

Collision Avoidance for Airborne system using GPS data and RADAR data

Prof. N.K. Srinath, and Dr. Ramakanth Kumar P

Abstract— The Airborne collision avoidance is required as the air traffic system continuous to grow. The various factors relating to the position of the aircraft at any instant of time is considered to avoid collision. This paper discusses collision avoidance in spite of parallel flights in space. It ultimately provide for certifying, safety-critical software developed for Collision avoidance System. The GPS information along with the RADAR data is accessed by the flight precisely surveillance. Time is an important factor for GPS system to calculate the position - longitude, latitude, and altitude, direction of motion and angle of motion. Precise time-oriented techniques of collision avoidance system provide both range and range-measurements of all air crafts as well as ground stations. It is desirable for an aircraft pilot to know the navigation parameters of not only his aircraft but also about the multiple flying aircrafts either relative/ absolute to his aircraft during sortie. To facilitate all these information, this paper shows the incorporation of a perfect and efficient multiple tracking systems like GPS, RADAR and display system on board. GUI and warning system are also provided to the pilot to maneuver the aircraft and avoid collision.

Index Terms— CAS, GPS, RADAR, NEMA

I. INTRODUCTION

Collision both in the air and on the ground is noticed quite regularly. Midair collisions occur about thirteen times a year on average resulting in multiple fatalities. [1]. One of the main rules for maintaining separation from other aircrafts is to maintain vigilance by each person operating an aircraft so as to avoid collision with other aircraft. Pilots need to know what to look for and how to look [2]. The limitation of the direct vision is the major handicap. The central part of the retina is called fovea. This part has one degree of horizontal and vertical vision. Due to the small area the complete details of the object is visible only if it is at a distance of 5 feet. The object in the sky is visible if it is less than five degrees on either side of this central vision. Atmospheric conditions such as haze, flight over open water, or an obscured horizon makes it difficult to visualize distance object. When the sun is low on the horizon the visibility of objects between the observer and sun is difficult. Optical illusion can affect the visibility of targets. Apart from these the other important factors that affect a pilot is

irritants in the air, fatigue, age, residual alcohol in the bloodstream and lower oxygen levels.

In aviation, the GPS receiver is used to complement visual navigation or just general navigation in airways when it becomes impossible to locate one's position visually due to weather or at night. However, GPS can also be used to guide airplanes to land in place of other less reliable aids like the non-directional beacons. The aircraft's computers use the latitude and the longitude information from the GPS to navigate from one point to another. Once a particular route has been identified, the preprogrammed system will direct the aircraft, through the autopilot, to fly straight or turn according to the route. This is executed automatically.

There are standard Rules that are applicable for all airplanes that operate in airways. Generally, the vertical separation between aircrafts is 1000 feet. Thus, aircraft flying east maintain an odd level whereas those flying West will fly an even level below a certain height. To accommodate more flights, certain airspaces have reduced the vertical separation to 750 feet. Time restrictions are also imposed on aircrafts to take off. Usually 10 minutes separation or about 70 to 85 miles between aircrafts are laid depending on the speed of the aircraft. In spite of all these precautions there are parallel aircraft in the air that causes collision.

A. Literature Survey

Collision avoidance System primarily depends on the time. Flying clocks are used as an integral part of the air born system since a long time. The ground stations are used to serve as depositories of time to all the navigation systems [2]. Using time reference the CAS, the other characteristics such as position, navigation and vehicle surveillance is obtained.

There are protective zone in which the paired aircrafts are placed behind the lead aircraft. To increase the protective zone collision alerting system is required. This protective increase zone may be from the any destination to any source. The various factors that are considered for protecting and to avoid collision are – blunder types, escape maneuvers and system delay time.[3] Climbing- turn breakout maneuvers, are effective as the total system delay should not exceed 10seconds. The factors that need to be considered are aircraft separations should not be less than 1000ft.

