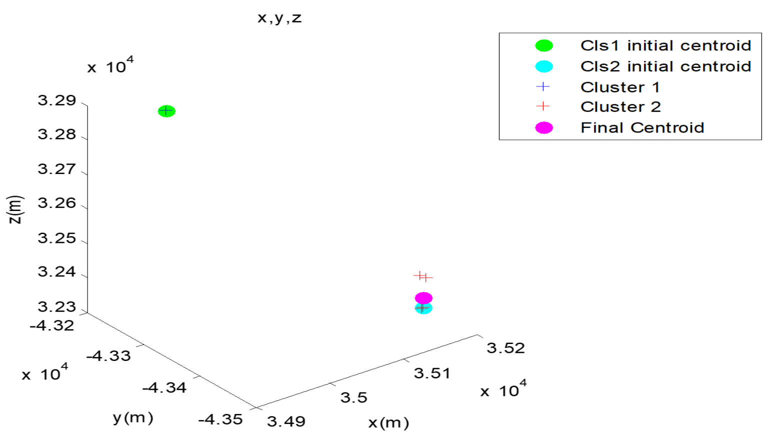

Figure 3.27: Clustering of the measured position by 7 sensors

When the alignment error of 0.5 degrees in the elevation of sensor 1 is given then Fig 3.27 represents the exclusion of sensor 1 for the calculation of object position.

Fig 3.28 shows the error vs time plot of this case. There is a significant change in the errors. In Z axis, error is around -150m in case of a triangulation method whereas in case of clustering process it is much less nearly -40 m.

Case V: Alignment Error has been added in both sensor 1 and sensor 2 azimuth.

When the alignment error of 0.5 degrees has been added in sensor 1 and sensor 2 azimuth, it can be viewed by the Fig 3.29 that it discarded both sensor 1 and sensor 2 which are the erroneous ones by putting them in a different cluster and the cluster centroid with the highest number of points will be the actual position.

Fig 3.30 shows the error boundary in this case with and without the nearest neighbor approach. In the k-means approach, it is lesser than the triangulation

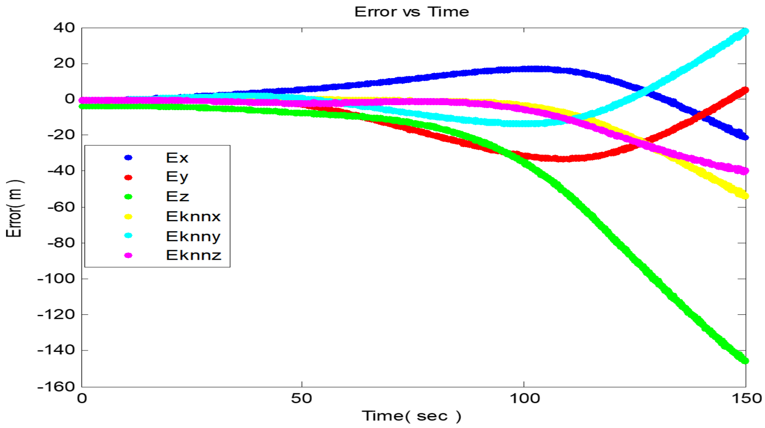

Figure 3.28: Error in X, Y and Z coordinate vs Time

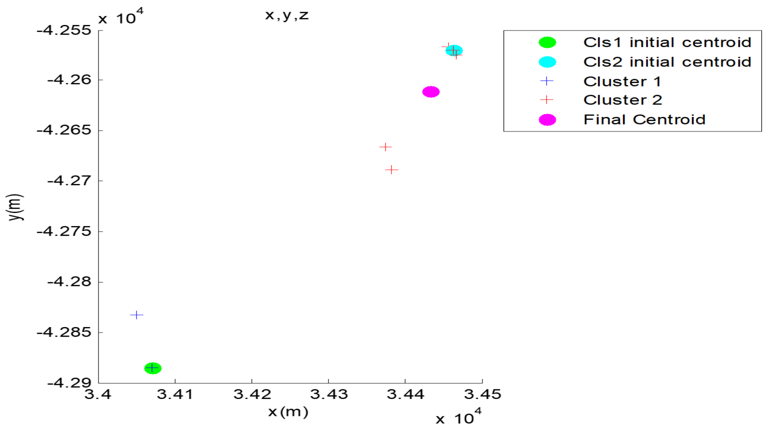

Figure 3.29: Clustering of the measured position by 7 sensors

approach.

