A Complex GPS Safety System for Airplanes

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Abstract. *There are many applications where the exact position and dynamics of different objects are needed in real time. We propose a system that is able to locate simultaneously several “objects” and to present them, in real time, on a map. The system is dedicated mainly to airports for tracking maintenance cars and persons (in this last case the system works as a personal locator device) and to avoid disasters that could happen on the runway. Several results and aspects of the system are investigated and presented.*

1 Introduction

The GPS and the GSM are two of the mature technologies existing on the market, with a large number of commercial applications. The GPS technology is mainly used to obtain the absolute coordinate and position of an “object”. However, in some applications, the GPS technology is applied for obtaining a time stamp and time synchronization of different processes moreover, for triggering different events. In car position, control and navigation systems [1], [2], [3], [4], [5], [6], physics [7], [8], aircrafts [9], railway transportation [5], [10], user position [11], telecommunications [12], geoscience [8], [13], [14], [15], [16], automotive safety systems [17], etc. the GPS technologies are wildly used.

On December 30, 2007, at the International Airport "Henri Coandă", Romania a Boeing 737 plane with 117 passengers and having 200 Km/h hit, during the take-off time, a maintenance car. Fortunately, no one was killed or injured in this incident, but the plane was severely damaged and the car was completed destroyed. Also, in another incident, which happened in 1987, a MD-80 airplane landed in heavy fog at Helsinki Airport and hit a maintenance car on the runway [18]. In both incidents, even if on the airports there were strict procedures regarding the landing and the take-off it seems that these procedures were not enough for avoiding accidents.

At this moment the standard method used to track the objects, vehicles and aircrafts is the surface movement radar in on the large airports. But the surface movement radar has several disadvantages and as it was presented previously it was unable to prevent this types of accidents. Moreover the surface movement radars are very expensive and, because of this, small airports like the one in Thessaloniki, Greece can not afford ground surface radar [20] and use camera systems to prevent different types of accidents. But these methods are prone to error and unusable in bad weather and low visibility conditions. One of the drawback of the surface movement radar is gave by the presence of building and other aircrafts that mask and blind the radar. This problem can be solved easily using a large number, but this number of radar antennas is limited by the health risks and by the electromagnetic radiation interference they produce.

Based on the effect of resulting disturbances of the Earth’s magnetic field due to the quantity of ferromagnetic metal existing in the aircrafts, the researchers and engineers have built a magnetic sensor able to be used in order to avoid runaway crashes [20]. But the big disadvantage of this sensor is given by the cover range – 50 meters. For a big airport like Frankfurt hundreds of these sensors must be placed [20]. But this sensor can be used only in the key point to complete the information offered by the surface movement radar [20].

To avoid the collisions between airplanes and other ground objects we believe that the air control staff must to have and to operate a system that should be able: to locate simultaneously a large number of different types of targets operating on the plane railway and to depict them, in real time, on a map. Such a system will contribute directly to the safety and efficiency of the air traffic services.

This paper presents a complete solution, software and hardware, for the above problem. Also, the obtained results are presented.

The remainder of this paper is organized as follows: Section 2 outlines the system concepts and organization. Section 3 presents the mobile platforms. Section 4 presents the master applications. Section 5 presents the results and finally, section 6 gives the conclusion.

2 The Airplane Safety System, Concepts and Organizations

The proposed system is based on the existence of several mobile locator devices able to acquire continuously the position of an “object” and to send it to the master application. These mobile devices should be placed on all vehicles used in the airports (maintenance cars, tow tractors, etc.).

The master application receives the positions from all mobile locator devices placed on the vehicles and equipments and represents, in real time, these positions on a map. Based on this information, the air control staff obtains a clear image of the positions and dynamics of the vehicles and equipments situated in the airport airside areas (airside areas include all areas accessible to the aircrafts). Having the information provided by the system formed by the mobiles locator platforms and the master application and knowing the airplane position, the planes will receive the take-off or landing clearance only when the procedure will support this decision (no reported vehicles and/or equipments located by the airplane safety system on the plane runway).

3 The Mobile Locator System

The mobile locator system is built having the Freescale MCF5213 processor as the heart of the system. The Freescale MCF5213 is a microcontroller on 32 bits having a Version 2 ColdFire variable-length RISC processor core.