Apart from air born collision, there are number of untoward incidence during landing because of obstacles and terrain. It is essential to provide look-ahead, as well as look up terrain advisory and warning indication to the pilot of an aircraft of a hazardous flight condition. Using GPS systems,

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Prof. N.K. Srinath, is with the R.V. College of Engineering, Bangalore, India, 560059, phone: 91-080-67178086; fax: 91-080-28601337

Dr. Ramakanth kumar P, R.V. College of Engineering Mysore Road, Bangalore, INDIA, 91 9886309520,

navigational data such as terrain and advisory and terrain warning [4] indications based on the current position and projected flight path of the aircraft is provided.

B. Collision Avoidance Advisories

Collision avoidance system provides the crew of an aircraft with traffic advisories which assist them in visually acquiring intruder aircraft, and resolution advisories which provide them with recommended vertical escape maneuvers for avoidance of an intruder that becomes a threat. This system consists of four main subsystems: Surveillance, the collision avoidance subsystem, displays and controls and the monitor.

The Collision avoidance system uses the information provided each second by the Surveillance subsystem to determine the slant range and closing speed of other aircraft in the vicinity of the HOST aircraft and determines the time in seconds to closest point of approach. The report of the other aircraft is obtained by GPS and RADAR system.

a) System Design

Each aircraft must include a miniature Micro-electro-Mechanical System, Inertial Measurement unit, a miniature GPS XR5M receiver, DR-5 RS-232 Transmitter, RADAR antennas - one at the bottom end and other at the top end of the aircraft, a display, a data link receiver/transmitter and a central processing system. The GPS system provides the information about the aircraft position [3]. This position information is shared with other aircraft over a DR5 transmitter. An intelligent display shows the relative positions of the aircraft in the immediate vicinity of the host aircraft and issues voice and flashing warnings if a collision hazard exists. This system provides situational awareness to the pilot and enhances the safety of flight. Radar remote detection system is used to locate and identify objects. The transmitter sends out a high energy signal which bounces off objects in their path back to the radar whenever it strikes a reflecting object. The radar determines range to an object by the round trip time-of-flight (at the speed of light) of a transmitted pulse.

The software developed for this system has to perform basic operations such as – extract the required data, convert it to the required form [5], store the data in the system, transmit the data for the other aircrafts, read the radar data to identify the presence of other object, verify the information with the GPS data, display the position of the object with reference to its position [6], calculate the exact distance of the object, help the pilot to navigate in the right direction [7] to avoid collision by displaying the information on the GUI and provide warning if there is violation in the decision taken by the pilot.

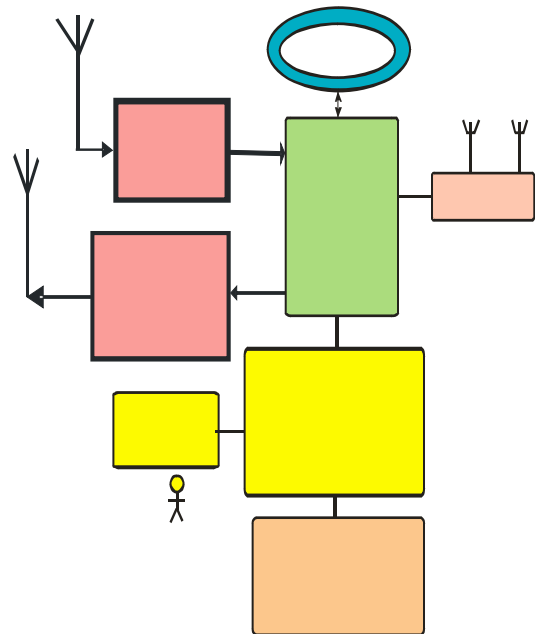


Figure - 1 System design with different components

17) GPS Data: The data that is required for the analysis is obtained in a specific format from the GPS system. It is called the NEMA data format. An NMEA standard defines an electrical interface and data protocol for communications between marine instrumentation.