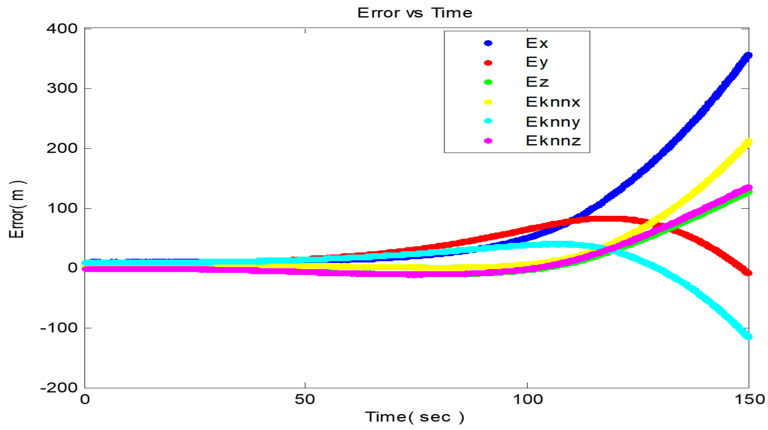

Figure 3.30: Error in X, Y and Z coordinate vs Time

Case VI: Alignment Error has been added in both sensor 1 and sensor 2 elevation.

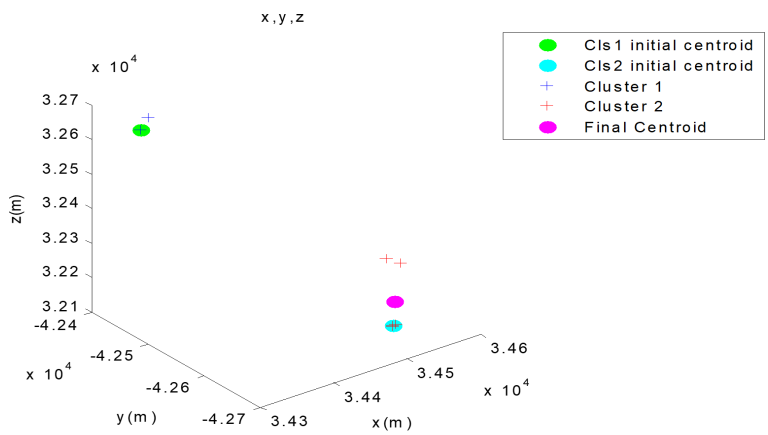

Figure 3.31: Clustering of the measured position by 7 sensors

In this case alignment error of 0.5 degrees has been added in the elevation of both sensor 1 and sensor 2. In Fig 3.31 it is shown that how the clustering process neglecting the effect of two erroneous sensors.

In Fig 3.32 the deviation of measured coordinates from the actual coordi-

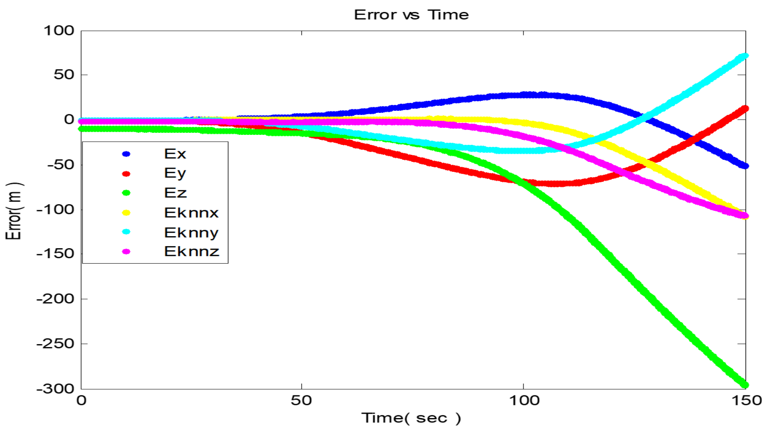

Figure 3.32: Error in X, Y and Z coordinate vs Time

nates has been shown. In-plane triangulation method it reaches to -300 m whereas in the k-means approach it is much less than the former one, around -100m.

Case VII: Alignment error has been added in sensor 1 azimuth and sensor 2 elevation.

