Evolution from 3D to 4D radar

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Abstract: - The increase in air traffic has the immediate consequence of creating new techniques for air traffic control, as well as new procurement data procedures and data reporting. For these purposes, secondary radars have been developed under the standard ADS-B that should be implemented in coming years on a mandatory basis. In this article, an application of ADS-B radars, capable of introducing the air traffic in real time using a simple form of 4D representation and a free graphical interface. This application, consisting of a network of computers arranged in three layers (Layer of ADS-B Data Acquisition, Business Logic Layer and Presentation Layer), offers numerous advantages to flying clubs, academies of pilots, control towers, air traffic controllers, aircrafts (IN ADS-B), airlines (green trajectories), airport service vehicles, and so on.

Key-Words: - ATM, ADS-B, Virtual Radar, Google Earth, 4D Visualization, GIS.

1 Current Air Traffic Management

The agents involved in the air traffic management system, ATM (Air Traffic Management), are currently conducting a thorough review because of the large increase in the number of flights and the need to improve the conservation of the environment [1], [2] and [3].

An important contribution to air traffic control is improving the location and identification of aircrafts, which are both in flight and on land [4].

At the present, air location is performed personally through the radio or automatically based on radars, among which can be distinguished: PSR (Primary Surveillance Radar) and SSR (Secondary Surveillance Radar).

The main feature of primary surveillance radars is to be able to detect and monitor air traffic in two dimensions. This implies major infrastructure requirements.

On the other hand, the secondary radar SSR is capable of controlling the aircrafts that emits through a transponder. This SSR transponder gives the location in three dimensions, like the GPS [5], as well as the identification and other parameters of the aircraft.

This procedure is required by the ICAO (International Civil Aviation Organization), FAA (Federal Aviation Administration) and Eurocontrol (the European air traffic manager) for future air traffic control of civil aviation. The combination of primary and secondary radars will provide higher security and significant environmental improvements in the flight of aircrafts.

According to a proposal from the FAA [6] the technique of aerial surveillance ADS-B (Automatic Dependent Surveillance-Broadcast) [7] and [8] has been chosen as the surveillance system for the next generation, being mandatory its implantation for the year 2020 inside all aircrafts.

ADS-B systems, as opposed to the current radars, generate position reports more frequently and not lose accuracy with distance.

These reports are broadcast regularly by radio and they can be received both by other aircrafts and by ground control systems. Receivers receive the information emitted by aircrafts, process it and generate a visual representation similar to the primary radar.

Within these reception systems we can find various equipments capable of processing the ADS-B signals provided by aircrafts equipped with it. Two manufacturers of simple ADS-B reception equipments are: Kinetic [9] and AirNav Systems [10].

In general, secondary or virtual radars based on ADS-B have many advantages: lower cost, they can be installed in terrestrial stations (OUT ADS-B) or on the own aircrafts (IN ADS-B), they make a detection in all directions, they allow the identification of the flight, we can know the trajectory, altitude, speed, they have a low consumption, etc.

2 4D radar design

In our research group the proposal was made to combine this type of radar with other existing technologies with the aim of facilitating better viewing of airspace. For that, the receiver SBS-1 Real Time Virtual Radar of Kinetic has been used [9].

The radar has been combined with existing techniques of visualization and representation in 3D and 4D through the 3D mapping system, of public use, and with more development at present: Google Earth [11].

For the visualization in Google Earth of ADS-B data received by radar, an API (Application Programming Interface) has been used. By means of the API, the client application developed in .NET is able to invoke the commands and services provided by Google Earth, in addition to being able to interact with its functions. In this way the setting, visualization and navigation of the user through Google Earth are easier.

This development has also been made with other Geographic Information Systems (GIS) for systems where the security and reliability requirements are important.

The general diagram of the system made can be seen in Figure 1. As we can see is very simple. Aircrafts emit periodically their signal and it is collected by an ADS-B receiver equipped with its corresponding antenna. The signals received by the radar are operated by a computer to allow different visualizations.

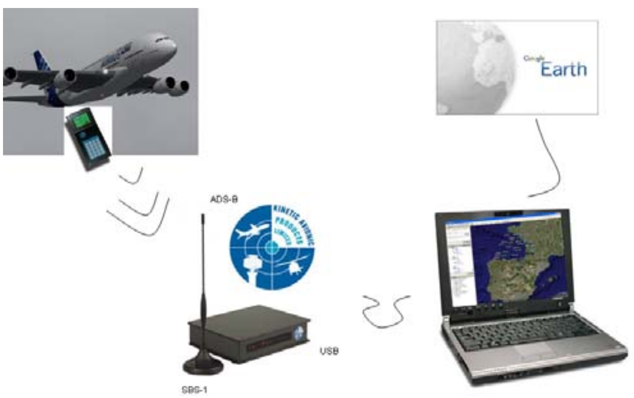

Fig. 1. General diagram

3 Display Modes

Developed system has several ways of presenting data of airspace. Thanks to the client application moving from one to another display mode is relatively easy for the user.