The format is as follows:

```
GGA,123519,4807.038,N,01131.324,E,1,08,0.9,545.4,M,46.9,M,,*42
GGA - Global Positioning System Fix Data
123519   Fix taken at 12:35:19 UTC
4807.038, N   Latitude 48 deg 07.038' N
01131.324, E   Longitude 11 deg 31.324' E
1           Fix quality: 0 = invalid
                        1 = GPS fix
                        2 = DGPS
fix
08         Number of satellites being tracked
0.9       Horizontal dilution of position
545.4, M  Altitude, Meters, above mean sea level
46.9, M   Height of geoid's (mean sea level) above
WGS84    Ellipsoid
(Empty field) time in seconds since last DGPS update
(Empty field)   DGPS station ID number
```

18) Radar data: Radar data is retrieved directly from the radar unit. Data is retrieved character by character in an asynchronous mode and passes onto the MIL-STD-1533B data bus. MIL-STD-1553B operates as Bus Controller, Remote Terminal, Monitor Terminal and Monitor/RT. A bus monitor is a terminal that monitors the exchange of information on the MIL-STD-1553 data bus. The standard strictly defines how bus monitors may be used, stating that the information obtained by a bus monitor be used "for off-line applications (e.g., flight test recording, maintenance recording or mission analysis) or to provide the back-up bus controller sufficient information to take over as the bus controller." A monitor may collect all the data from the bus or may

collect selected data.

The electronic hardware between a remote terminal, bus controller, and bus monitor doesn't differ much. Both the remote terminal and bus controller (and bus monitor if it is also a remote terminal) must have the transmitters/receivers and encoders/decoders to format and transfer data. The requirements upon the transceivers and the encoders/decoders don't vary between the hardware elements.

Sample RADAR data

1. Time: Chronologic= 0 Milisec Message Time:
0.088000 Milisec RADAR Bus-1 CMD f811
31-R-00-17 DATA 0007
2. Time: Chronologic= 1 Milisec Message Time:
0.088000 Milisec RADAR Bus-1 CMD fba2
31-R-29-02 BC - RT DATA 0e10 1c06
3. Time: Chronologic= 1 Milisec Message Time:
0.104000 Milisec RADAR Bus-1 CMD 18b2
03-R-05-18 BC - RT DATA 0000 0000
0000 0000 0000 0000 0000 0000 0000 0000 0000
0000 0000 0000 0000 0000 0000 0000 STATUS
1800

To implement the system without errors we need to consider the different error that may creep in GPS/RADAR system. Some of the errors that are identified in ephemeris data [12] - Errors in the transmitted location of the satellite, Satellite Clock - Errors in the transmitted clock, including SA, Ionosphere-Errors in the corrections of pseudo range caused by ionospheric effects, Troposphere - Errors in the corrections of pseudo range caused by tropospheric effects, Multipath - Errors caused by reflected signals entering the receiver antenna and Receiver -Errors in the receiver's measurement of range caused by thermal noise, software accuracy, and inter-channel biases.

Flight test error statistics are provided considering the absolute difference from both vertical and horizontal errors source associated with radar altimeter. The errors that are being calculated are plotted:

