

# Researches on Simulation and Validation of Airborne Enhanced Ground Proximity Warning System

Ma Shidong, He Yuncheng, Wang Zhong, Yang Guoqing

**Abstract**—In this paper, enhanced ground proximity warning simulation and validation system is designed and implemented. First, based on square grid and sub-grid structure, the global digital terrain database is designed and constructed. Terrain data searching is implemented through querying the latitude and longitude bands and separated zones of global terrain database with the current aircraft position. A combination of dynamic scheduling and hierarchical scheduling is adopted to schedule the terrain data, and the terrain data can be read and delete dynamically in the memory. Secondly, according to the scope, distance, approach speed information etc. to the dangerous terrain in front, and using security profiles calculating method, collision threat detection is executed in real-time, and provides caution and warning alarm. According to this scheme, the implementation of the enhanced ground proximity warning simulation system is realized. Simulations are carried out to verify a good real-time in terrain display and alarm trigger, and the results show simulation system is realized correctly, reasonably and stable.

**Keywords**—enhanced ground proximity warning system; digital terrain; look-ahead terrain alarm; terrain display; simulation and validation

## I. INTRODUCTION

ENHANCED ground proximity warning system (EGPWS), computes the aircraft current position, atmospheric pressure altitude, and flight track etc. through receiving the data of air data computer, radio altimeter, inertial navigation system, ILS, and the current aircraft configuration data. Combing with the airborne terrain database, obstacle database, and airports database around the world, EGPWS determines the potential conflict with the terrain and obstacles [1]. If unsafe conditions happen when approaching to the terrain, the unsafe terrain will be shown on the navigation display, and on primary flight display, the warning message will appear, the visual and aural alarm signals will be sending out to remind pilots to take effective measures, the main function of EGPWS is to avoid controlled flight into terrain.

Honeywell has researched and developed a series of EGPWS products for many years, and the global terrain database is released regularly, users can update it through its website [2] [3]. These products, for example, the advanced KMH980 hazard perception system, with integrating air traffic information, airborne collision-avoidance system and EGPWS, has powerful functions and this product is widely used in commercial, military, general aviation and other fields. In NASA Langley Research Center and other companies, synthetic vision is used to research and avoid controlled flight into terrain. In other researches, EGPWS integrating with synthetic vision is a new trend in EGPWS development [4] [5].

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Meanwhile, in foreign countries, the implementation methods and processing algorithms of EGPWS system are continuously improved and innovated. In America, many new algorithms are designed and many national patents are applied in EGPWS system, the practical techniques are being verified. EGPWS system has few studies in our country. At present, only northwestern polytechnical university [6] and civil aviation university of china have some studies, but they are not comprehensive enough, and not practical. In defense industry, because of confidentiality, the research of EGPWS system is unknown. Furthermore, the research, development, and implementation of EGPWS are not clear yet.

In this paper, the global digital terrain database is designed and constructed based on square grid and sub-grid structure. Terrain data searching is implemented through querying the latitude and longitude bands and separated zones of global terrain database with the current aircraft position. A combination of dynamic scheduling and hierarchical scheduling is adopted to schedule the terrain data, and the terrain data can be read and delete dynamically in the memory. According to the scope, distance, approach speed information etc. to the dangerous terrain in front, and using terrain alarm profiles calculating method, collision threat detection is executed in real-time, and provides caution and warning alarm. Enhanced Ground Proximity Warning Simulation and Validation System are implemented with a good real-time in terrain display and alarm trigger.