The software, running on the microcontroller acquires continuously the GPS position and sends this information, through a GSM connection, to the master application. The software acquires the position from a RCB-LJ ultra-low power GPS receiver produced by the uBlox company. The GPS receiver is based on the ANTARIS® GPS Engine that was jointly developed by Atmel and uBlox. This core provides: a) excellent navigation performance under dynamic conditions, in areas with limited sky view (like urban and canyons), b) high sensitivity (acquisition -140 dBm, tracking -149 dBm, by using an active antenna) for a weak signal and c) support of DGPS (Differential GPS) and multiple SBAS (Satellite Based Augmentation Systems) systems like WAAS (Wide Area Augmentation System) and EGNOS (European Geostationary Navigation Overlay Services).

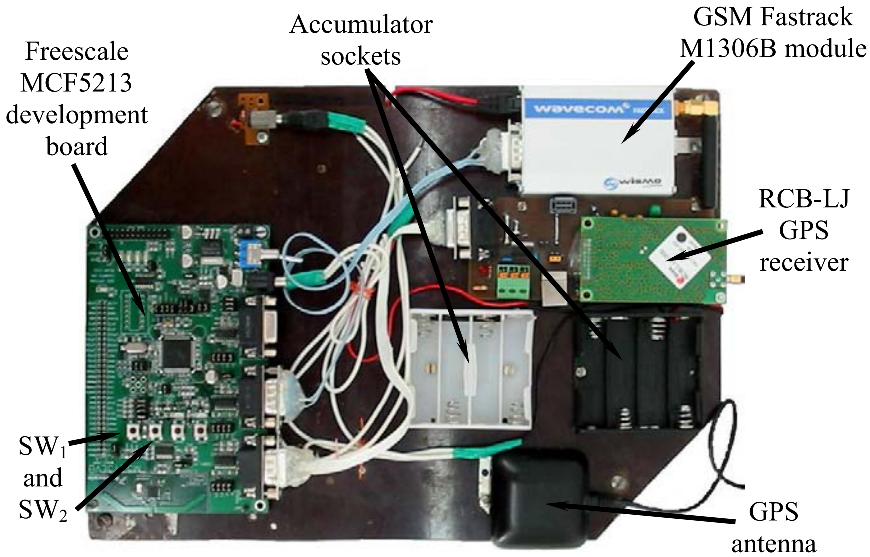

Fig. 1. The mobile locator prototype board.

The position obtained from the GPS systems is sent through the GSM cellular network. The GSM module is a Fastrack M1306B cellular Plug & Play Wireless CPU module with GSM/GPRS connectivity for machine to machine applications.

For determining the accuracy of the acquired position the DOP (Dilution of Precision) parameter was used. The DOP parameter is a unitless value that indicates when the satellite geometry provides the most accurate results. This parameter can be determined for the horizontal position – horizontal dilution of precision (HDOP) – and for the vertical position – vertical dilution of precision (VDOP).