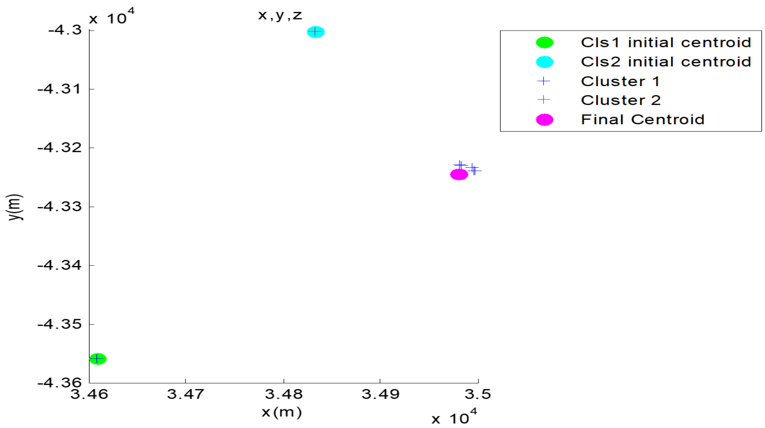

Figure 3.33: Clustering of the measured position by 7 sensors

While exploring different cases, in this case, alignment error of 0.5 degrees has been added in the azimuth of sensor 1 and the same amount of alignment error has been added in the elevation of sensor 2. Fig 3.33 shows the elimination

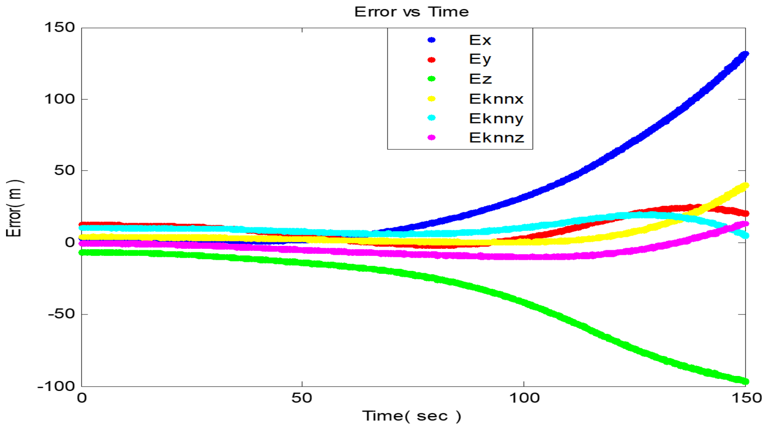

Figure 3.34: Error in X, Y and Z coordinate vs Time

of erroneous measurements from the final result.

In Fig 3.34 the error of the difference between actual and measured coordinate position vs time becomes much less as compared to the triangulation method. In triangulation, it is in range of -100 to 150 m whereas in k-means it is around 0 to 50m only.

3.2.4 Findings and Discussion

For finding the location of a moving target, it is necessary to keep track of the target at each time instance. Electro-Optic sensor can give the direction of the target/object. So if we know the direction of the object with at least two sensors then the position of the object can be identified by the help of the triangulation method. We are considering seven sensors as per convenience to identify the target location. One must know that as the number of measuring instruments increases the accuracy in measurement improves but we must consider for several other factors such as cost of installation, operation, maintenance etc. If one sensor out of seven tracking some other object or has some of alignment error then final measurement will become erroneous. So it is necessary to eliminate the effect of the erroneous sensor to get a more accurate final measurement. At first, it is described that in the ideal case when all the sensors are error-free than the triangulation method is the best and the position of the target can be easily identified with the help of this method.

If some alignment error has been added in one or more sensors then the deviation between actual and measured target position is comparatively high. Noise has not much effect as compare to alignment error in case of erroneous measurements. For getting the more accurate tracking measurement we must have to discard the effect of erroneous sensors. For which K-means technique has been applied. Clustering is done so that the erroneous sensors measurements can be ignored and the largest cluster centroid is considered as more accurate position of the target.

Here different cases have been studied, in which we assign alignment error in one sensor's azimuth, one sensor's elevation, two sensor's azimuth, two sensor's elevation and one sensor's azimuth with other one's elevation. Several other combinations can be applied to eliminate the erroneous measurements.

So we find here that the actual position of moving objects can be identified by eliminating the effect of erroneous sensors by applying the clustering technique.

3.3 Model-3: Multi Sensor Data Fusion Technique for Target Tracking Based on the Combination of Triangulation Method and K-means Algorithm

Overview

Combining group of items that have similar features is known as Clustering. Main goal of data fusion is to combine several information to find out more accurate result. We basically deal with the finding the positions of the flying object using Electro-Optical Sensors. Here the tracking information from the various sensors are combined together to identify the actual position of the moving object. A single sensor can only provide the direction of the object, therefore at least two number of sensor is required for the identification of target location. We discussed how to improve the positional accuracy level of the moving object by using the triangulation method with clustering algorithm. Triangulation method is applied with each two combination of EOS and position generated by all this combinations taken as input for clustering. Clustering is applied with the main focus of eliminating the effect of erroneous sensor measurement and get the accurate position of the object.