## II. CONSTRUCTION OF GLOBAL DIGITAL TERRAIN DATABASE

The construction of global digital terrain database is foundation of achieving warning alarm and terrain display. The terrain data should be small enough to facilitate the use of relevant methods of data processing, for example, in searching and scheduling terrain data, the need of real-time display should be met. Global digital terrain database is constructed based on square grid structure, and it is widely used in continuous surface digital representation. With simple structure, small amount of data storage, it is convenient to analyze and calculate [7]. Furthermore, there has airport database, which includes airport name, runway length, location of runway center, entrance location, airport height, and runway direction etc. According to the square grid scheme, each square grid has a covering range of about  $256 \times 256$  nautical mile, as shown in fig.1; these squares grids can also be divided into different levels of sub-grid to provide higher accuracy for terrain data. For example, each square grid can be divided into 16 sub-grids, which is  $64 \times 64$  nautical mile covering range; again, the sub-grids can also be divided into 16 sub-grids,

which is  $16 \times 16$  nautical mile covering range, again  $4 \times 4$ ,  $1 \times 1$  nautical mile, and finally  $0.25 \times 0.25$  nautical mile for highest accuracy which present the terrain data near airport.

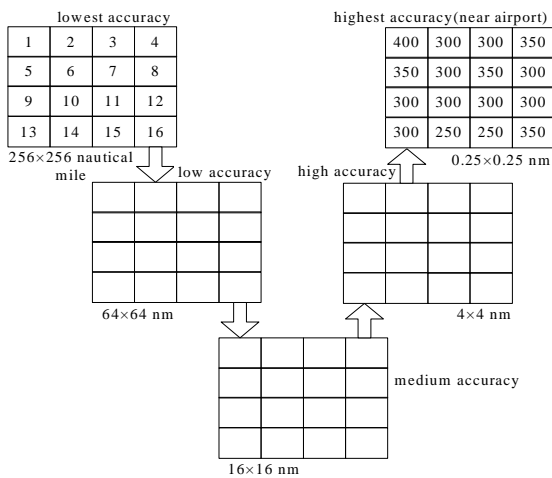


Fig.1 Grids and sub-grids of terrain database

In each square grid, there is a data header, and reference height of the grid is stored in the data header. Reference height is the highest point of the grid elevation representing the entire square grid [8]. Moreover, a flag is included in data header, which representing that in some areas there is no more detailed resolution classification. For example, in marine areas, no matter what resolution it is, the maximum elevation value is the same, so there is no need to divide the square grids. The structure of data header of square grid is shown as fig.2.

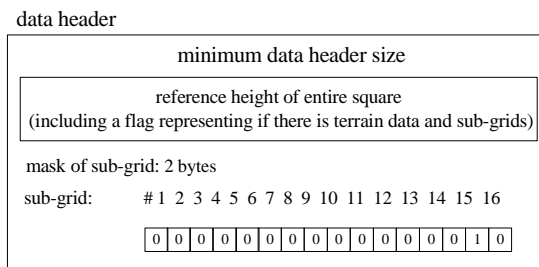


Fig.2 Data header structure of square grid

For the mountains and areas near the airport, more accurate data can be provided by terrain database. In this case, the flag contains a 2-bytes mask, illustrating that in the next level sub-grids, there has different elevation values. For example, the number "1" in the 15th bit is a 2-bit mask as shown in fig.2. When going to the next level of sub-grid, each grid will also have a data header illustrating that whether there have different elevation values and whether can be divided again.

When reading terrain data, the reference height of the data header is reading first, and through the flag to determine whether there has more accurate data in the next level sub-grid. If there has more accurate data, then judging the 2-bit mask in the data header of next level sub-grid, and finally the most accurate terrain data will be read and displayed.

The structure of the terrain database provides great flexibility for application. With small amount of data storage, it is fast and easy to read. Moreover, when necessary, terrain data can be added and modified without changing other parts of the grids.

#### A. Real-time Searching of Terrain Data

The terrain data in database are used in terrain threat detection and terrain display, with the processing of terrain collision detection, the topographic information is also displayed on navigation instrument. Terrain collision detection is based on current aircraft position, velocity etc. Through searching terrain database, the aircraft current location is determined, and the current terrain data around aircraft is got, scheduled and stored.