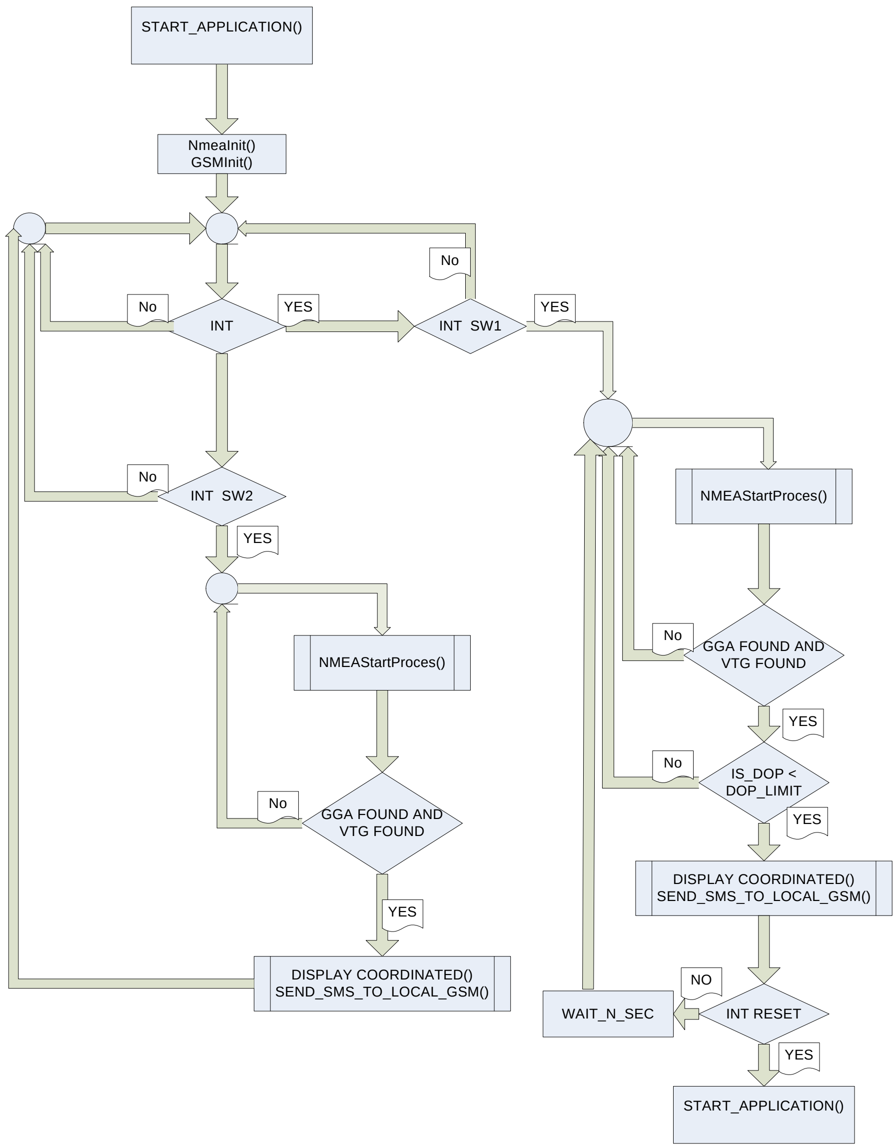

Fig. 2. Software diagram from the mobile locator system.

But, the most commonly used DOP parameter is the position dilution of precision (PDOP). PDOP is a combination of HDOP and VDOP. PDOP parameter is the mathematical representation of the quality of the navigation solution; mainly, this quality is based on the geometry of the satellites on the sky (required to calculate the position) and on the receiver's mask angle of the antenna (the mask angle determines the minimum elevation angle below which the receiver will no longer use a satellite / the satellites in its computations). The number of the visible satellites and their relative positions in the sky mainly control the PDOP; however, the PDOP can be affected (made larger) by signal obstruction due to the terrain, foliage, building, vehicle structure, etc.

A PDOP value of 1 indicates an optimum satellite constellation and the highest quality data. Meanwhile, a PDOP values in excess of 8 are considered poor. For example, a point calculated with a PDOP of 30.0 may be placed by more than 150 m from its true location [19].The mobile locator system has two working modes. The first one, named **tuning mode**, is used in order to set up the confidence threshold level in the master application. Due to the position error generated by: the geometry of the satellites used in position calculation, by the signal path obstruction (by buildings, foliage, covers, snow, etc.), the multi-path effects, the ionospheric and tropospheric effects, etc. around each plane runway a safety zone must be imposed.

If an “object” is placed on the airplane runway or in the safety zone, the airplanes will not receive the take-off or the landing clearance. In this case the risk of an impact is considered high. Mainly, because the position’s error is also determined by the receiver himself – due to the antenna shortcomings (poor gain of the GPS antenna, poor directivity of the GPS antenna, poor matching between antenna and cable impedance, poor noise performance of the receiver's input stage or the antenna amplifier), to the electrical environment (jamming from the external signals, jamming from the signals generated by the receiver itself), to the presence at the GPS module level of different satellite based augmentation systems (WAAS and EGNOS), etc. –, the confidence threshold level is different for different GPS receivers. In the tuning mode the airplane safety system determines the confidence threshold level around the plane runway for a specific PDOP value. In this mode the mobile locator systems send the GPS position for all the PDOP values. Making a statistical analysis and correlating the true position with the determined position the confidence threshold level is determined for the RCB-LJ GPS module presented above.