3.3.1 Introduction

The tracking of objects using distributed multiple sensors is an important field of work in the several application areas of robotics, military applications, mobile systems etc. Data fusion is the technique of integrating different information to generate the more accurate information. Similarly, Multi-sensor data fusion (MSDF) defined as the process of combining the information provided by several sensors to get the more accurate information related to a system. Multi-sensor data fusion can be used for several military applications as well as non-military applications. For military applications such as location and characterization of enemy weapons, air to air or surface to air defence, ocean monitoring and for non-military applications such as robotics, medical, environmental monitoring, detection of system faults and many more. The single sensor measurement can not be as useful as the combination of multiple sensors. It improves accuracy, reliability, precision etc.

There are different tracking systems which can track the location of the moving object and Electro-Optic sensor is one of them. It can provide the direction of the object and with the help of at least two sensors the location of the moving object can be find out.

Here it is described how the triangulation method can be used with the clustering technique to improve the accuracy in the location measurement of moving object. Here we are considering seven sensors. Each sensor combined with all other six sensors and after applying triangulation with each combination. A total twenty one numbers of different position measurement of the object is achieved. Thereafter, K-means clustering is used to cluster them and provide the more accurate result. It is well known that if the data points increase in the data set then the accuracy and precision also increases. But we must take care of complexity of scenario if this works in real-time.

In the presence of any erroneous sensor there is huge difference between the actual position and measured position. So we have to neglect the effect of erroneous sensor in the final measurement, here we are using K-means clustering technique to improve the accuracy of position measurement of moving object.

3.3.2 Proposed Scheme

Approach for applying combination of triangulation method and clustering algorithm.

Step-1: At first the triangulation method is applied for each of the two sensors combination for all seven sensors, thus we get a total 21 number of different combinations.

Step-2: Assign the number of desired clusters K (For our case here, K=2)

Step-3: Choose any one measurement randomly and assign it as the centroid of cluster 1.

Step-4: Find out Euclidean distance from all the remaining measurements and select the farthest as the initial centroid for the cluster 2.

Step-5: Calculate Euclidean distance of each measurement from the centroid of each cluster.

Step-6: Each time update the cluster centroid using the nearest measurement available.

Step-7: Repeat step 5 and 6 till all the measurements are clustered and the final position will be the centroid of the largest cluster.

3.3.3 Results and Analysis

K-means clustering approach is applied on total twenty one different combinations of position measurements and centroid of largest cluster is considered as final result.

$Ex = X - x$, $Ey = Y - y$, $Ez = Z - z$

Where X, Y and Z are the actual position coordinates and x, y and z are the measured considering all EOS together. Ex, Ey and Ez are the component wise errors.

Applying clustering algorithm on all twenty one combination of position measurement and two cluster centroid found out. Centroid of the largest cluster is the position of the flying object. We can calculate the component wise error Ekmx, Ekmy and Ekmz of measurement after applying clustering algorithm by following manner.

$Ekmx = X - kmx$, $Ekmy = Y - kmy$, $Ekmz = Z - kmz$

Where X, Y and Z are the actual position coordinates and kmx, kmy and kmz are the measured centroid of the largest cluster obtained using K-means on all twenty one different combinations.

Case I: Ideal case where all the sensors are error free.

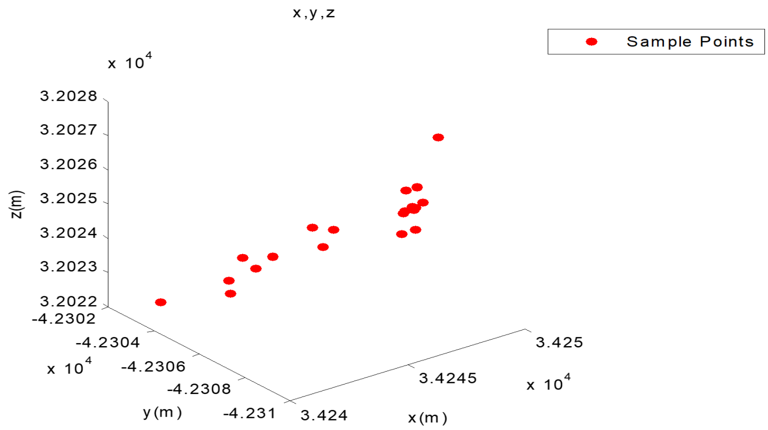

Figure 3.35: Measured Positions by the combination of sensors

Here we considered seven EOS hence we obtained 21 different combinations. Fig 3.35 represents the measured position by combining each sensor with all remaining sensors taking one at a time by triangulation method. It shows all 21 combinations of measurements at a particular time instance.