The 3D display modes are: overall panoramic view, view of a certain plane, view from the cockpit, side view of the plane and view from an airport.

Regarding the view of a specific plane, there is a choice between two options: north-oriented aerial view and aerial view oriented according to the aircraft. The only difference between them is the orientation of the camera from Google Earth.

Next each of the displays will be described.

The overall or global panoramic view makes it possible to visualize all aircrafts together with their respective trajectories in a large area, providing various possibilities such as: zooming on a specified area, see characteristics (ADS-B information) of any aircraft that is in flight, rotating camera in tilt (angle between the normal to the ground surface and the camera position in relation to the object that is viewing), in addition to being able to use the controls provided by Google Earth (see Figure 2).

As shown in Figure 2 planes are concentrated in a particular area. That is because they are in the surroundings of the receiving antenna, inside the area of coverage of it, approximately 200 kilometres (120 miles, or 105 nautical miles).

We must remember that only aircraft that transmit information under the ADS-B standard will be displayed, since they are the only detected planes by the virtual radar.

The images or icons for each of the aircraft appear in different colours depending on the inclination that they have regarding the horizontal axis.

So, if the aircraft is descending, it will be represented by a blue icon, whether it is rising in red and on the other hand if the aircraft maintains its altitude without wide variety of inclination it will remain in gray. This is really interesting to get an overall picture of the status of air traffic without having to change multiple times of view or analyse ADS-B data of each aircraft.