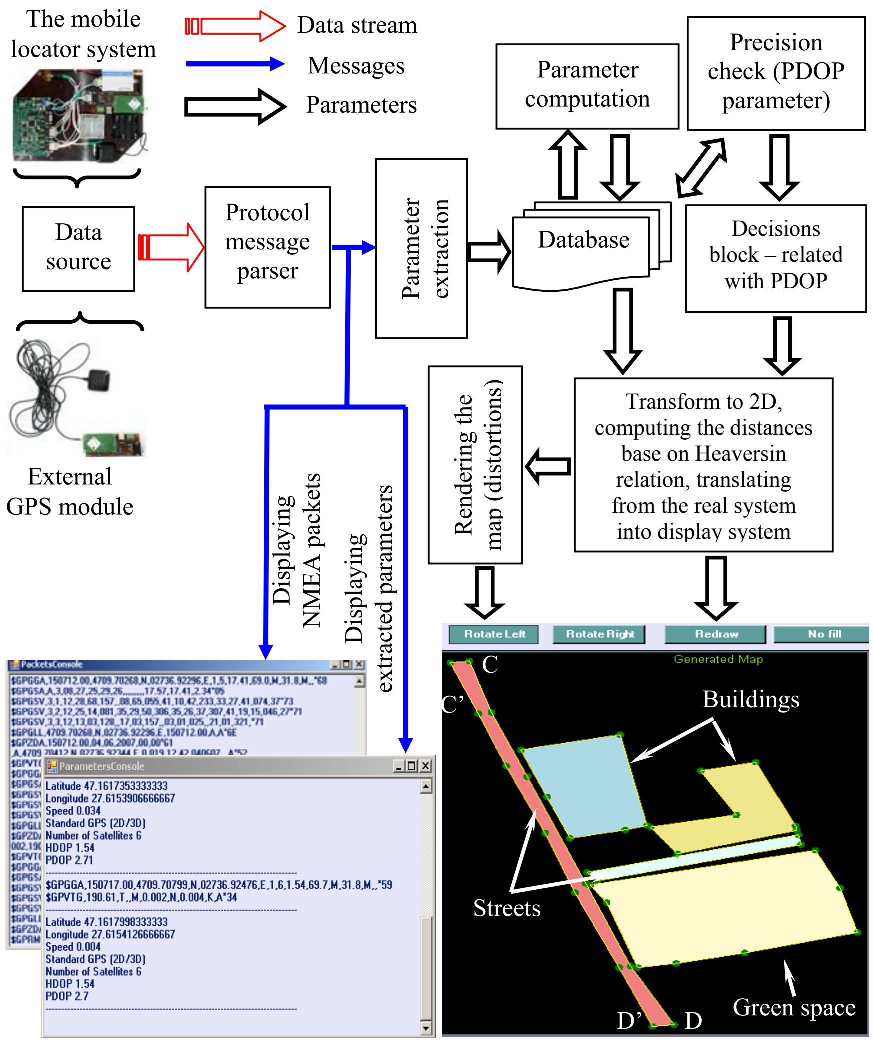

Fig. 3. The data flow for the master application.

The second working mode is used in order to track the mobile locator system's positions. This mode was named **tracking mode**. In this operating mode, from time to time the tracking module sent its coordinate and its unique ID code. The time period between the mobile locator coordinate communications can be set from 10 second up to several thousands of seconds (e.g. 5 minute is a usual time interval that was used in system tests and validation). For maximum accuracy, the GPS receiver is set in Continuous Tracking Mode (CTM). Our GPS module can be interrogated up to 4 times in a second. If the PDOP parameter is smaller, then a predefined threshold determined in the tuning process of the entire system, the position will be sent to the master application; if the PDOP is grater then the same threshold a new set of coordinates position will be acquired. If after several readings from the GPS module the performance reflected through the PDOP parameter does not improve the mobile locator system will send the coordinate together an error message and with the PDOP value. The communication between the GPS module and the microcontroller is a serial one, based on the NMEA 0183 standard protocol. The NMEA (National Marine Electronics Association) protocol is an ASCII based standard data communication protocol used by the GPS receivers.

The working modes are selected based on the state of the two external switches, SW_1 and SW_2, **Figure 1**. The application waits until the GGA message is received from the GPS module. If the PDOP is smaller then a predefined threshold (PDOP parameter is encapsulated in the GSA NMEA message) then, in the next step, the position is extracted and sent through the GSM module to the master application (see **Figure 2**, the software diagram); after this, the cycle presented above is repeated.

4 The Master Application

The master application has two working modes: the map mode and the tracking mode. The data flow for the master application is presented in **Figure 3**. The master application was written in C# (Visual Studio 2005) and the SQL supports the data base.