The aircraft's current position is determined by the latitude and longitude, and latitude and longitude information is provided by navigation system. First, according to different latitude, the global terrain can be divided into different latitude bands, for example, the latitude bands 1 to 4 as shown in fig.3. It also can be subdivided into different partitions in each latitude band. These different partitions are not the same sizes, and they can not be overlapped. The figures, as shown in fig.3, for example 1.1, 4.2 etc. represent these partitions. In each partition, it also can be subdivided into different areas. In order to facilitate calculating and scheduling, the size of these areas is limited, the maximum longitude and latitude is 4 degrees, and these areas can be overlapped.

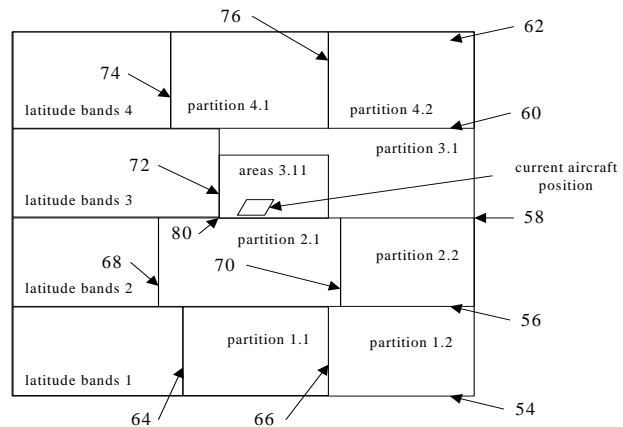


Fig. 3 Terrain data searching

When searching the terrain data during flight, in which latitude band the aircraft is should be determined first, and then determine in which partitions, finally determine in which areas. Searching terrain data in this way, processing time can be reduced greatly [8].

In determining latitude band, the latitude transmitted by aircraft navigation system should be compared to the different latitude bands stored in terrain database. For example, the figures 54, 56, 58, 60 as shown in fig.3, respectively define the lower boundaries of latitude bands 1, 2, 3 and 4. When determining, the latitude information should be compared to each latitude band, determining whether the latitude greater,

equal to or less than each latitude band. If equal to the latitude band, the aircraft is in the latitude band, if greater then the latitude band, then compare the aircraft latitude to the next latitude band, vice versa. Continue this process of comparison, and eventually the aircraft position can be determined in a certain latitude band.

Once the latitude band is determined, the next step is to determine in which partition the aircraft is. This is realized through comparing the current aircraft longitude to the longitude band stored in terrain database, as shown in fig.3, the figures 64、66、68、70、72 etc. represent the longitude boundaries of every partition. If the aircraft is in the latitude band 2, then current aircraft longitude should be compared to the longitude boundaries 68 and 70. If current aircraft longitude is equal to boundary 68, the aircraft is in partition 2.1, if less then 68, the aircraft is not in any partition, if greater then 68, then continue to compare the current aircraft longitude with boundary 70, until the partition is determined. In the course of comparison, the latitude bands and longitude boundaries are stored avoiding repeated determining and comparison. Because the partition is not overlapped, so in this way, every partition is uniquely determined.

Once the partition is determined, the next step is to determine in which area the aircraft is. The area is defined by 4 degrees longitude and latitude, its border is marked by area corner, for example, the area 3.11 is marked by the its area corner 80. Through comparing the current aircraft longitude and latitude with the area, if the aircraft position is within 4 degrees nearby corner 80, the aircraft is inside area 3.11. After determining the aircraft position in the terrain database, the terrain data of this area can be scheduled and processed.

### B. Real-time Scheduling of Terrain Data

The terrain data is stored in a ROM, in order to facilitate updating the terrain data according to aircraft's current position, after the terrain data in ROM is decompressed, it is transmitted to RAM, with the data in RAM the terrain map can be generated, and the map is displayed with current aircraft position as its center[9], as shown in fig.4, with the aircraft's position changing, the terrain data in ROM is continuously transferred to RAM and the map is generated and displayed in real-time.