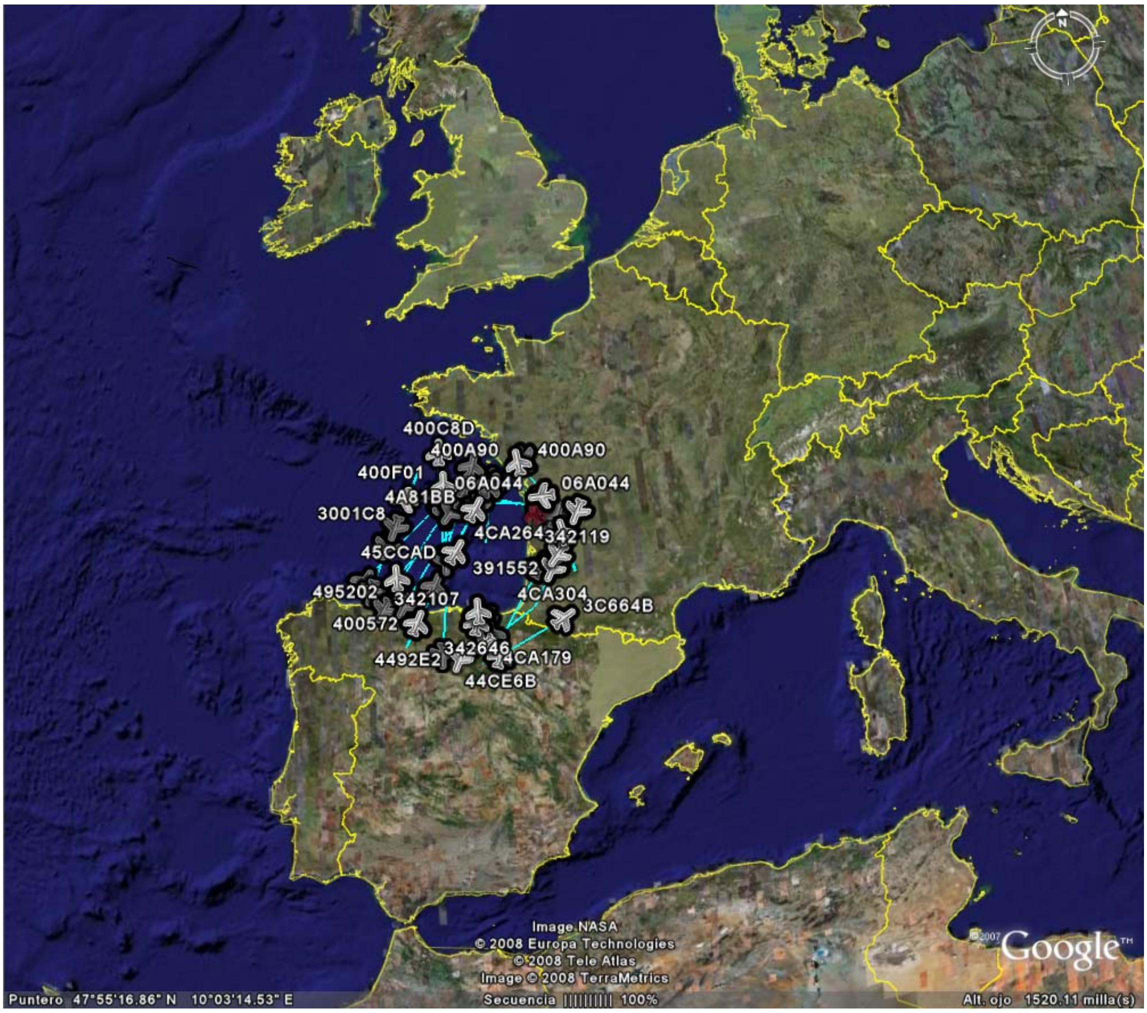

Fig. 2. Overall panoramic view

As it is shown in Figure 2 and 3, per aircraft in flight, in addition to colour depending on its range of tilt, it is presented its corresponding trajectory. This is represented in real time by the client application from the data received by the virtual radar during a certain period of time.

Client application provides at all times an updated list of aircraft that are in flight, and we can access this list whatever the selected display mode. However, only with the selection of the individual view, an aircraft of that list can be selected, including the opportunity to visualize the trajectory of the aircraft and giving the option to the user to inform about the flight characteristics provided by emissions of ADS-B data such as: State, Show Trail, Code, Callsign, Country, Longitude (º), Altitude (ft), Latitude (º), Speed (kts), Track (º), Registration, Vert Rate, etc.

The individual view of an airplane allows a choice between north-oriented aerial view and aerial view oriented according to the direction of the aircraft.

The first one positions the camera of Google Earth to the north and moves depending on the speed of the aircraft and depending on when it reaches new ADS-B information regarding that plane.

On the second view, it is similar to the previous one with the only difference that in this view the camera is oriented in the same direction that the displayed aircraft.

The individual view gives us, with the previous ones, the chance to choose between view from cockpit and side view.

Regarding the first one, view from the cockpit, there is a virtual positioning of the camera of Google Earth in the cockpit of the selected aircraft, with a visualization similar to that which would have the own pilot of the aircraft, but obviously under ideal conditions provided by the maps of Google Earth.

Fig. 3. Zoom of the global panoramic view

As shown in Figure 4, for each aircraft there is a white line perpendicular to the ground. This line represents the projection of the plane on the terrestrial surface, so we can find out their exact location in a graphic way. We can consider this line as the shadow of the aircraft.

Regarding the side view, it represents graphically and virtually the side of the plane from its outside. This is the best perspective to assess in detail the angle of inclination of the aircraft with respect to the horizontal axis, being particularly interesting when aircraft are landing, taking off or even when they make changes in their trajectories.

In Figure 4, we can distinguish that the aircraft has taken off, then it has been changing its trajectory and at the same time has been increasing their flight. Moreover it shows that the icon of the plane is red, this is because the aircraft is still ascending. Once the aircraft reaches the proper altitude and maintains almost constant for the remainder of the flight, the colour of the icon of the plane will return to the reference one.

The latest display mode is the view from an airport. In this case, the client application gives the option of choosing between a set of airports located within the coverage area of the radar.

In Figure 5 airport of Bilbao (Spain) is represented seen from the control tower. It is the closest airport to our radar. It was seen in the image that a plane appears on the right side with the intention of landing. Because of the distance that is, it is more visible the trajectory than the aircraft itself. Obviously this changes once the plane will approach the runway. It should be taken into account that this aircraft, if it had not been for this application, would be virtually hardly noticeable due to limitations of the human eye, incapable of distinguishing an object to so much distance, and due to the environmental conditions of rain, fog, night, and so on.

