Chapter 2

Research Methodology

2.1 Basic working principle of Electro-Optical Tracking System

The electro-optical system consists of two parts. One is the optical sensor and another is the mount on which the optical sensor rests. The sensor changes its direction as per the movement of the mount. Whenever any object is detected by the electro-optical sensor, the direction of the mount describes the direction of the object. The direction of the object is defined by the azimuth and elevation angle. Electro-optical sensor measurement is two dimensional. So it is not possible to get the exact position of the object using only one sensor. The triangulation method is applied with two sensors measurement for getting the object location.

Electro-Optical Tracking System comprises of at least two numbers of EOS. Target location and tracking elements are fused via a programmed video tracker. EOS is utilized as a part of every one of the three stages i.e. airborne, land-based and naval systems for observation, target detection and tracking. The key role of EOS is to help with the vision to the operator for targets of interest at the required range, additionally, it encourages the administrator to get the settled Line of Sight (LOS) during observation with the moving stage. EOS can be rotated in the horizontal plane as well as the vertical plane. It produces the object position in terms of LOS as azimuth and elevation angles. Electro-optical sensors are electronic detectors. It converts light rays into electronic signal.

Range is the distance of the object from the origin. Azimuth is the angle measured with respective to north horizontally in clockwise direction. Elevation is the angle measured vertically upward (+ve) and vertically downward (-ve) with

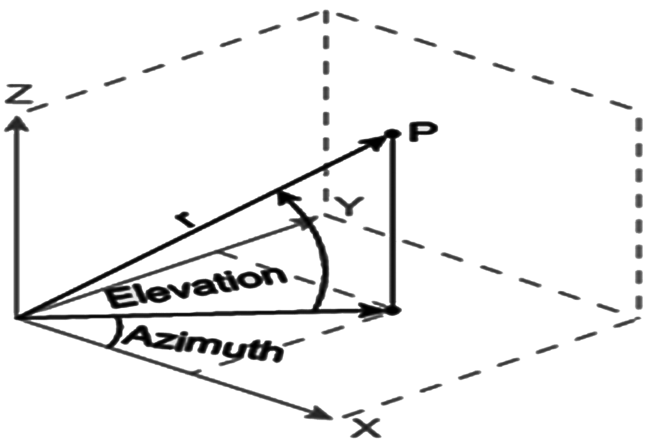

Figure 2.1: Range, azimuth and elevation convention of sensors for target tracking

respect to horizontal plane (XY Plane).

The Electro-Optical sensor are used in many applications such as

- Lamps that automatically switched on as per illumination.
- Position sensors are activated when an object interrupts the light beam.
- Flash detection to synchronise multiple cameras.
- Photographic sensors that detect distance, absence, and presence of an object in the field of view.

Target position measurement requires atleast two numbers of Electro-Optical Sensor (EOS). But as we increase the number of EOS the accuracy in the position measurement is more.

2.2 Basic working principle of Radar System

Radio detection and ranging (RADAR) is an object tracking device which is used to identify an object by using radio waves. It determines the range, angle and the velocity of the unknown objects. Radar is operated in ultra high frequency or microwave part of radio frequency. There are various applications of radars. It is widely used to detect aircraft, ships, guided objects, motor vehicles, navigation, defence sectors etc. A radar system consists of transmitter, wave guides, antennas, duplexer and receivers.

Radar is a three-dimensional tracking system. It measures the object location in the polar coordinate system. The radar sends a pulse signal and receives back the reflected signal and calculates the range of the object by the time difference of sending and receiving the signal. At the same time, it measures the angle at which an object is available. Therefore, it produces range, azimuth angle and elevation angle of the object.

A basic radar system is shown in Fig 2.2. It consists of two antennas one is transmitting and another is receiving, sometimes the same antenna is used for both transmitting and receiving purpose. Electromagnetic waves which is in the range of radio and microwave domain transmitted by the transmitting antenna and the waves propagates through the medium and reflected off the object and return back to the receiver.

