Coordinated Positioning System Based on GPS for Assistance of Civil Protection Operations

Tiago Barroso, José Sanguino, António Rodrigues
Instituto de Telecomunicações / Instituto Superior Técnico, Technical University of Lisbon, Portugal
Email: tvbarroso@gmail.com; sanguino@lx.it.pt; antonio.rodrigues@lx.it.pt

Abstract–The purpose of this project is the development of a coordination positioning framework with the purpose of aiding civil protection operations. For this, the developed system makes use of the Global Positioning System (GPS) to gather positioning information about the users and the existing mobile communications systems of the second and third generations, in order to transmit the gathered information and other data between the users. The applications developed let any kind of image be used as a map, from digitalized cartography to aerial photographs, as long as it is associated with its geographical coordinates. Other than transmitting positioning information, the applications also let users share sketches that are made on the maps and can contain information like waypoints or points of interest, and extra geographical information, gathered from the GPS receiver or introduced manually, for any map in use. All the information and data is transmitted over the network through a system of permissions and authorizations in the form of a database. Also, if necessary, new maps can be introduced in the network without having to bring the system offline. The applications developed were tested in order to assess their capabilities and viability as a commercial product.

Keywords: GPS; coordinated positioning.

I. Introduction

In situations like firefighting, search and rescue, evacuations and similar, the forces involved need to be highly coordinated. To achieve this, a precise knowledge of the terrain and the position of every element, either human or mechanical, is needed. The information about the terrain can be obtained using maps and the best way to obtain positioning information is through the use of the Global Positioning System (GPS). GPS provides its users with many kinds of positioning information like geographical coordinates, direction and speed. Some systems were developed that merge these two kinds of information (terrain and positioning) allowing users to be connected to a network and exchange not only positioning information but also other kinds of information like text and sketches that can be drawn over the maps. The cartography used may be any kind of image, from a digitalized map to an aerial photograph as long as the application has access to the geographical information of the image. The association of an image with its geographical information is called georeferencing. This process allows not only the users' positions to be shown on the chosen cartography, but also their orientation, if they are connected to two GPS receivers. To control the flow of information in the network, a system of permissions was created, in the form of a user database. The system developed was tested to assess its capabilities, performance and viability as a commercial product.

II. Relevant Technologies

This project makes use of a variety of technologies that were integrated to achieve the end result. The users connect to GPS receivers using Bluetooth, and make use of the available mobile communication systems to connect to the network. The system developed also needed to be able to communicate with the user database to check for permissions and makes use of Earth browser Google Earth to show certain elements of the network.

A. Global Positioning System (GPS)

The GPS system is an electronic information system that provides its users with positioning, velocity and time (PVT) information. It was created by the USA's Department of Defense with two levels of use: a civilian use, with certain limitations and a military use, much more precise than the civilian, [1]. The system is divided into three segments, which can be seen in Fig. 1:

- A space segment comprised of over 30 satellites, [2], in an orbit with an average altitude of 20.200 Km above the Earth surface, arranged in six planes, each with an uneven number of satellites, which transmit various kinds of data like satellite time, position of the satellite in space (ephemeris), approximate position of all the satellites (constellation almanac), satellite's condition, difference between the satellite time and GPS time and signal delays estimate. This information is transmitted in two frequencies: Link 1 (L1), with a central frequency of 1574.45 MHz and Link 2 (L2), with a central frequency of 1227.6 MHz, [3];
- A control segment, which can be divided in three parts: one main control station, responsible for monitoring and managing the satellite constellation, various monitoring stations, which track all satellites in line of sight in order to obtain distance data used for ephemeris and satellite time calculations and several fixed antennas, used to transmit this information periodically to the satellites, [1,4].
- A user segment, which encompasses all devices capable of receiving the messages transmitted by the satellites. This devices need to receive, decode and process the data received, in order to create PVT information. This process is explained in greater detail in [1].