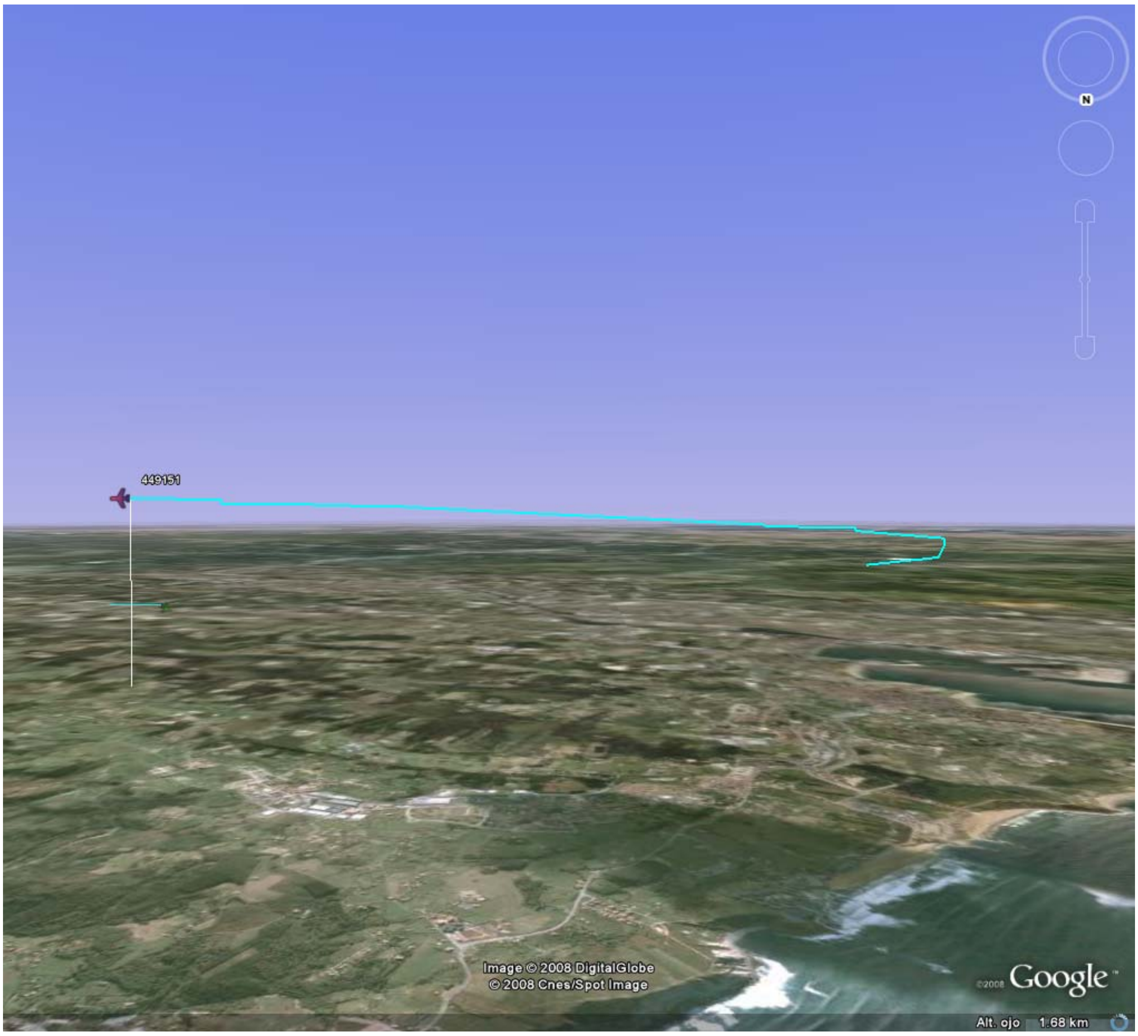

Fig. 4. Lateral view of an airplane taking off

This display mode facilitates greatly the air traffic control, not only at airports but also in their vicinity or areas that are under the coverage area of the virtual radar.

However, graphic display is wider, because thanks to the tools provided by Google Earth, the user may move freely through the screen of Google Earth regardless of the client application that is being implemented, while he is viewing the flights of aircrafts in real time.

The user should always consider the temporal dimension of the application since a representation in 4D is being done. If we see in real time, icons that represent aircrafts identify the current position of the plane, more precisely as a view of a smaller area is selected. The trajectories serve only to know the previous positions and to get an idea of what the predictable trajectory is in the near future.

In the panoramic view of the figure 3 the same situation of Figure 6 was presented as three overlapping trajectories. But notice that when a zoom is made, we can appreciate the separation among the trajectories and that only one of the aircrafts is present at this moment over the area of the selected plane.

Even in the case in which the three aircrafts were on a par, there would be no problem because as it can be appreciate in the image, the separation between trajectories is more than enough to comply the standards of air traffic.