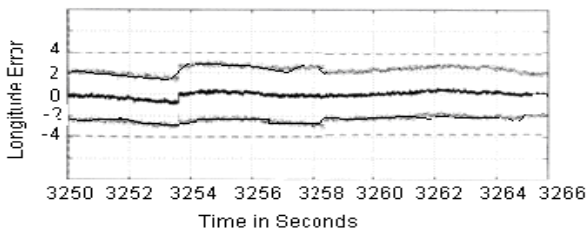


Figure - 2 Latitude Error

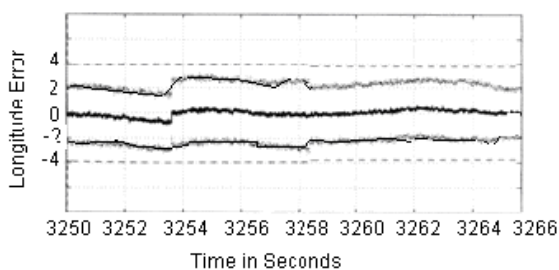


Figure - 3 Longitude Error

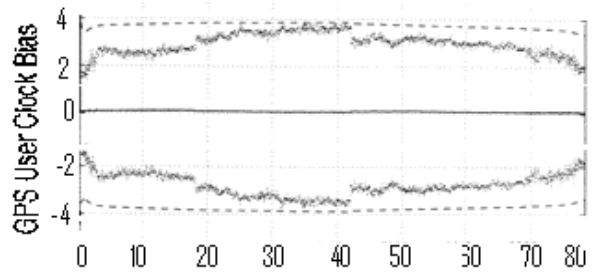


Figure- 4 Altitude Error in meters

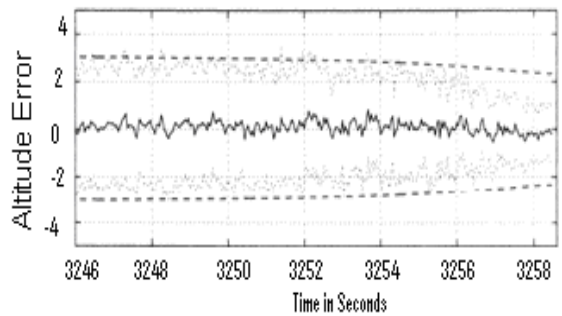


Figure - 5 Clock Error

Considering all the error that may creep in, it is inevitable to compare the data obtained by the GPS with the RADAR data. Considering all errors it is observed that the error is in the range of +12 to -12 feet. These errors are tolerable as the distance between the two aircrafts are greater 300 feet to avoid collision.

The data of the aircrafts, which is received from the GPS receiver, is in the form of geographical co-ordinates. They exist in the form (ddmm.mmmm), where,

- dd - degrees
- mm - minutes
- mmmm - decimal minutes

These units are not appropriate for the distance and bearing calculations. They must be converted to degrees and decimal degrees, then to radians.

1. mm.mmmm to dd.dddd
2. Radians = dd.dddd / 57.3
3. $d = \arccos(\sin(\text{LatH}) \times \sin(\text{LatT}) + \cos(\text{LatH}) \times \cos(\text{LatT}) \times \cos(\text{LonH} - \text{LonT}))$

where d = distance between two aircraft's in radian

$$c = \left[\frac{\arccos(\sin(\text{LatT}) - \sin(\text{LatH}) \times \cos(d))}{\cos(\text{LatH}) \times \sin(d)} \right]$$

where c = course or bearing

5. Degrees = radians X 5.2957795

6. Screen co-ordinates :

$$X_s = V_{xr} - \frac{V_{xl}}{W_{xr} - W_{xl}} (X_w - W_{xl}) + V_{xl}$$

$$Y_s = V_{yt} - \frac{V_{yb}}{Y_w - W_{yb}} (Y_w - W_{yb}) + V_{yb}$$

$$W_{yt} - W_{yb}$$

where,

- X_s x coordinate value of screen
- Y_s y coordinate value screen
- X_w x coordinate value of window
- Y_w y coordinate value of the window
- V_{xr} Viewports x coordinate right
- V_{xl} Viewports x coordinate left
- V_{yt} Viewports y coordinate top
- V_{yb} Viewports y coordinate bottom
- W_{xr} Windows x coordinate right
- W_{xl} Windows x coordinate left
- W_{yt} Windows y coordinate top
- W_{yb} Windows y coordinate bottom

b) 2.2 Threat detection

The Collision Avoidance System obtains the target aircraft range, relative altitude and altitude rate with respect to its own. Depending on the information, the traffic (potentially triggering a Threat Detection(TD)) or a threat (potentially triggering Resolution Advisory(RA)) based on whether it is within different protected volumes of airspace surrounding the Traffic alert and Collision Avoidance system.

These volume thresholds are based on a range test, calculated using the time to Closest Point of Approach. It is shown in fig 6.