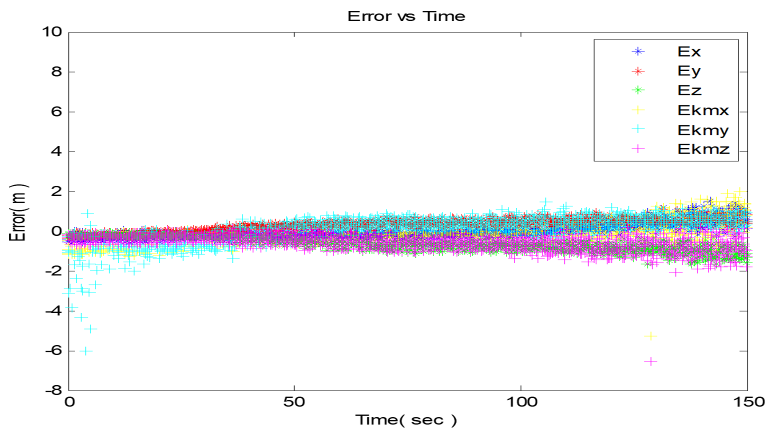

Figure 3.36: Error in X,Y,Z coordinate vs time

Fig 3.36 presents the deviation of measured path from the actual path with respect to time. It is observed that triangulation method applied on seven sensors is capable enough to obtain the moving target position which can easily visualize by Fig 3.36, where the errors in X, Y, Z coordinates are very less. And same pattern of error is there after applying K-means algorithm.

In next all cases a random Gaussian angular noise of 5 sec is applied in azimuth and elevation in all EOS for experimentation.

Case II: Alignment error has been added in sensor 1 azimuth and all other are error free.

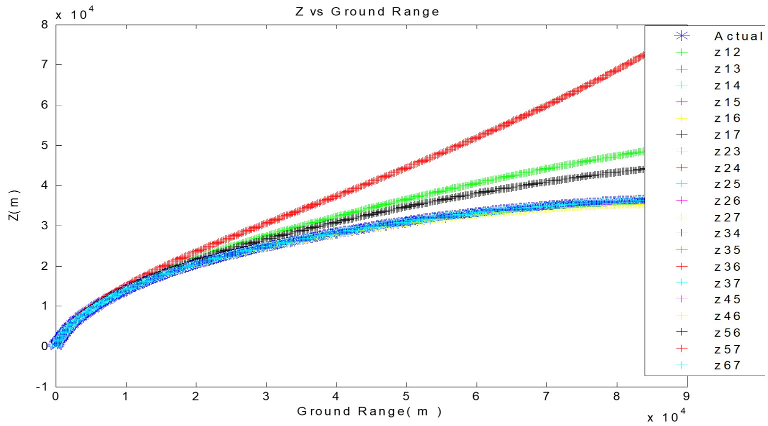

Figure 3.37: Z vs Ground Range for actual and all possible combination of seven sensors taking two at a time

In this non-ideal case when sensor 1 has alignment error of 1 degree. Fig 3.37 shows the Z vs Ground Range for all possible combination of seven sensors taking two at a time vs the actual one. It can be observed easily that since sensor 1 is erroneous that's why the combinations containing sensor 1 deviated from the actual one.

Fig 3.38, is Z vs Ground Range for the actual and K-means measured which is almost overlapped to each other which shows that the calculated position is much similar to the actual one.

Fig 3.39 represents how the erroneous measurement discarded from the final measurement and Fig 3.40 represents that error boundary is much less than the