It should be taken into account that we are still at a high altitude in comparison with that of the aircraft, so this separation will increase as the camera comes close to the current position of the plane.

In short, it is necessary to make a proper interpretation of the images considering the accuracy of the display and the time factor.

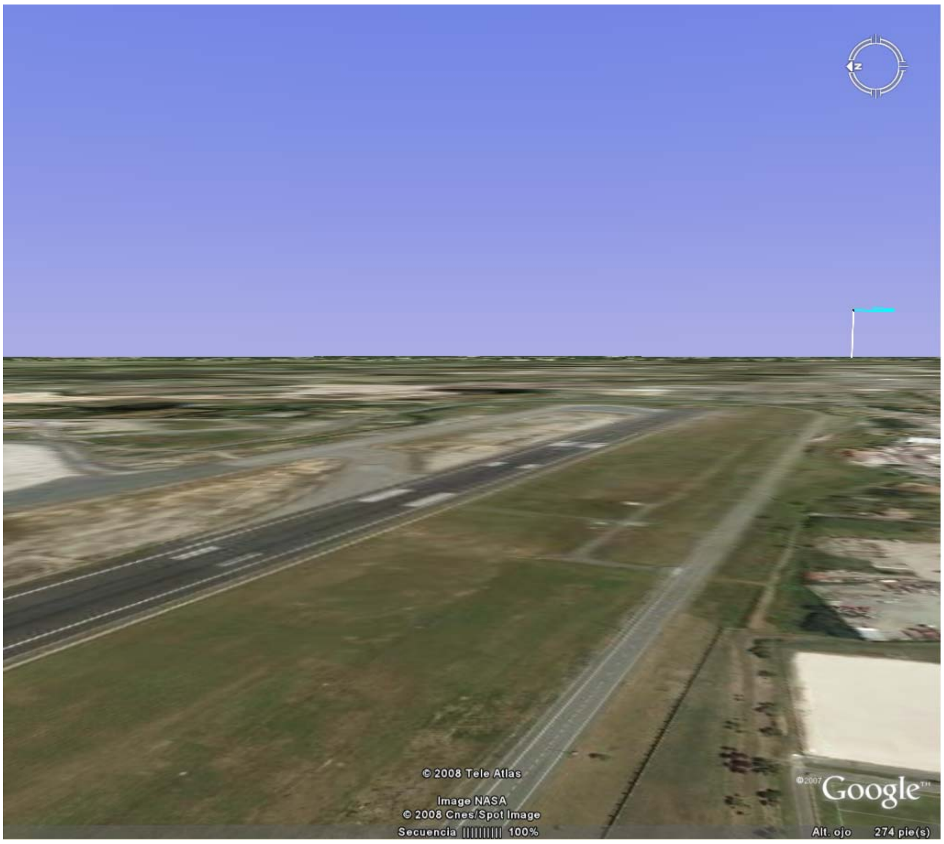

Fig. 5. View from the Bilbao airport in Google

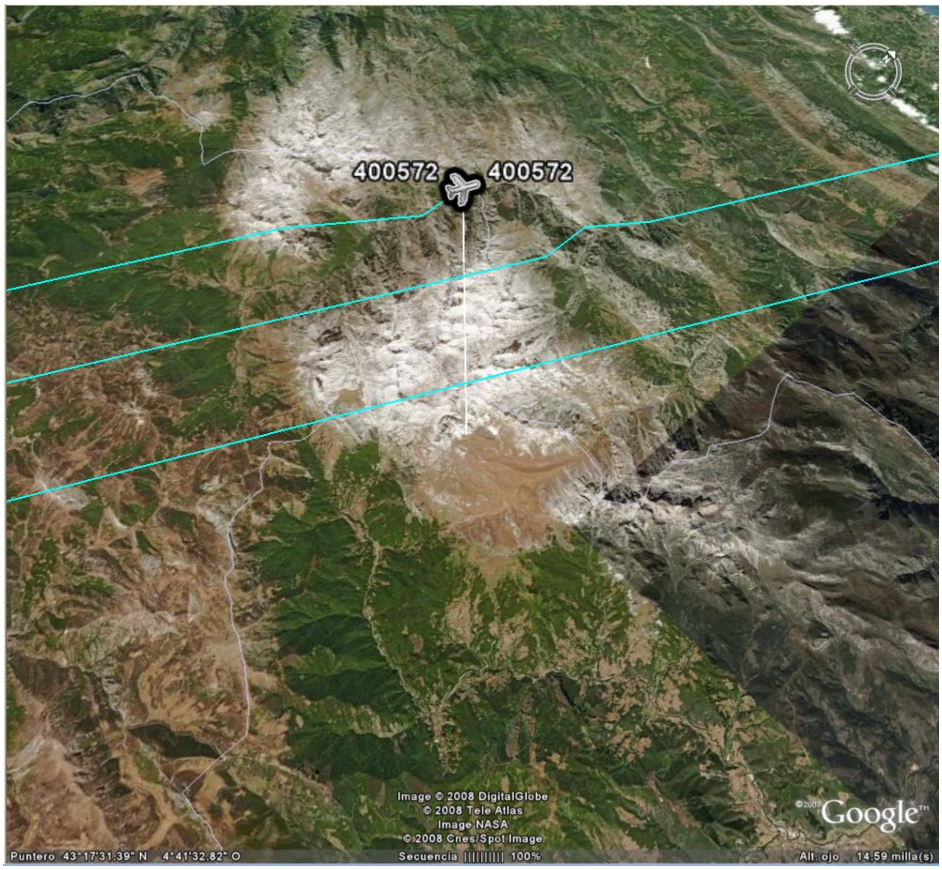

Fig. 6. View of trajectories

4 Application layers

The application designed by our research group at the University of the Basque Country consists of three basic layers, each one with its corresponding .NET application.

We have denominated them as following:

- Acquisition Layer (AL)
- Business Logic Layer (BLL)
- Presentation Layer (PL)

Both Acquisition Layer and Presentation Layer must firstly establish a TCP socket with the server (application Business Logic Layer), in order to be able to transmit, receive, store and interpret the data in format ADS-B.

In Figure 7, the diagram of the three mentioned layers is shown.

5 Acquisition Layer (AL)

In this layer, data with ADS-B format and collected by the virtual radar are managed. The radar sends data collected from various aircrafts to the associate PC via USB.

In each PC the application Base-Station of Kinetic is running. This application is responsible for representing data in table form. In addition, in each PC is running a .NET application whose functions are:

- Get ADS-B data from the Base-Station in real time.
- Managing a TCP communications port for data transmission. With this aim, we will use open sockets on demand of the central server.

6 Business Logic Layer (BLL)

In this layer, a server is responsible for centralizing and managing the data from each virtual radar. The missions of this central server are:

- To collect data from all PCs associated with each virtual radar.
- Storing this information in a database located on the same server.
- To provide communications interface so that customers can access to data, transmitted in real time, of the radars for those who are authorized.
- To offer customers the option of being able to access the information from the database provided they are authenticated.

7 Presentation Layer (PL)

In this layer, an application created on the client equipment gets the data in real time from the central server through the above mentioned TCP socket. The client can also access to the database of the server if it has permissions.