Detection and search radars scan space volumes two to four times a minute with pulse of short radio waves. As the target is build of metal and reflects radio waves, the radar measure distance to the reflector by measuring round trip time.

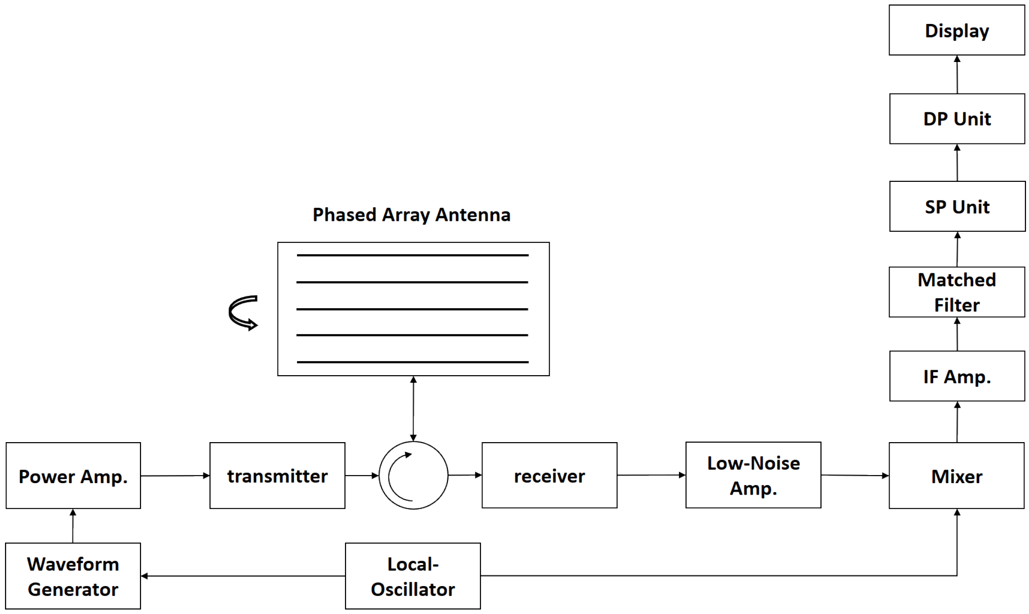

Figure 2.2: Block Diagram of Basic Radar System

The received pulse has to lie within a time period called 'Range gate'. An early warning radar is a radar which is used for long range detection of the target. In early warning radars there are a number of design features which improves the performances. It operates at lower frequencies. Since the frequency is low so the wave length is long. Bad weathering condition like rain and snow does not effect in its performances. The target acquisition radar is used in short range application but it has more inherent accuracy than the surveillance radar. An example of the target acquisition radar is anti-aircraft warfare, which is used to detect the target and then take the proper action.

2.3 Basic working principle of Passive Target Tracking System

A never-ending demand for finding the location and improving the measurement accuracy of target location either static or dynamic motivates researchers to find out more efficient and accurate solution. Target location finding helps largely in military prospects where the opponent's incoming target is estimated within milliseconds. Apart from this, it helps in emergency evacuation situations, navigation purposes, tracking a person, various search operations etc. The aviation sector has also significantly modernized with the help of positional location technology.

A lot of passive target tracking techniques are available to find out the unknown target location. Time Difference Of Arrival (TDOA), a widely used passive target tracking technique which is used to derive the position of the target. By applying cross-correlation techniques on signals received by two different receivers one hyperbolic equation can be formed. With the help of a minimum four receiving stations, a unique intersecting point can be derived from hyperbolic equations that gives the position of a target precisely. The accuracy of the target position depends upon the geometric location of the receivers with respect to the target location. A simulation study was carried out with seven numbers of receivers. We considered all thirty-five combinations taking four receivers at a time out of seven. From this simulation study, a unique relation between target position measurement errors with the average range difference error is established. With the help of the above relation, receivers can be prioritized and four receivers could be placed best geographical locations. By considering four high prioritized receivers minimum target position measurement error could be achieved. An attempt is focused to draw the error boundary and error factor of target position measurement with the range of the target. It is clear that the error factor is varying linearly with the range of the target.