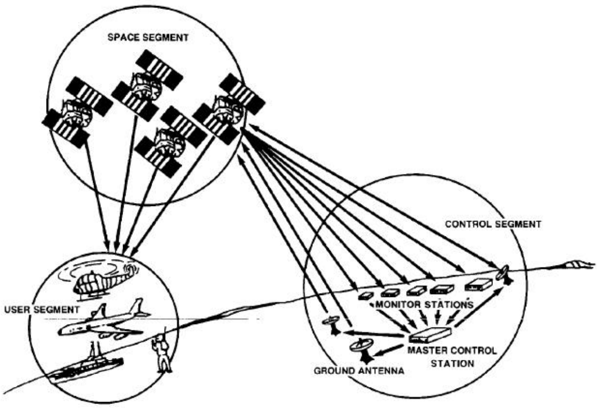


Figure 1. Segments of the GPS system, [1].

B. *Bluetooth*

Bluetooth technology is a wireless communication system created with the aim of replacing connection cables between electronic devices. The system consists of a radio-frequency (RF) transceiver and a set of protocols which enable various types of data to be traded between different devices. This technology operates in the 2.4 GHz band. The low cost and low consumption allows it to be used on all kinds of devices with a wide range of applications. A detailed explanation of this technology can be seen in [5].

C. *Mobile Communication Systems*

At the moment, there are several technologies that allow users' devices to connect to the Internet. These can be from the 2nd or 3rd generations of mobile communication systems. The technologies commonly used that allow for data packets transfer are:

- General Packet Radio Service (GPRS) is a data bearer service based on packet switching that is delivered as a network overlay for Global System for Mobile Communications (GSM) networks. More information can be seen in [6] and [7].

- Enhanced Data rates for GSM Evolution (EDGE) is an improvement over GPRS increasing data rates by up to three fold. EDGE new features and capabilities are shown in [7], [8] and [9].

- High Speed Packet Access (HSPA) is an improvement over the 3G mobile telecommunication base data transmission technology, Wideband Code Division Multiple Access (WCDMA), increasing its data rates by over three times. HSPA is a combination of two technologies: High Speed Downlink Packet Access (HSDPA) and High Speed Uplink Packet Access (HSUPA). HSDPA is shown in detail in [9] and HSUPA information can be seen in [10].

- HSPA+ is the evolution of HSPA, bringing this technology a step closer to the 4th generation of mobile telecommunications in terms of data rates and features. More on this technology is shown in [10].

D. *Structured Query Language (SQL)*

The paper [11], written by E.F. Codd, became the base of today's relational database model. In 1979 the first relational database was created along with a language called Structured English Query Language (SEQUEL), [12], which would later be renamed SQL, as seen in [13]. It was published as a standard by the American National Standards Institute (ANSI) in 1986 and has suffered several revisions over the years. All its history can be seen in [14] and the latest standard in [15]. Most of the actions performed on a database are done with SQL statements. An extensive SQL tutorial is shown in [16].

E. *Keyhole Markup Language (KML)*

The application Google Earth is an Earth browser where points, paths and other kinds of data can be marked on maps based on their geographical information. This information can be extracted to files in the form of KML or KMZ files. KML is the language used by Google Earth and also Google Maps. KMZ is a compresses form of a KML file. These files can also be used to add all kinds of information to the browser, enabling it to show users and sketches of the network created for this project. Everything about this language is available at [17].

III. System Description

A. *State of the Art*

This project has taken into account recent and past projects in the field of GPS based coordination systems. One such system is being developed by a consortium composed of Instituto de Telecomunicações (IT), Y-Dreams, Miguel Rios Designer, and is called I-Garment. It consists of a network of users, with the majority being users on foot but also vehicles and some stationary like management centers. They share information through the use of several sensors, some of them located in the clothes of the users. This project was thought as a means of helping firefighters and civil protection operatives. All the information about the development of this project can be seen in [18]. In Fig. 2 the architecture of this system is shown.