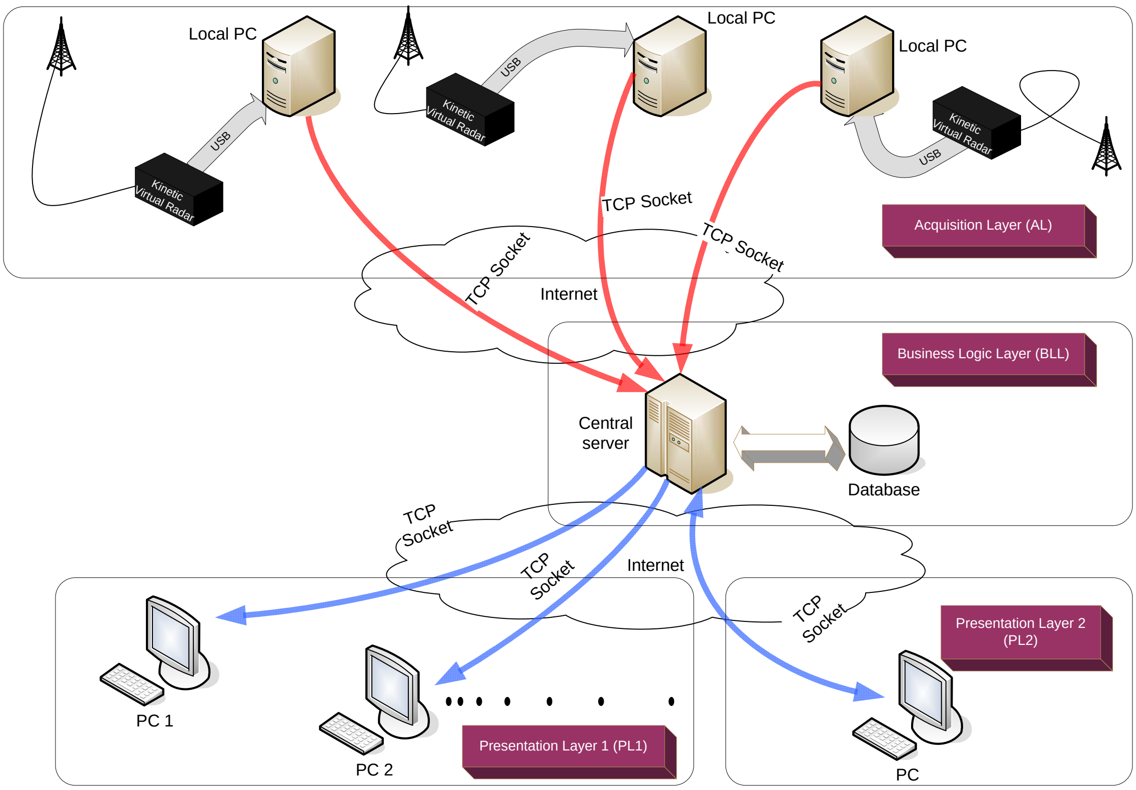

Fig. 7. View of Layers

With these obtained data the client application (PL) makes the corresponding representation in Google Earth, providing at any time an updated list of aircrafts that are in flight, as well as access to full information on each aircraft (information provided by the virtual radar). It also provides to the user the ability to choose among the different views and options that we have been previously mentioned:

- Overall Panoramic View.
- View of a certain airplane.
- View from the cockpit.
- Side View of the plane.
- View from Airports.

8 Images Temporary

In the figures 8 to 11, four time instants taken from the ADS-B information received by the client application from the presentation layer are represented. Just start to run the application view from cockpit of the aircraft is selected, aircraft with CODE “400C4B”.

In Figure 8 the beginning of data capture is presented. In this case, the plane 400C4B was already in flight. In this image part of the coastline as well as two aircraft over the sea can be seen.