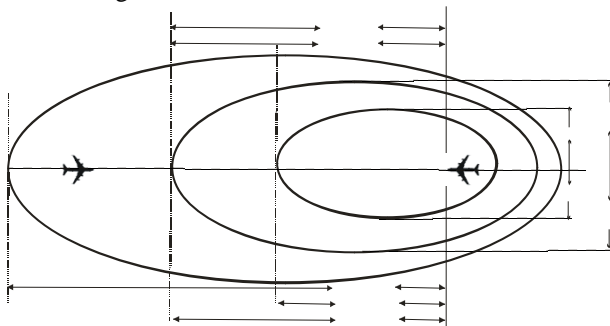


Figure-6 Threat Detection Range TD and RA

The nature of providing an effective collision avoidance system results in the need to have numerous special conditions spread throughout the functions and these are dependent on encounter geometry, range and altitude thresholds, and aircraft performance. Using range, altitude (when available), and bearing from nearby aircraft that are provided to collision avoidance system by the Surveillance function, the collision avoidance system logic initiates and maintains a three-dimensional track of each aircraft and uses this information to determine the time to closest point of approach and the altitude of each aircraft at closest point of approach. The CAS logic uses the altitude information to estimate the vertical speed of each nearby aircraft and maintains a vertical track for each aircraft.

(i) Tracking aero plane on ground

The CAS tracker also uses the difference between its own aircraft altitude received from GPS and radar altitude to estimate the approximate elevation of the ground above mean sea level. This ground estimation logic functions whenever the own aircraft is below 1750 ft AGL (Above Ground Level). The ground level estimate is then subtracted

from the altitude received from GPS/RADAR. If this difference is less than 360 feet, Traffic Collision Avoidance Systems considers the reporting aircraft to be on the ground. If aircraft is on the ground it inhibits the generation of advisories against this aircraft. This methodology is shown graphically in Fig.7

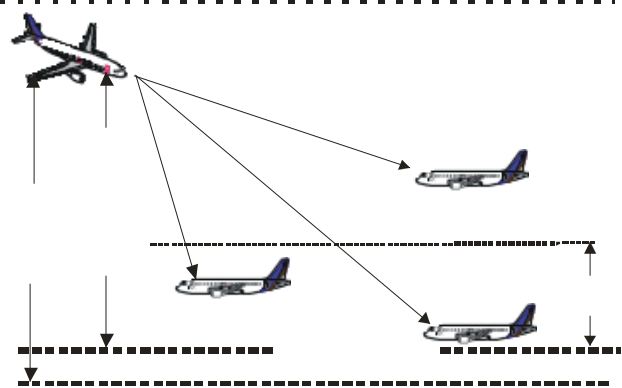


Figure-7 Ground Target Determination

(ii) Vertical separation:

Vertical separation at closest point of approach must be within the range depending on the altitude in which it is flying. The table-1 shows a target to be declared as intruder. If this logic declares an aircraft to be an intruder, a Traffic Advisory will be issued against the aircraft.

Altitude (feet)	Altitude Threshold(feet)
<42000	750
>42000	1000

Table-1 Altitude intruder index by TA

(iii) Range and altitude Test

Range and altitude tests are performed on each altitude-reporting intruder. If the range and altitude are not met with the threshold altitude as shown in the table-2, the intruder is declared a threat.

Altitude (feet)	Altitude Threshold(feet)
<1000	N/A
1000-5000	200
5001-10000	250
10001-20000	300
20001-42000	400
>42000	650

Table – 2 Altitude indicating Threat by RA

1) Action for the Advisory Selection:

When a Target (intruder) is declared a threat, a two step process is used to select the appropriate advice for the encounter geometry. The first step in the process is to select the upward or downward motion. Based on the range and altitude tracks of the Target, the collision avoidance System logic models the Target's flight path from its present position to closest point of approach. The closest point of approach logic then models upward and downward sense for HOST aircraft, as shown in Figure-8, to determine which sense provides the most vertical separation at closest point

of approach. In the figure-8, we see that the closest point will be when the collision avoidance aircraft takes the upward motion. It is calculated and the decision is provided to select the downward sense logic.