2.4 Co-ordinate systems and transformations

We have used different kinds of co-ordinate systems in this research work. All those co-ordinate systems are discussed below.

2.4.1 ENU Coordinate System

The East-North-Up (ENU) coordinate system is defined with respect to a location on the earth's surface. It is called as local coordinate system (Fig. 2.3). In this system, the origin is arbitrarily fixed to a point on the earth's surface, the +X axis points to the east, the +Y axis points to the north and the +Z axis points to the vertically upward direction. The Z-axis passes through the center of the earth when using a spherical earth simplification, or is along the ellipsoid normal when using a geodetic ellipsoidal model of the earth.

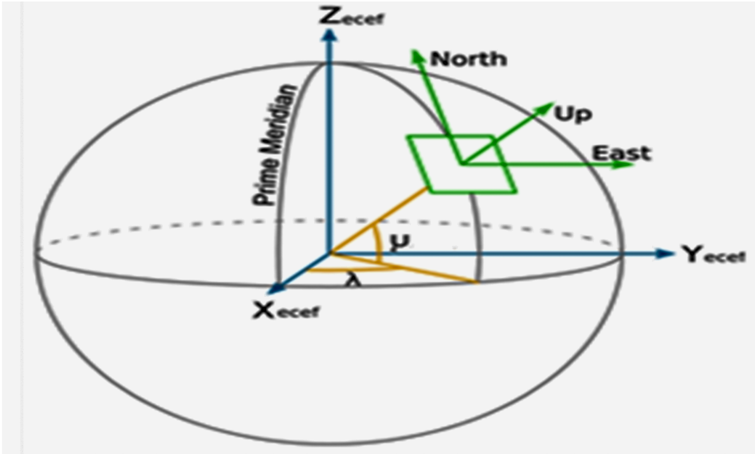

Figure 2.3: ENU and ECEF coordinate systems

2.4.2 ECEF Coordinate System

In the Earth-Centered, Earth-Fixed (ECEF) coordinate system, the origin is at the center of the earth, the X-axis intersects the sphere of the earth at 0° latitude (the equator) and 0° longitude (prime meridian in Greenwich), the Z-axis extends through true north and the Y-axis is orthogonal to both the X and Z axes following the right-hand rule (Fig. 2.3). The ECEF axes rotate with the earth, and therefore coordinates of a point fixed on the surface of the earth do not change. μ represents latitude and λepresents longitude of a location.

2.4.3 Cartesian and spherical coordinates:

The Cartesian coordinate system specifies each point uniquely in space by three numerical coordinates, which are the signed distances to the point from three fixed perpendicular directed lines (Fig. 2.4). Each reference line is called a coordinate axis or just axis of the system, and the point where they meet is its origin, usually at the ordered pair (0, 0, 0).

The spherical coordinate system is a coordinate system where the position of a point is specified by three numbers: the radial distance of that point from a fixed origin, its polar angle measured from a fixed zenith direction, and the azimuth angle of its orthogonal projection on a reference plane that passes through the origin and is orthogonal to the zenith, measured from a fixed reference direction on that plane.

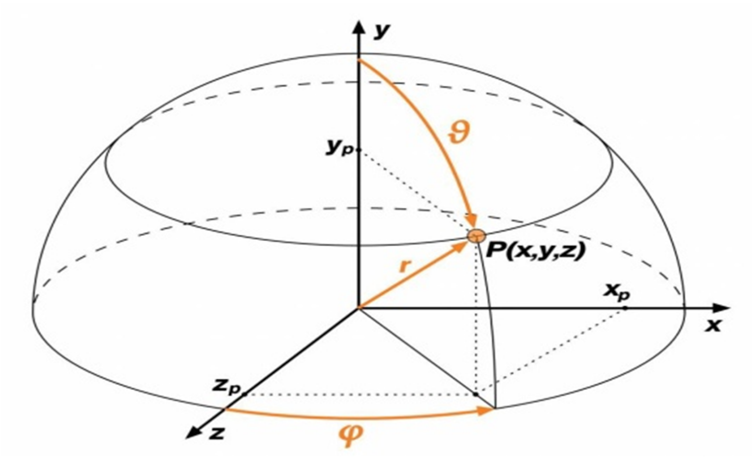

Figure 2.4: Cartesian and spherical coordinates

Radar can track an object and determine the range, azimuth, and elevation of the object. So it is essential to convert the range, azimuth and elevation into the Cartesian Coordinate (X, Y, Z). The conversion of the value of azimuth and elevation from degree to radian is required.