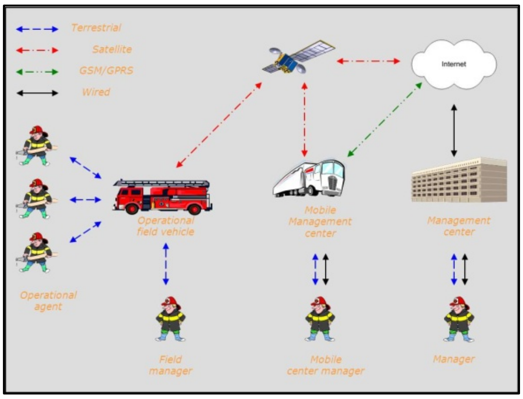
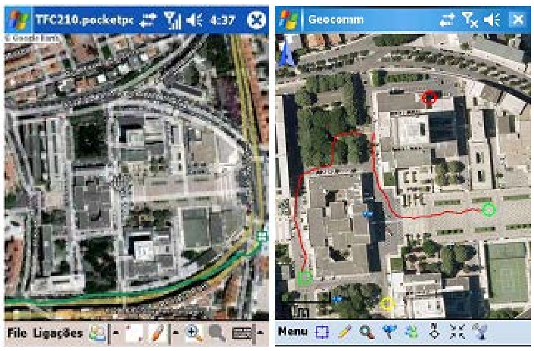


Figure 2. I-Garment System, [18].

Also from IT but from the Lisbon pole in Instituto Superior Técnico, there are two master theses worth mentioning due to the similarities between them and this project. One is TFC 210, developed by Daniel Santos and Ricardo Matos, [19], and the other is "*Geocommunicator:*

Sistema de posicionamento coordenado baseado em GPS”, developed by Filipe Tocha, [20]. Both use Personal Digital Assistants (PDA) as users of their respective networks and allow geographical information to be shared. They also allow users to draw and transmit sketches drawn on the cartography used. TFC 210 makes use of a map distribution system to keep the cartography stored on the PDA to a minimum, as seen in [21]. Geocommunicator was developed after TFC 210 so it improves on some aspects like power management, energy consumption and data transmission and introduces new ones like user authentication. Fig. 3 shows the interface windows of these applications.



a) **b)**

Figure 3. TFC 210 (a) and Geocomunicator (b) windows.

B. *System Architecture*

One of the main aspects and earliest choices needed to be made for this project was the architecture of the system that was going to be developed. An early attempt at Peer-to-Peer architecture was made but the need of a central hub and a permission system changed that to Client-Server architecture. The final architecture used on the system, with GPS and Internet connections, can be seen in Fig. 2.

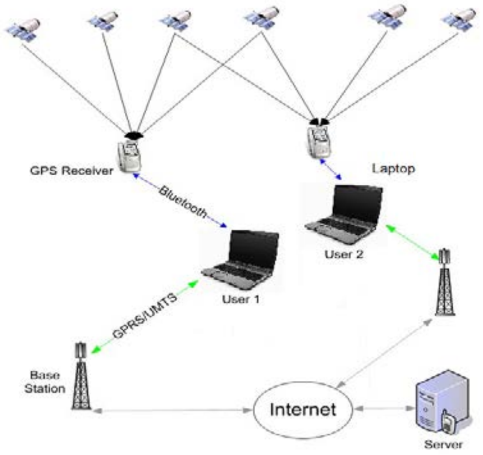


Figure 4. System architecture.

When comparing with Peer-to-Peer (P2P) networks, the transmission of large blocks of information, like maps, is harder in pure Client-Server architectures, as only the server is in charge of it but it was the logical choice because of the permissions system that was implemented and to keep the data centralized and secured. Also, with the use of a server, many kinds of clients may be developed, because as long as the same communications protocols are used, they are able to connect to the network, [22]. To achieve the desired architecture, two applications were developed: one, the Client, is meant as a mobile terminal, and is to be used on the vehicles used in civil protection operations. The other application, the Server, is meant as a fixed station, to be installed on the central of operations, and with access to the permissions database.

This project was conceived to be used with computers equipped with touch screens, like the ones available from Sunit: In-Vehicle Computers and shown in Fig. 5. One of these units was provided to the project by Datelka.

Figure 5. Vehicle computer, from Sunit: In-Vehicle Computers, class d.