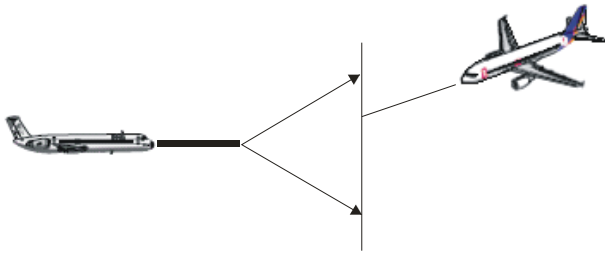


Figure-8 Decision to take downward path

When the range and altitude track of the Target, is equidistance, the HOST is designed to select the nonaltitude crossing. If the nonaltitude crossing provides at least altitude limit of separation at closest point of approach, this will be selected even if the altitude-crossing sense provides greater separation. If altitude limit cannot be obtained in the nonaltitude crossing sense, an altitude crossing resolution advisory will be issued. Figure-9 shows an example of encounters in which the altitude crossing and nonaltitude crossing resolution advisory senses are modeled and the noncrossing resolution advisory RA sense is selected.

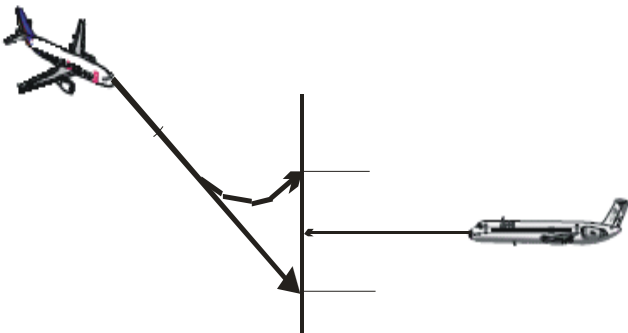


Figure – 9 Equidistance for the host

The Resolution advisory is designed such that it provides least disruption to the existing flight path while providing AL (altitude limit) of separation. The table-3 provides the resolution advisory that can be issued when only a single intruder is involved in the encounter. The Collision avoidance system logic should continuously monitor the vertical separation that will be provided at closest point of approach and modify the initial RA if necessary.

When both HOST and Target aircraft are converging vertically with opposite rates and are currently well separated in altitude, the Traffic collision avoidance system will first issue a vertical speed limit to reinforce the pilots. If the pilots do not respond to this initial RA and if either aircraft accelerates towards the other aircraft, the initial RA will strengthen as required. This would reduce the frequency of initial RAs that reversed the vertical rate of the HOST aircraft (e.g. pose a climb RA for a descending aircraft).

Figure - 10 shows an encounter where it is necessary to increase the climb rate from the 1500 fpm required by the

initial RA to 2500 fpm. This is an example of an Increase Climb RA.

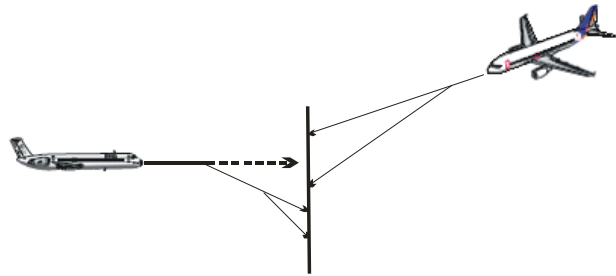


Figure – 10

Figure-11 depicts an encounter where an initial Descend RA requires reversal to a Climb RA after the intruder maneuvers.