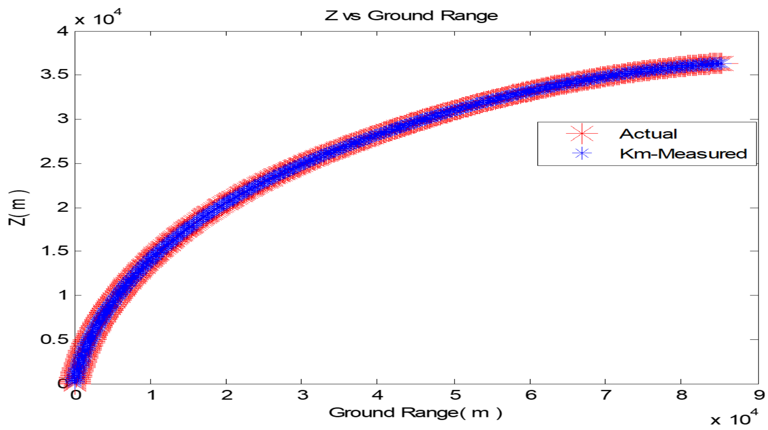

Figure 3.38: Z vs Ground Range for actual vs K-means measured

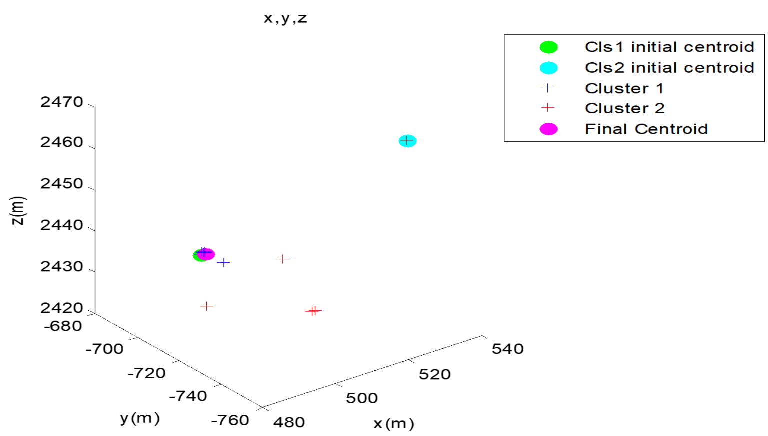

Figure 3.39: Clustering of the sample points

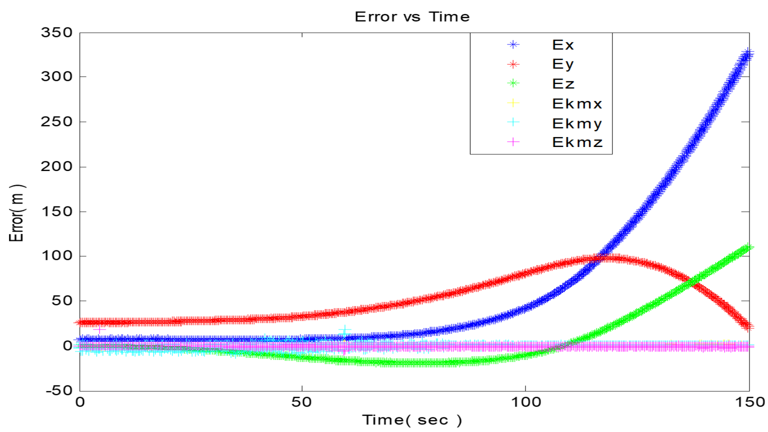

Figure 3.40: Error in X,Y,Z coordinate vs time

normal triangulation method which goes upto 350 m whereas in K-means case it is around of 10 to 15m.

Case III: Alignment error has been added in sensor 1 in elevation and all other are error free.

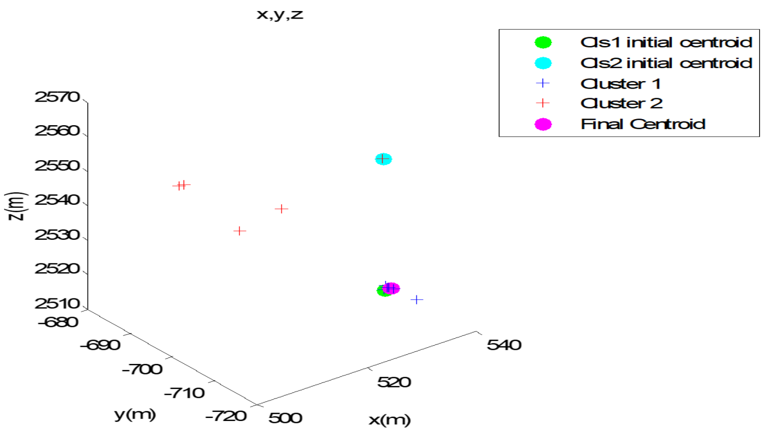

Figure 3.41: Clustering of the sample points

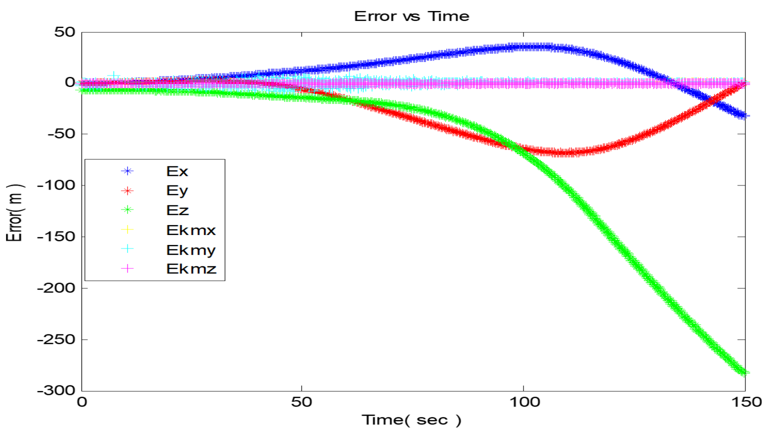

Figure 3.42: Error in X,Y,Z coordinate vs time

Fig 3.41, show the elimination of the erroneous sensor 1 from the final measurement of the location. Fig 3.42 represents the much lesser error in the coordinates as compared to the error in plane triangulation method.