The connection to the GPS system is achieved through receivers connected using Bluetooth or integrated in the computer used. Any kind of GPS receiver can be used, as most deliver their information according to the National Marine Electronics Association (NMEA) standards, which can be seen in [23]. Fig. 6 shows the receivers used during the development of this project and in Table I their specifications can be seen.

(a) BT-1300 **(b)** GP-600 **(c)** BT-338

Figure 6. GPS receivers used in this project.

TABLE I. GPS receivers’ specifications.

Model	**Transfer Rate (bps)**	**Channels**	**Acquisition time (Hot/Warm/Cold)**
BT-1300 (QStarz)	115200	66	1/33/35 (sec)
GP-600 (ANYCOM)	38400	15	8/38/45 (sec)
BT-338 (GlobalSat)	38400	20	1/38/42 (sec)

To connect to the network, any kind of wireless Internet modem used by any of the Internet Service Providers (ISP) available may be used. Some vehicle computers even have integrated modems.

C. *Application for Mobile Devices*

This application was designed to be used on computers installed on vehicles that are used on civil protection operations. This type of computers usually has touch screens, meaning it can be used without resorting to a mouse. The interface of the application was created taking this into account, so all the buttons are big, so they can be easily selected, even in the middle of an operation. The standard window of the application can be seen in Fig. 8.

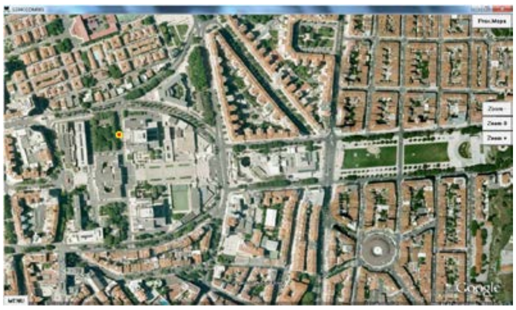


Figure 7. Main window of the Client application.

This window shows the user's position, if he is present in the area covered by the map, and, if the user is connected to the Server, the positions of every other user online.

The process of calculating the representation of a user on the cartography being used has two steps: first the conversion of the geographic coordinates into map coordinates and second, from map coordinates into screen coordinates. Fig. 9 shows the calculations involved in the first step.

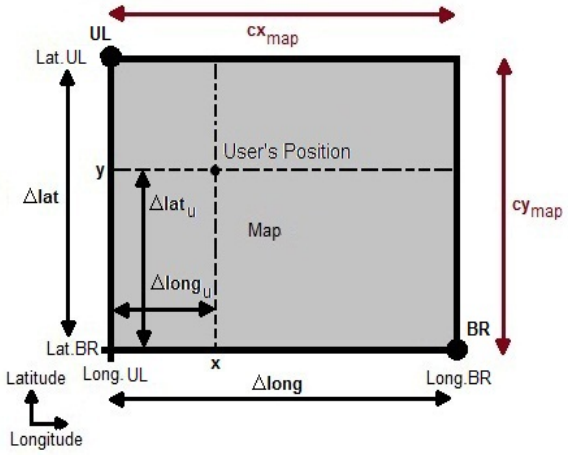


Figure 8. Converting geographical coordinates into image coordinates.

After knowing the user's position in the form of geographical coordinates, we calculate the variation, in degrees, of the corner with the lesser latitude and the user's latitude to obtain Δlat_u and the variation, also in degrees, of the corner of lesser longitude and the user's longitude, obtaining $\Delta long_u$. Δlat that stands for the variation of latitude between the two corners of georeferencing, corresponds to the height of the map, cy_{mapa}, and $\Delta long$, that stands for the variation of longitude between the two corners of georeferencing, corresponds to the width of the map, cx_{mapa}. With these associations, the horizontal coordinate, x, can be calculated through (1) and the vertical coordinate, y, using (2). The origin of the image is its lower left corner.

$$x = cx_{mapa} \,.\, \Delta long_u \,/\, \Delta long \tag{1}$$

$$y = cy_{mapa} \,.\, \Delta lat_u \,/\, \Delta lat \tag{2}$$

In the second step, the conversion of image coordinates into screen coordinates, the level of zoom used needs to be taken into account. Fig. 10 illustrates this step of the calculations.