R = Range.

Az = Azimuth in radian.

El = Elevation in radian.

Then, in Cartesian coordinate

X = R * Cos(El) * Sin(Az).

Y = R * Cos(El) * Cos(Az).

Z = R * Sin(El).

So, from these formulae, one can easily convert the given Radar's data to the Cartesian coordinate (X, Y, Z).

2.5 Three Dimensional Triangulation Algorithm

Triangulation is a method that is based on the trigonometry laws useful to determine the location of a fixed point. According to the triangulation method, if two angles and one side of a triangle are known, the other two sides and the angle of that triangle can be calculated.

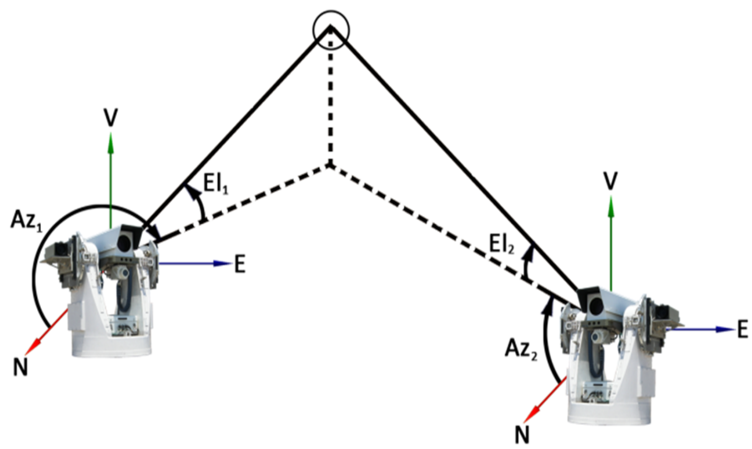

Figure 2.5: EOTS Triangulation Method

The triangulation method is used to measure the position of a fixed point based on the basis of trigonometry laws. These laws state that if one side and two angles of a triangle are known, the other two sides and the angle of that triangle can be calculated. Earlier triangulation was mostly assisted with maritime navigation, where it was helpful for sailors to track their position. Historically, triangulation has also played a vital role in the field of surveying and civil engineering. In addition to this, it is the principle behind the Global Positioning System (GPS) technology. A GPS receiver processes radio signals sent from four different satellites to determine longitude, latitude, and altitude. (In theory, the signals from three satellites could be used to adjust and fix the location; however, more numbers of satellites are used in order to improve the precision of the measurement.)

Nowadays, triangulation is widely used at various platforms such as astrometry, binocular vision, metrology, navigation, surveying, and model rocketry. In computer vision, the triangulation method points towards the tracking a position in 3D space given its projections onto at least two images. The coordinates of an image cannot be measured with arbitrary accuracy. Instead, various forms of noise, like geometric noise from lens distortion lead to inaccuracies in the measured image coordinates. As a result, the lines generated by the corresponding image points do not always intersect in 3D space. The problem, then, is to find a 3D point that optimally fits the measured image points. Here, triangulation is one of the methods which can solve the problem. We use azimuth and elevation angles provided by different Electro-Optic sensors for measuring the position by triangulation method.