In the map mode, the master application communicates with the GPS receiver connected to the serial port. In this mode, the system is able to acquire the position of the different points and to store this information; finally, based on these points the map is drawn, see **Figure 3**. The map is sketch in real time (in the same time with the point acquisition).

$$\phi = \arccos\left(\sin\phi_1 \sin\phi_2 + \cos\phi_1 \cos\phi_2 \cos\left(\lambda_1 - \lambda_2\right)\right) \qquad \textbf{(1)}$$

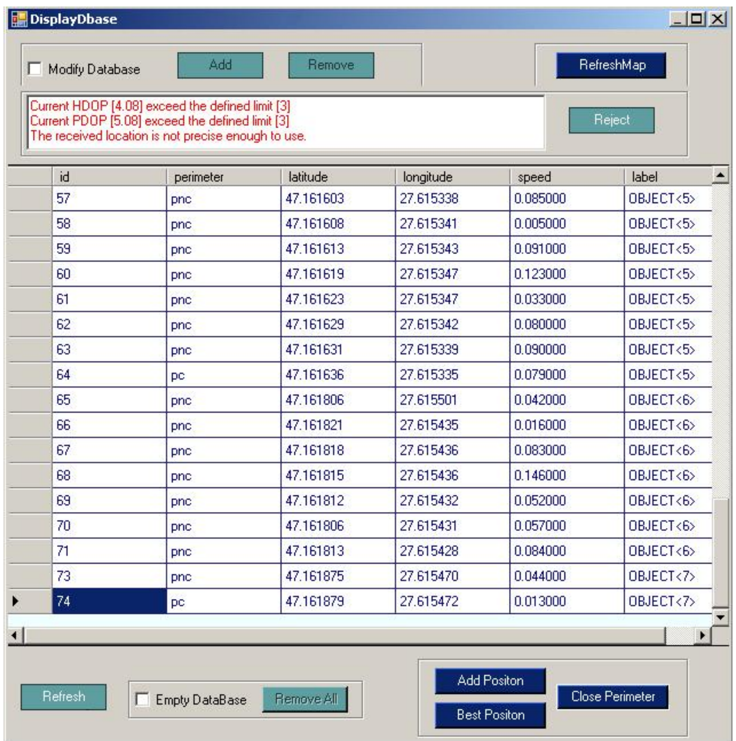

Fig. 4. Data base edit window.

For two points with coordinates $\{\phi_1, \lambda_1\}$ and $\{\phi_2, \lambda_2\}$, (longitude and latitude), the easiest way to determine the angle between the two radius (that have as an end point the center of the earth and the second endpoint one of the two points previously presented) is:

Due to the errors that the relation (1) introduces, mainly the rounding errors, this relation is infrequently used in navigation. The Haversine relation is more accurate and, in consequence, it is used in a larger number of applications:

$$\phi = 2\arcsin\left\{\sqrt{\sin^2\left(\frac{\phi_2 - \phi_1}{2}\right) + \cos\phi_1 \cos\phi_2 \sin^2\left(\frac{\lambda_1 - \lambda_2}{2}\right)}\right\} \qquad \textbf{(2)}$$

Even if the relation (2) is more accurate than the relation (1) for a larger type of distances it also induces some large errors, especially from the points placed on opposite diameters. For these reasons a more complicated relation, (3), is used for the all types of distances:

$$\phi = \arctan\left\{ \frac{\sqrt{[\cos\phi_2 \sin\Delta\lambda]^2 + [\cos\phi_1 \sin\phi_2 - \sin\phi_1 \cos\phi_2 \cos\Delta\lambda]^2}}{\sin\phi_1 \sin\phi_2 + \cos\phi_1 \cos\phi_2 \cos\Delta\lambda} \right\} \qquad \textbf{(3)}$$

The relation (3) is used by the master application to render the map from its acquired points. In the database are stored, for each single point; the point position (longitude and latitude), the object id from each point (it gives the belonging of each point to an object), the point id and the perimeter information (closed or not). The acquisition of the coordinates for each point can be done using a manual method and in an automatic way. In the manual procedure of acquisition, the user of the system acquires a point and according to the PDOP value he saves or rejects the point position. In the automatic coordinate acquisition mode, the system acquires 10 values in 10 seconds and saves the best values, having the smallest PDOP value.