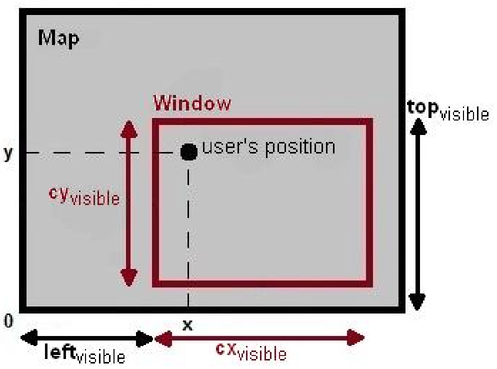


Figure 9. Converting image coordinates into screen coordinates

By knowing the width, $cx_{visible,}$ and height, $cy_{visible}$, of the image visible on the screen, the coordinates of the image corresponding to the left and upper borders of the window, $left_{visible}$ and $top_{visible}$, respectively, the image coordinates of the user, x and y, and the width, cx_{window}, and height, cy_{window}, of the window, we can calculate the screen representation of the user's position in screen coordinates. Unlike the image, the point of origin of the screen coordinates is the upper left corner. The horizontal coordinate, x_u, of the user is given by (3) and the vertical coordinate, y_u, is given by (4).

$$x_u = (x - left_{visible}) \,.\, cx_{window} \,/\, cx_{visible} \tag{3}$$

$$y_u = (top_{window} - y) \,.\, cy_{window} \,/\, cy_{visible} \tag{4}$$

Once the screen coordinates are obtained, the representation of the user's position can be shown onscreen, through the use of the markers shown in Fig. 10.

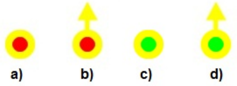


Figure 10. Markers for the user's position onscreen.

Marker a) from Fig. 11 is used when the user is not connected to the Server and, in contrast, marker c) is used when he is connected. Both markers only show the position of the user on the map. When the user has at his disposal two GPS receivers, he can also show his orientation on the map and markers b) and d) are used when offline or when connected to the Server, respectively.

The orientation of a user is calculated by converting the geographical coordinates, also called, LLA (Latitude, Longitude and Altitude), into ECEF (Earth-Centered, Earth-Fixed) coordinates, also called XYZ. After that the azimuth is calculated. This whole process is explained in [24]. The markers for the users' positions received from the server can be of two kinds, class 1 and class 2. The only difference between main user's markers and the two classes of received users is the color. The two classes can be used to distinguish different types of users like operatives on foot and vehicles or two kinds of vehicles (direct and support roles). While the application user's markers are yellow, class 1 users' markers are orange like shown in Fig. 11 a) and class 2 users' markers are blue, as illustrated in Fig. 11 b).

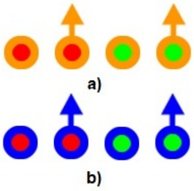


Figure 11. Markers for user's coordinates received from the Server.

Fig. 12 shows a zoomed image used by the application as a map, with the orientation of the user marked on it.

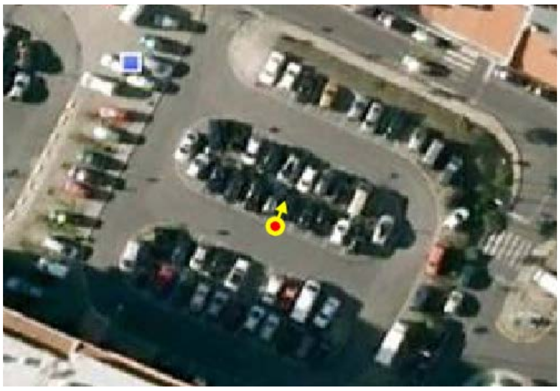


Figure 12. Orientation of a user marked on the application.

As shown back in Fig. 7, the main window of the application presents the user with five possible commands: "Prox. Mapa", "Zoom +", "Zoom 0", "Zoom –" and "Menu".