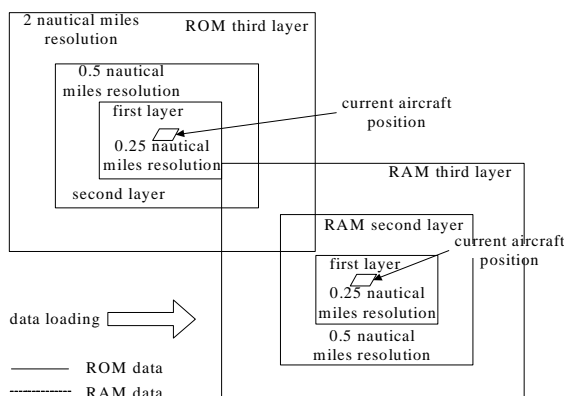


Fig.4 Searching and scheduling of look-ahead terrain data

In order to provide a relatively large display range, for example 160 and 320 nautical miles display range, and to reduce the amount of processed data and time, the terrain data in RAM is constructed by the form of hierarchical data, that is, the terrain data nearby the aircraft have the highest accuracy. With distance increasing, the terrain data accuracy becomes less and less. The current aircraft position is in first layer, in this layer, the terrain data has highest accuracy, then following by second and third layers, and their accuracy become less and less. In every layer, the terrain data is stored with the current aircraft position as its center. There have terrain boundaries in every layer, when aircraft fly over the boundary, the terrain data in RAM will be updated from ROM, as shown in fig.4. This hierarchical data is displayed in variable accuracy, and it can reduce the amount of data processed in memory, for large-scale terrain display, it can reduce processing time [10]. As mentioned above, terrain data in ROM is also constructed by this hierarchical data structure.

### III. IMPLEMENTATION OF LOOK-AHEAD TERRAIN WARNING

Except for landing, look-ahead terrain warning works in all flight phases and its working height is above 30 feet. Integrating current aircraft position, altitude, speed and other information, with internal global terrain database, look-ahead terrain warning gives a caution or warning for potential conflicts to the terrain. If terrain or obstacles appear within security profile, then caution or warning starts. The security profile has a certain space respectively in front of the aircraft, below and above the aircraft, in front of aircraft, there is a width of 0.25 nautical miles, and extend with three degrees angle. The security profile boundary angles below and above aircraft is a function of aircraft flight path angle [11]. Look-down distance of the security profile is a function of nearest or destination runway height. This can prevent unwanted cautions or warnings caused by taking off or landing. Look-ahead distance is a function of aircraft speed and the distance to the nearest airport. The security profile of look-ahead terrain warning is shown as fig.5.

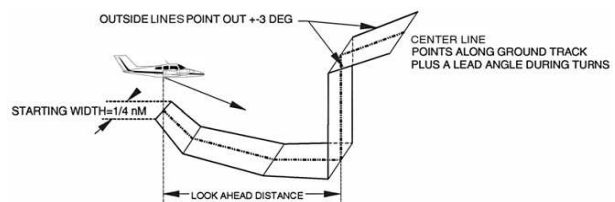


Fig. 5 Security profile of look-ahead terrain warning

According to processes and principles of look-ahead terrain warning, collecting parameters on every aircraft system, such as radio altitude, speed, vertical speed, flight path angle etc, with these parameters, the security profile is generated. Then current flight area terrain is found in terrain database, and the potential conflict to the terrain or obstacles is detected. If terrain or obstacles appear within security profile, then caution

or warning starts. The algorithm process of look-ahead terrain warning is shown as fig. 6.