Finally the distance, represented in meters, is obtained as:

$$d = R \cdot ø \qquad \textbf{(4)}$$

In (4) R is Earth radius (approximately 6378 Km) and $ø$ is the value computed with one of the relations (1), (2), or (3).

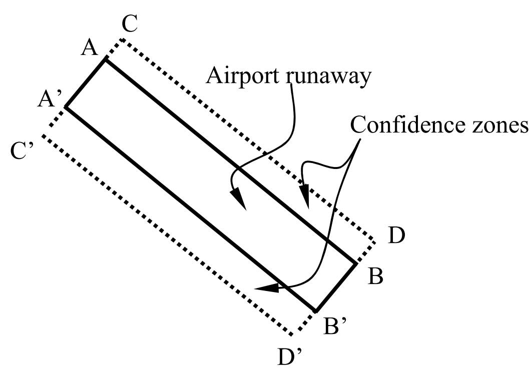

Fig. 5. The plane runaway collision zone: CDD’C’.

In the tracking mode, the master application has connected a GSM module to a serial port. The mobile locator system sends the position of the different objects tagged by them from time to time. This time interval between two consecutive sessions of position determination and position communication can be set in the automatic way from the master applications. In the final stage, the determined position is presented on the map.

Due to the obtained position error from the GPS module, a confidence zone (ACDB and A’B’D’C’) must be placed around the plane runaway (ABB’A’ zone) in order to be sure that no type of collision will take place, see **Figure 5**. The confidence zone was determined using the maximum distance error related to the mean position and is equivalent with the AC distances from **Figure 5**. The mean position was determined using a large series of coordinate positions recorded in conditions as closed as possible to real conditions.

There are now only two difficulties for having a correct representation of the runaway collision zone. First, the runaway is represented through the coordinates (longitude and latitude) and the confidence zones are determined using the estimated distance error of the GPS module. Finally, all information is stored in database in coordinate (longitude and latitude) form.

The second problem is related to the Earth curvature and it must be taken into account in order to obtain an excellent representation. The long range distances (as the distance between two cities like Paris and Moscow) are more difficult to determine exactly from the coordinates (longitude and latitude) than the short ones and, as a result, the computational error is greater than in case of the short distances. From the geographically point of view, long range distances involve following a curved line which is not like the approximately straight line used in a normal case. Practically this problem is solved by breaking the curved line into several straight segments. In our case, all the distances are short (e.g. the airport runaway is around 3.5 Km) and, for these type of distances, the obtained errors are very small and the problem can be translated to be solved in a flat surface.

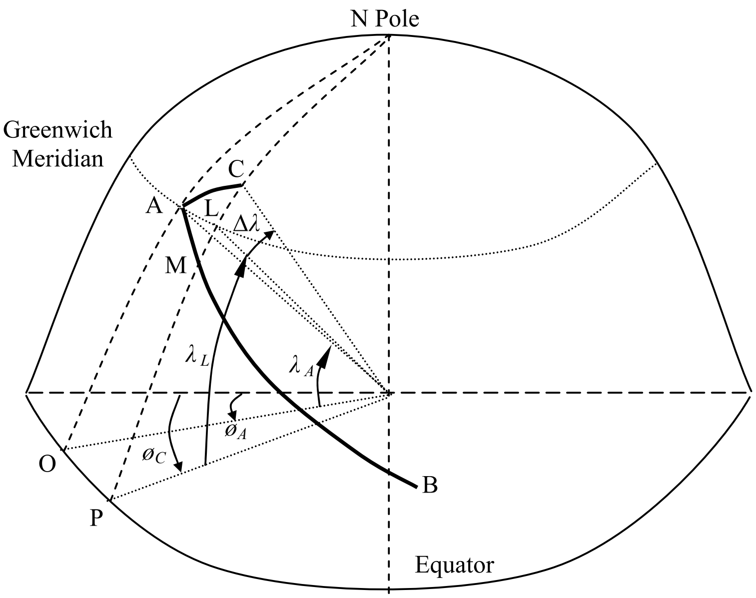

Fig. 6. The real plane runaway edge, AB, and the collision zone determination base on AC.

In order to find out the C point coordinates we must to add $\Delta\lambda$ and $ø_C$ - $ø_A$, see **Figure 6**, to the A point coordinates.