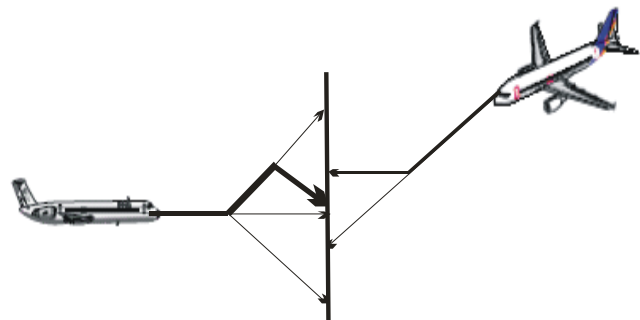


Figure – 11

In coordinated encounters, it is required to reverse RA. Reversals are not permitted for the first nine seconds after the initial RA to allow time for both aircraft to initiate their RA response. RA reversals are not permitted if the aircraft are within 300 feet of each other and the reversal would result in an altitude crossing RA.

In coordinated encounters, the logic that considers issuing an increase rate RA late in an altitude crossing RA is disabled. At high altitude the aircraft installation may be configured to inhibit climb or increase climb RA because of aircraft climb performance limitations. This information in real-time is provided by the input from the Flight management system – GPS, RADAR or Altimeter.

Because of aircraft climb performance limitations at high altitude or in some flap and landing gear configurations, an aircraft installation may be configured to inhibit Climb or Increase Climb RA under some conditions. These inhibit conditions can be provided via program pins in the TCAS connector or in real-time via an input from a Flight.

TCAS is designed to handle multi-aircraft encounters, i.e., those encounters in which more than one TARGET is detected at the same time. TCAS will attempt to resolve these types of encounters by selecting a single RA that will provide adequate separation from each of the intruders. This RA can be any of the initial RAs shown in Table 3, or a combination of upward and downward sense RAs, e.g., Do Not Climb and Do Not Descend. It is possible that the RA selected in such encounters may not provide altitude limit

separation from all intruders.

II. RESULT AND CONCLUSION

The data regarding the flight position with respect to altitude, longitude, latitude, bearing obtained by RADAR alone is not reliable. It is necessary to have a redundant source that provides accurate information. To achieve this, data is being collected from GPS as well as RADAR. The data obtained online is processed immediately as the GPS data is obtained every one second and the RADAR data is obtained asynchronously. The time obtained for maneuver the aircraft will depend on the target plane vicinity to the host. The host has advisory software. The first advisory is Traffic Advisory (TA) which points the presence of the target plane. With the knowledge of the altitude of the target plane, the position of the HOST can be altered to see that the altitude is on the safe range. If the TARGET plane is closer, there is Resolution advisory which displays on the HOST plane the course of action that needs to be taken. The time gap of around twenty seconds is good enough for the HOST to maneuver the plane to change its altitude by climbing or descending. The RA provides the rate of climb or descends depending of the position of the target and its movement with respect to the host. The table 3 provides the trend depending on the position of the target with respect to time of closest point of approach.

RA (40 Sec.) Below	RA (28 Sec.) Below	RA (40 Sec.) Above	RA (28 Sec.) Above
Climb	Maintain Climb	Descend	Maintain Descend
1500 to 2000fpm	2001 to 4400fpm	-500 to -2000fpm	-2000 to -4400fpm

Table – 3 Climb and Descend by RA

It is concluded that by changing the altitude of the aircraft, it is possible to avoid collision. It should be noted that the problem that is tackled here is the mid air collision with the flight being above 1750ft. It indicates that the aircraft would have traveled away from the aerodrome and there will not be much control from the control tower.

It is also observed that 80% of the collision occurs very near to the aerodrome and below 1750ft. Since we are looking at the possibility of mid air collision due to the enhanced traffic in the air, the precaution provided enables error free and zero mid air collision.

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Srinath N.K. Information Science and Engineering, R.V. College of Engineering, Mysore Road Bangalore. Completed ME in systems engineering, Rookee university, Pursuing PhD at Avinashlingam University for Women. Fellow of IETE, Life Member of CSI and Member of ISTE



Dr. Ramakanth Kumrar P, P Professor of CSE department, R.V. College of Engineering, Bangalore, Completed M.S in Computer Science from BITS Pillani, Doctorate from Mangalore University in Computer Science and Engineering