2.6 Data Fusion

Multi-sensor data fusion is coming up as an independent discipline and it is used in a variety of applications. Data collected from multiple sensors cannot be used directly because of the dissimilarity of data values. Data fusion techniques are used to combine those data to get the most accurate and complete unified data. The coverage areas of data fusion systems include artificial intelligence, pattern recognition, and statistical inference. Sohn and Lee [37] studied application areas of data fusions and found that it is very large. It is used in military applications that include guidance for autonomous vehicles, remote sensing, automated target recognition, battlefield surveillance, and automated threat recognition systems. It is also in the nonmilitary application such as condition-based maintenance of complex machinery, monitoring of manufacturing process, medical pattern recognition and robotics.

A prime example of data fusion is humans. We rely on a fusion of smelling, touching, and tasting food to ensure it is edible or not. Similarly, all senses are used to collect and brain fuses to perform most of the tasks in our daily lives. Our brain always fuses the data gathered from all senses of humans explaied by Crowley and Demazeau [38].

2.7 Clustering Algorithm applicable on tracked data

Clustering is the technique of classification of objects or entities into different groups. In this process, a data set is partitioned into subsets or clusters. By this partitioning, the data in each cluster share some common features or attributes according to some pre-defined classification rules. Clustering is used in the following fields widely such as statistics, pattern recognition, and machine learning. The main goal of clustering is to determine the intrinsic grouping in a set of unlabeled data.

Yadav and Sharma [39] explained different types of the clustering algorithm and pointed out taht K-means is the most popular partitioning method of clustering. It was firstly proposed by MacQueen in 1967. K-means algorithm partitioned the data set into k different non-overlapping clusters. K- means clustering technique is the simplest form of the available association algorithms. In the K-means clustering algorithm, the nearest measurement to the currently available set is selected to update the set. Smith and Singh [40] shown taht the K-means algorithm is very easy to implement and it is capable of finding the solutions at a very less computational cost.

K-means algorithm is used for machine learning approach. This algorithm proposed that if most out of the K nearest samples belong to a category, then the sample belongs to that category. The main advantage of using K-means clustering over other techniques is that K-means clustering does not require any kind of training set or sample and also it has a very less computational cost. It is most suitable for real-time applications where time is very critical factor.

K-means clustering technique can be improved by using weighted K-means clustering, where weight is assigned to each of the data and then it is used for the classification using normal k-means cluster technique.

K-means clustering algorithm divides the dataset value into k different clusters. K-means clustering algorithm identifies the best localization of cluster centroid, where we can consider the center of the data cluster. For clustering using the K-means technique, we consider the Euclidean distances between the estimated position of the target by the different sensors.

Ma and Yu [41] explained that suppose if there are N samples and K is the number of clusters then the cluster which is having the highest number of samples, then this whole sample belongs to that cluster. Weighted clustering is also a good implementation of K-means clustering.

Here Euclidean distance is used to partition the sample into different clusters. Then Euclidean distance between 2 points in 3-Dimensional space (X,Y,Z) can be calculated as follows-

Suppose $X1$, $Y1$, $Z1$ is the coordinate of the first point and $X2$, $Y2$, $Z2$ is the coordinate of the second point.

Then the Euclidean distance D defined in equation (2.1).

$$D = \sqrt{(X1 - X2)^2 + (Y1 - Y2)^2 + (Z1 - Z2)^2} \tag{2.1}$$

Three different approaches of implementation of K-means clustering algorithm are elaborated in the following that is used in this research.

- **Approach 1: Random Clustering**

  In this case, assign random clustering to the sensor's estimated target position and do the K-means clustering with others remaining estimated positions. After that, the largest cluster centroid will be the estimated target position.

- **Approach 2: Clustering Based on Farthest Distance**

  Calculate the Euclidean distances between each of the sensor's estimated target positions and find out that which are at the farthest distance to each other. After that do the clustering based on the farthest estimated position and then repeat K-means Clustering for other remaining positions and largest cluster centroid will be estimated position of the target.

  This is better than the random clustering because if one choose random clusters then it may happen that the clusters are near to each other. Then the clusters are assigned with some wrong points, which leads to a big deviation from the actual result.

- **Approach 3: Recursive K-means Clustering**

  This the extended version of approach 2. Here, the K-means clustering is applied again on the largest cluster identified by the previous iteration.