The slope made by the airplane runaway with Equator can be determined based on:

$$\alpha = \operatorname{mod}\left\{ a\tan\left[\frac{\sin(\phi_A - \phi_B)\cdot\cos(\lambda_B)}{\cos(\lambda_A)\cdot\sin(\lambda_B) - \sin(\lambda_A)\cdot\cos(\lambda_B)\cdot\cos(\phi_A - \phi_B)}\right], 2\pi\right\} \tag{5}$$

Knowing α, the CL and AL segments distances can be determined directly based on AC segment distance. Having CL and knowing the Earth radius, Δλ results directly from (4). Using basic geometric relations, $ø_C$ - $ø_A$ is easily determined, **Figure 7**. In similar ways, the other points D, D' and C' are determined.

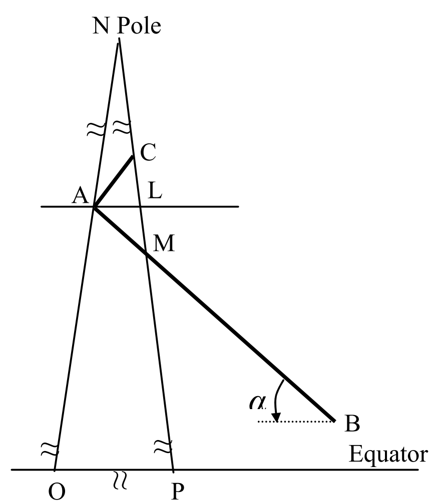

Fig. 7. The geometrical problem for collision zone coordinates determination.

In this implementation of the master application, the vehicles and all the associated other devices and equipments used or associated with these vehicles, tracked by the mobile locator systems, are only placed in real time on the map. In this stage of the system development, there an automatic warning module to notify the human operator when a vehicle is placed on the plane runaway is not implemented.

5 Results

In testing the system, three mobile locator systems were used and one master application. All the mobile locator systems were identical. The master application was installed on a laptop PC. First, the map was generated, see **Figure 3**. The tests were conducted in a perimeter of around 600m x 200m. The tests were done for static and, also, for dynamic mobile locator systems, in conditions as close as possible to the real ones (those on the airports) – we are referring here to the electrical, the environmental and the weather conditions. The airplane safety system showed its ability to track and present the positions for all the mobile locator systems.

Table 1. A statistical analysis of the results obtained for the case when there are no obstacle to obstruct the GPS.

	Coordinate		Distance from the mean position [m]	PDOP
	Latitude [deg]	Longitude [deg]		
Minimum	45.451501	28.043954	0.258944	1.7
Maximum	45.451552	28.044004	3.614854	1.7
Average	45.451523	28.043977	2.229548	1.7
Deviation	0.000020	0.000014	0.988741	0
No. samples	226			

The standard existing software tools were used for determining the confidence threshold level for the master application. First, one of the mobile locator systems was placed on the perimeter, in three different situations. Second, the master application continuously received the position information and saved the results into a data base. All this time the mobile locator system was set to work in tuning mode. Finally, the data were analyzed. The results of the statistical analysis are presented in **Table 1**, **Table 2** and **Table 3**. The data given in **Table 1** and **Table 2** were acquired on very good weather conditions, on a sunny day without clouds, water vapors or smoke. Unlike these, the data presented in **Table 3** were acquired on a raining day. As a conclusion, these last distance errors are affected by the weather conditions and they cover the worst case situation.

The analyzed situations correspond to three different cases. In the first analysis, the GPS receiver was placed in such a position that it had direct line of sight with all the satellites on the sky. For this case, the results are presented in **Table 1**. Even if in other applications this situation is not so frequently encountered, in our case (in the environments of airports airside areas, characterized by large open space) this situation represents the normality. From the **Table 1** we can conclude that a confidence threshold level of 4 m is enough.

Table 2. A statistical analysis of the results obtained for the case when the GPS view to the sky is obstructed by a wall for one side.

	Coordinate		Distance from the mean position [m]	PDOP
	Latitude [deg]	Longitude [deg]		
Minimum	45.451279	28.044010	0.271503	3.5
Maximum	45.451343	28.044157	6.637724	3.9
Average	45.451313	28.044080	3.271895	3.8
Deviation	0.000019	0.000042	2.091876	0.1
No. samples	299			

Table 3. A statistical analysis of the results obtained for the case when the GPS view to the sky is obstructed by two walls (for right and back side).