Case IV: Alignment error has been added in azimuth of both sensor1 and sensor 2

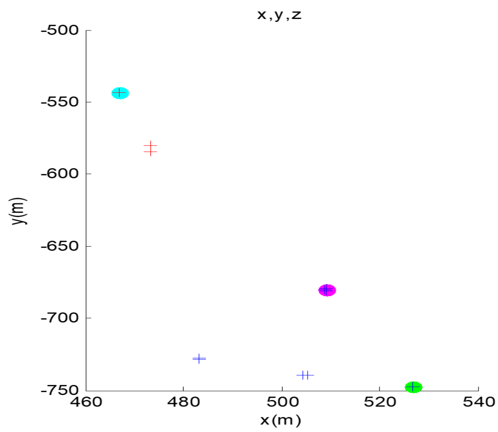

Figure 3.43: Clustering of the sample points

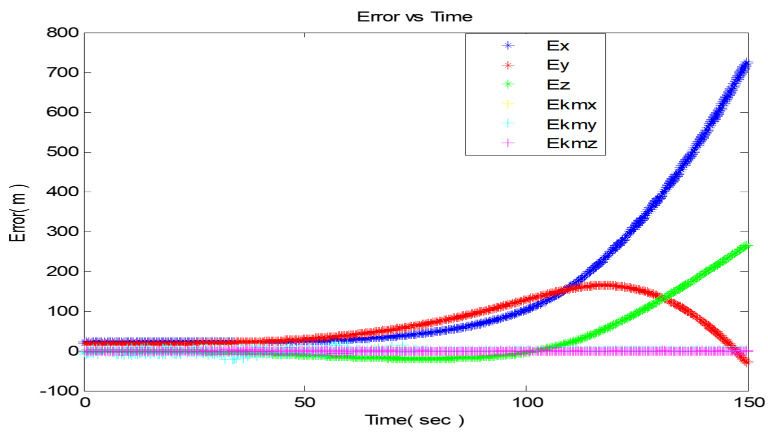

Figure 3.44: Error in X,Y,Z coordinate vs time

When alignment error of 1 degree entered in both sensor 1 and sensor 2 azimuth then the Fig 3.43, show the elimination of the erroneous sensor 1 and sensor 2 combined combination from the final measurement of the location.

Fig 3.44 shows the error vs time plot in this case. There is significant change in the errors. In case of triangulation method it is around 750m whereas in case of clustering process it is much less nearby to 20-30 m.