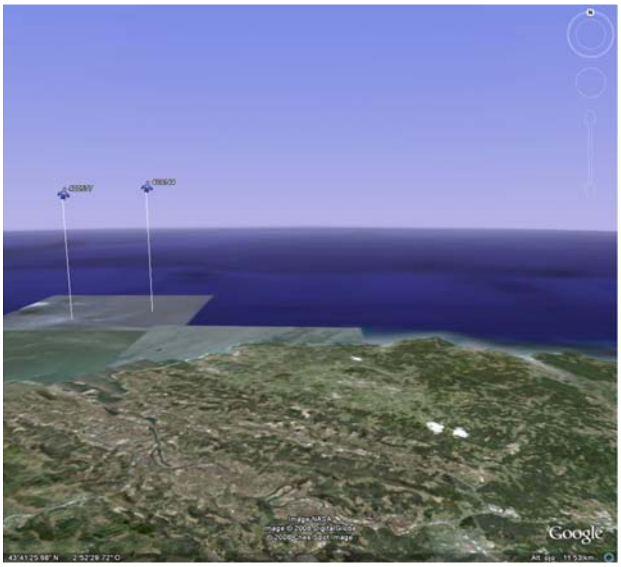

Fig. 8. Sequence 1

Fig. 9. Sequence 2

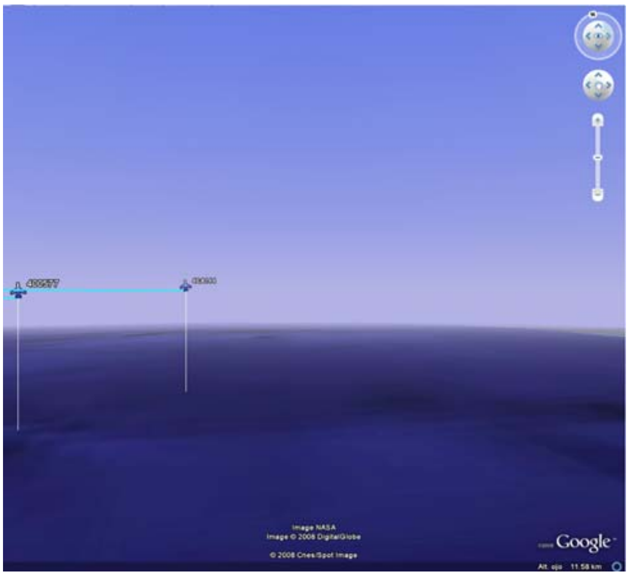

Fig. 10. Sequence 3

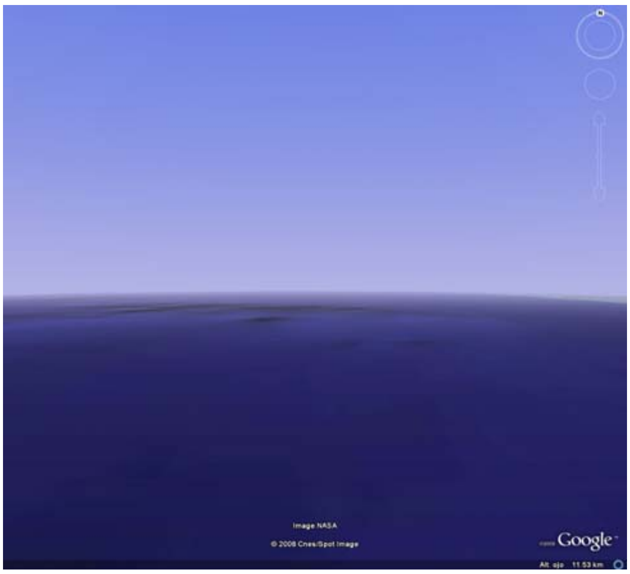

Fig. 11. Sequence 4

Figure 9 shows the previous image but once few minutes passed. In this case, the portion of the coastline that can be seen is minimal.

Turning to the next image, figure 10, the plane is completely over the sea and aircrafts that can be seen in front will slowly disappear because their route is different. Hence in the next image, figure 11, we can not see other planes from the aircraft cockpit, as these are enough to the left with respect to the trajectory of the plane and, therefore, they are outside the range of vision.

9 Applications

The applications of virtual radars and their representation in 4D vary widely depending on location, needs, topology, etc.

We can clearly distinguish two types of systems: one basic that is shown in Figure 1, which consists solely of one radar, and other one more complex consisting of several virtual radars connected via a computer network in order to expand the coverage area, project that has also developed by means of a more professional GIS.

The basic system is mainly directed towards pilot courses and flying clubs, whose main interest in both cases is represented in a graphical way the trajectories followed by each of the aircrafts for further analysis, always reduced to the closer surroundings. This representation of trajectories has the advantage that can be done in real time, as we has been presented, or it also offers the possibility of being able to visualize prerecord any trajectory previously done and that we have previously had to store in the corresponding database. This will facilitate the learning of future pilots since they may see their own trajectories and analyze the manoeuvres.

Regarding the complex system, it is designed to obtain an optimum air traffic management by air traffic controllers at airports, aircraft operators, civil protection or by other agencies.

In addition, in this case, the ability to predict possible violations of separation between aircrafts both in the air and on runways is added. From the trajectory defined by the ADS-B data received by the receiver, through an extrapolation of the previously followed trajectory, using the tools of the application and with the GIS, we can predict whether these trajectories are going to get to interfere at the same point and at the same instant of time (4D).

It is also interesting for air companies and for the own aircrafts. In recent years, it is considering deregulating the navigation system and not require the use of aerial highways, in order to optimize routes and reduce fuel consumption and emissions of polluting gases. This would occur as consequence of that aircrafts would follow an alternative route, much more direct between origin and destination. These kinds of routes that favour the reduction of fuel used are known as green trajectories. In order to follow these green trajectories, aircrafts should have incorporated the enough technology to visualize the new trajectory and keep to it detecting (IN ADS-B) and avoiding other aircrafts or obstacles (sense and avoid).

Another important potential application that is being considered is to provide service vehicles at airports with ADS-B transponder (employment on land). Thus, vehicles may represent graphically each of the movements that taxi-aircrafts will do or those who are doing manoeuvres (landing or takeoff) in the runway to avoid possible collisions or accidents.

10 Conclusions

The future needs of aviation and improving of the information and communication technologies will change the landscape of current air traffic control.

Those changes will be linked to the introduction of a system for disseminating the identification and the position of aircrafts currently included in the ADS-B technology.

In this paper we present an application to improve the use of data from a radar through their graphical representation in three dimensions, and the consideration of the temporal dimension: 4D.

The representation in 4D allows us to visualize the location of aircrafts in a more intuitive and closer form to reality, providing this way the air traffic control, navigation of aircrafts, learning from the pilots, and so on.

11 Acknowledgments

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