	Coordinate		Distance from the mean position [m]	PDOP
	Latitude [deg]	Longitude [deg]		
Minimum	**45.450934**	**28.044003**	**0.222265935**	**1.8**
Maximum	**45.451199**	**28.044291**	**17.23316686**	**5.8**
Average	**45.451075**	**28.044135**	**6.008740634**	**4.6**
Deviation	**0.000048**	**0.000070**	**4.65934139**	**1.2**
No. samples	**150**			

The second analysis models the situation when a building obstructs the direct line of the site to the satellites placed in only one direction on the sky. This simple situation models a multi-path environment. In this type of environment not only some satellites are masked but from a part of the satellites the GPS will receive a direct path waves, while, in addition, other radio waves will be reflected by the buildings. For this case, a confidence threshold level of 7 m is more than enough.

When the direct satellites line of sight is blocked for two directions, the error increases and the confidence threshold level must to be set at almost 20 m. This situation is a very infrequent one on the airports but it should be taken into consideration.

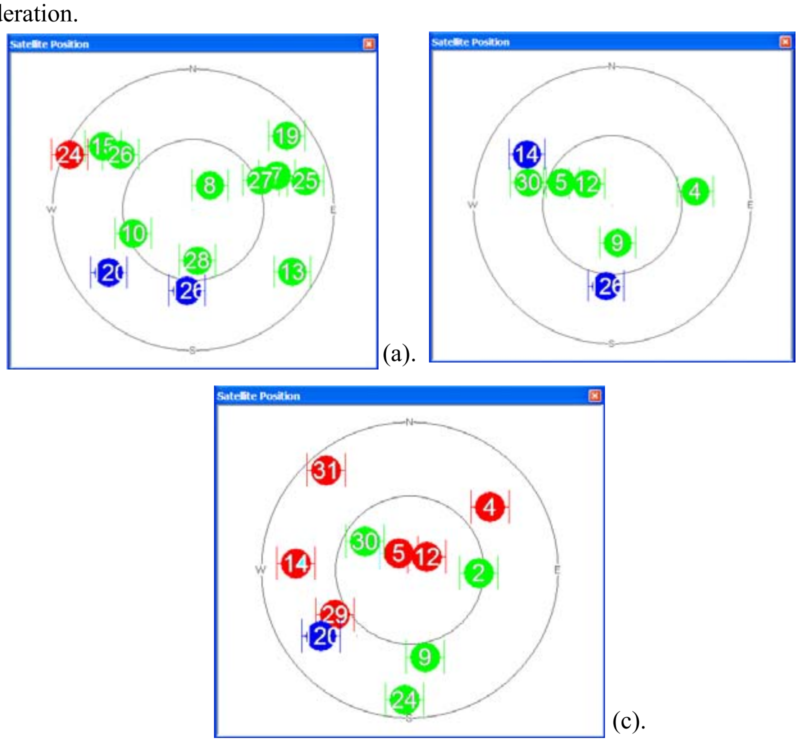

Fig. 8. Some satellites patterns on the sky for: (a). PDOP = 1.7, (b). PDOP = 3.5 and (c). PDOP = 5.3.

In **Figure 8** the PDOP parameters values for different satellites position on the sky are presented (with green - the active satellites, with blue - the satellites with limited connectivity, with red - the satellites with low signal) related with the situation presented in the **Table 1**, **Table 2** and **Table 3**. The examples presented in **Figure 8** were chosen from a variety of PDOP values starting with good PDOP value, 1.7, that generates a good GPS performance and ending with a quite high PDOP value, that generates a degrade of the GPS performance.

6 Conclusions

The paper presents a complete solution for an airplane safety system, able to avoid incidences that could happen during landing or take-off between an airplane and the different types of vehicles used in the airports or all other devices and equipments used or associated with these vehicles.

The main idea of the system is based on the existence of several mobile locator devices able to acquire continuously the position of an “object” and to send it to the master application. The master application receives the positions from all mobile locator devices placed on the vehicles and equipments that could be present on the plane runway and then it represents them, in real time, on a map. Based on this information, the air control staff obtains a clear image of the positions and dynamics of the vehicles and equipments situated in the airport airside areas. As a result of the conducted tests, the airplane safety system proved its ability to track and present, without any problems, the positions for all the mobile locator systems.

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