Case V: Alignment error has been added in elevation of both sensor1 and sensor 2

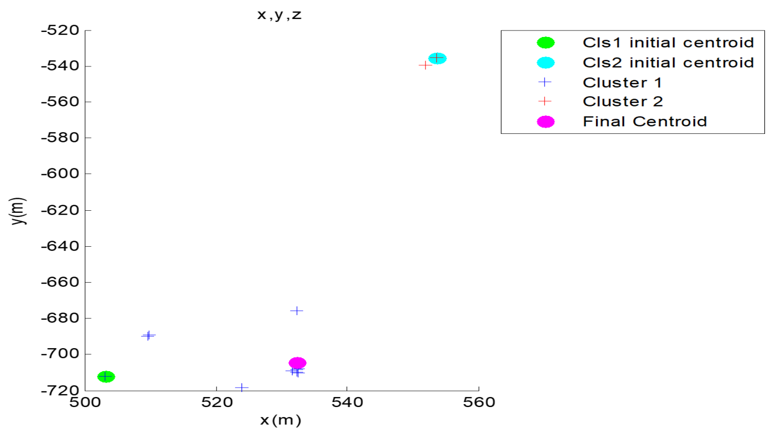

Figure 3.45: Clustering of the sample points

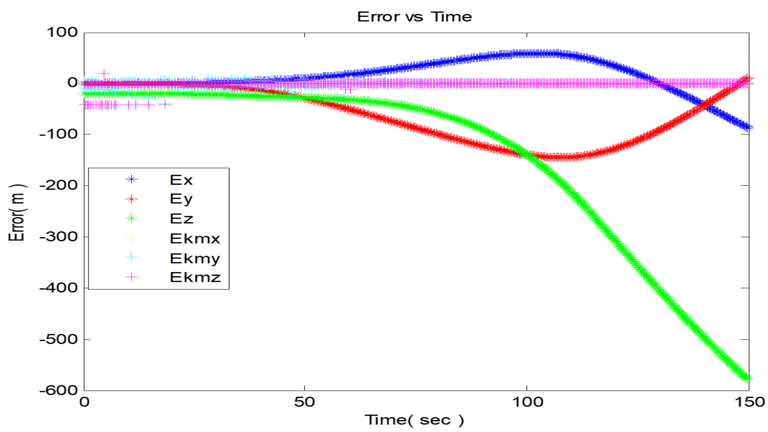

Figure 3.46: Error in X,Y,Z coordinate vs time

In this case alignment error of 1 degree has been added in the elevation of both sensor 1 and sensor 2. In Fig 3.45 it is shown that how the clustering process neglecting the effect of two erroneous sensors.

In Fig 3.46 the deviation of measured coordinates from the actual coordinates has been shown. In plane triangulation method it reaches to -600 m whereas in K-means approach it is much less than the former one, around 20-30m.

Case VI: Alignment error of 1 degree has been added in sensor 1 azimuth and sensor 2 elevation.

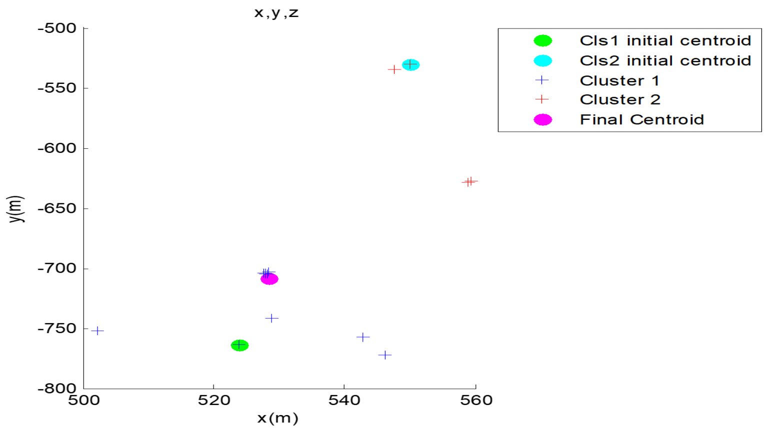

Figure 3.47: Clustering of the sample points

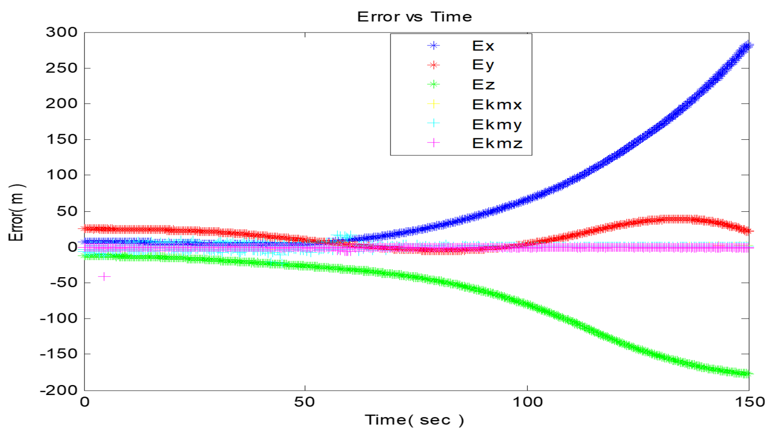

Figure 3.48: Error in X,Y,Z coordinate vs time

In the study of different cases, in this case alignment error of 1 degree has been added in the azimuth of sensor 1 and the same amount of alignment error has been added in the elevation of sensor 2. Fig 3.47 shows the elimination of erroneous measurements from the final result by putting them in a different cluster.

In Fig 3.48 the error of difference between actual and measured coordinate position vs time become much less as compare to triangulation method.

3.3.4 Findings and Discussion

The main aim is here to eliminate the effect of erroneous measurement from the final measurement. Different scenarios have been discussed where one or more than one sensor is having some kind of alignment error. It has been noticed that presence of alignment error produces more errors as compare to presence of the noise. Hence here some kind of alignment error has been introduced in one or two sensors and the K-means clustering approach is implemented to discard the erroneous effect. Also the error in the measurement (difference between actual and measured) of the coordinates is shown in each case. It can be quite easily observed that while using only triangulation method the error boundary is very high as compare to the combination of triangulation method with K-means clustering approach.

Therefore the more accurate measurement of the moving object can be identified by combining the triangulation method along with K-means clustering, which provide better result than only applying triangulation method.