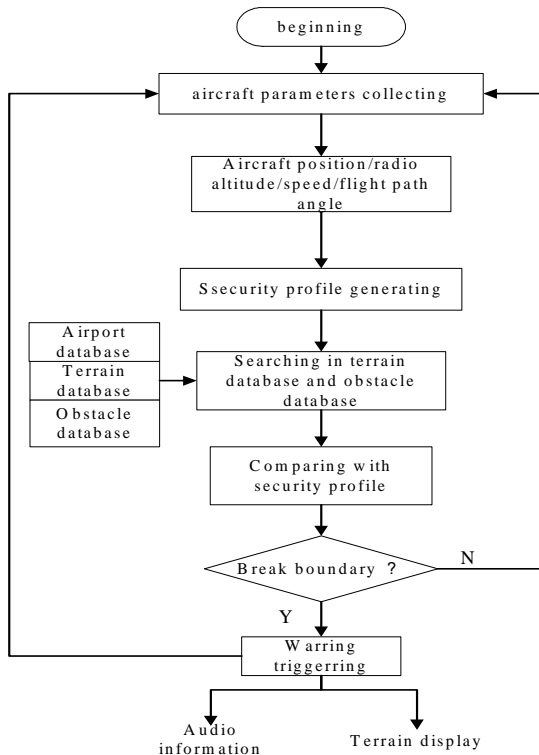


Fig. 6 Algorithm of look-ahead terrain warning

#### A. Computation of Security Profile

Look-ahead distance of security profile is computed based on aircraft ground speed by determining a certain distance range along the ground track of aircraft speed. To reduce unwanted cautions or warnings, the look-ahead distance is limited. But, there are two different look-ahead distance, one is terrain caution, which is started within 60 seconds before the aircraft colliding with terrain. Another is terrain warning, which is started within 30 seconds before the aircraft colliding with terrain.

The look-ahead distance of terrain caution is determined by flight time to dangerous terrain or obstacles multiplied by current ground speed, as mention above, take the flight time as 60 seconds, the calculation method of look-ahead distance of terrain caution is shown as formula 1.

The look-ahead distance of terrain warning is also determined by flight time to dangerous terrain or obstacles multiplied by current ground speed, take the flight time as 30 seconds, the calculation method of look-ahead distance of terrain warning is shown as formula 2.

$$S_1 = 60 V \quad (1)$$

$$S_2 = 30 V \quad (2)$$

$V$  is ground speed,  $S_1$  and  $S_2$  are respectively look-ahead distance of terrain caution and look-ahead distance of terrain warning. The vertical distance of security profile is

determined by distance of aircraft position to nearest airport and flight height level [8], the function relationship between vertical distance and distance to airport and flight height level is shown as fig.7.

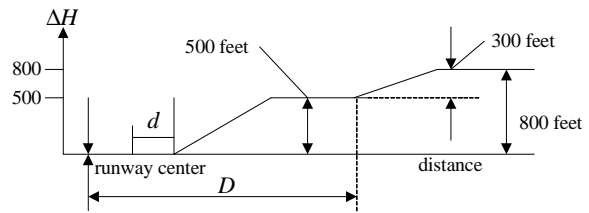


Fig.7 Relationship between vertical distance and distance to airport

In fig.7, the horizontal axis represents the horizontal distance from aircraft to runway, and the vertical axis represents the vertical distance of security profile. The vertical distance maintains 0 when horizontal distance is within  $d$  to the runway end, that is to say, in this range, the cautions or warnings can not be started to the terrain below the aircraft. From  $d$  point, with increase of horizontal distance, the vertical distance of security profile increases at a gradient of 100 feet per mile and finally increases to 500 feet high, then maintain the height to  $D$  point,  $D$  is 12 miles. After this, the vertical distances increase again at gradient of 100 feet per mile until 800 feet high, and then maintain the height unchanged. When aircraft flight at or above flight level 3000 feet, the vertical distance of security profile will maintain 800 feet high unchanged.

#### B. Implementation of Terrain Display and Warning

Terrain display is to demonstrate a certain range terrain on the navigation display in accordance with a certain color scheme. According to the aircraft's current altitude, location and color scheme, the terrain data is processed and the nearby terrain is displayed as a map. And the map is displayed by different colors such as red, yellow and green with different densities. These colors are transformed with the changes of aircraft height. The terrain display color scheme is shown as fig.8 [12].

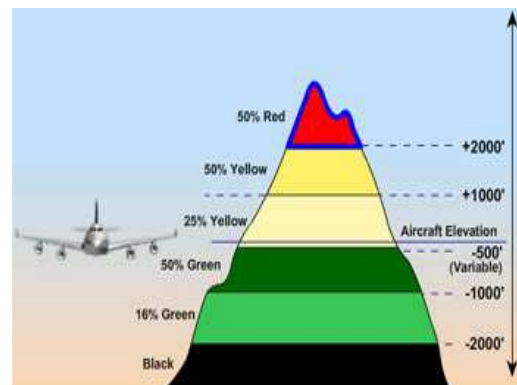


Fig.8 ND terrain display color scheme

As shown in fig.8, the red color represents the terrain that significantly higher than the aircraft's current altitude, the terrain that is 2000 feet (609.6 meters) or above higher than aircraft altitude is displayed in high-density red.

The terrain that is 2000 feet (609.6 meters) to 1000 feet (304.8 meters) higher than aircraft altitude is displayed in high-density yellow.

And the terrain that is 1000 feet (304.8 meters) higher than aircraft altitude to 500 feet (152.4 meters) lower than the aircraft is displayed in medium-density yellow.

Any terrain that is 2000 feet (609.6 meters) lower than aircraft is displayed in black color. Other color scheme is demonstrated as fig.8.

Except the rules of terrain display, if there are dangerous terrains or obstacles during flight, warning or caution starts, and the red or yellow grids appear on navigation display to display the scope of warning or caution terrain. The red grids represent warning terrain and the yellow grids represent caution terrain.

#### IV. SIMULATION AND CONCLUSIONS

According to above EGPWS design scheme, simulations and experiments are executed to verify its functions. First, the aircraft's current position is determined in terrain database, and then the terrain data nearby the aircraft is searched and after data processing and scheduling, the terrain map is displayed in navigation display. The dangerous terrains or obstacles are distinguished by the security profile and if there have dangers, warning or caution starts, and the red or yellow grids appear to display warning or caution terrain.

If dangerous terrains or obstacles appear in the scope of caution distance, terrain caution will be started within 60 seconds before the aircraft colliding with terrain. The audio information is "CAUTION TERRAIN", and the terrain map is automatically pop-up on the navigation display, and yellow grids appear on ND representing the caution terrain.

If dangerous terrains or obstacles appear in the scope of warning distance, terrain warning will be started within 30 seconds before the aircraft colliding with terrain. The audio information is "TERRAIN, TERRAIN PULL UP", and the red words "PULL UP" appear on primary flight display, and "PULL UP" appears on the map in red, subsequently red grids appear on ND representing the warning terrain[12] [13].

In each simulation time cycle, the aircraft's position should be updated, and the forecast flight track should be recalculated to update the scope of terrain, with the security profile, the dangerous terrains can be distinguished. In this way, real-time computation of terrain warning according to aircraft position, speed, etc. is implemented, and the modes and levels of warnings can be updated. Simulations and experiments are shown as fig.9 and fig.10. In fig.9, the terrain map nearby aircraft is displayed according to above color scheme, and the scope of warning or caution terrain is displayed in fig.10 with red or yellow grids.



Fig. 9 Terrain map displayed on ND

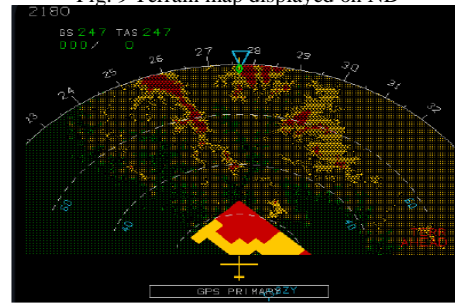


Fig. 10 Scope of warning or caution terrain

In this paper, enhanced ground proximity warning system's functions and workflow are analyzed, and EGPWS simulation and validation system is designed and implemented. According to this scheme, the implementation of this system is realized to verify a good real-time in terrain display and alarm trigger, and the results show system is realized correctly, reasonably and stable.

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