"Prox. Mapa", the first command available to the user, allows the application to cycle through a list of stored maps. The system uses a configuration file, "InfoMapas.txt", to store the georeferencing information of all the images in use. With the file, the application can switch maps and continue to show all the users' positions and sketches.

The command "Zoom +" can be accessed by the corresponding button or by double-clicking any part of the map. If the button is pressed, the center of the zoomed image is the same as the one shown in the window at that moment. However, if the image is double-clicked, the point clicked becomes the new center of the window. The amount of image on the window is reduced by half each time the zoom level is increased, which means that the number of screen pixels associated with each image pixel doubles. The application corrects the center of the image when the center chosen by the user would make the screen show the background of the window. After using the command "Zoom +" the user can pan the image to scroll the map. Pan is done when clicking and dragging the image. The application saves the position clicked and after a very short timer, records a new position. By subtracting both the initial and final positions, the application knows where to move the center of the image and then repaints the window with the new center. If the user drags the image in a manner that would show the background of the window, the application doesn't let him drag it any further.

The command "Zoom 0", when pressed, resets the image to its starting zoom level. This is the level where the whole image is shown on the window and covers it entirely. Every time the image shown is cycled through the "Prox. Mapa" command, this is the level of zoom of the new image painted on the window.

The command "Zoom –" decreases the level of zoom of the image shown on the window, showing twice the amount of image than before it's applied. This never goes beyond the level of the command "Zoom 0", otherwise, the background of the window would be shown and always keeps the center of the image.

The command "Menu" shows the bottom bar menu which has the following options: "Receptor GPS", "Rede", "Esquemas" and "Pontos Georreferenc".

- Pressing the "Recetor GPS" button opens the following sub-menu, shown in Fig. 13.

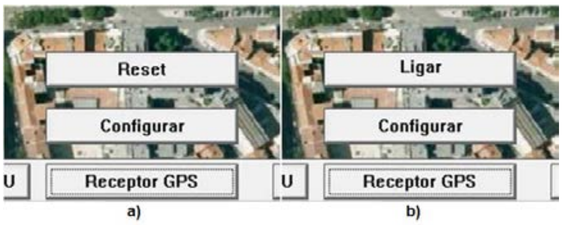


Figure 13. "Receptor GPS" sub-menu.

The menu has two sets of options: the first, shown in Fig. 13 a), appears when the application is connected to a GPS receiver and the second, shown in Fig. 13 b), appears when the application is not connect to any receiver. The command "Reset" turns the connection to the receiver off and then on again while the command "Ligar", attempts to establish a connection to the receiver. The last command, "Configurar", present in both situations, shows a window that lets users change the parameters needed to connect to a receiver. Using "Configurar" and then "Reset", lets users change the GPS receivers used without closing and re-opening the application.

- The "Rede" button opens the network sub-menu, which has only one command: "Ligar". This command allows the application to connect to the Server.

- The button “Esquemas” opens the sub-menu related to sketches, which has the options shown in Fig. 14.

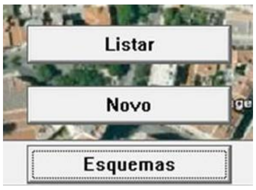


Figure 14. Sketches sub-menu.

The command “Listar” shows a list of all the sketches stored. Selecting or deselecting any of the sketches listed makes them visible or hidden, respectively. The command “Novo” cleans all the menus and buttons from the map, leaving only a button, “Fim”, and allows for a new sketch to be drawn. Sketches are stored as a group of geographical points that are connected when drawn. They are painted on the window in the same way as the users positions’ representations, but are connected.

- The “Pontos Georreferenc” button opens a sub-menu containing additional options related to georeferencing as shown in Fig. 16.

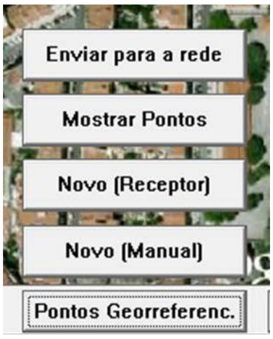


Figure 15. Georeferencing sub-menu.

The command “Novo (Manual)” allows for an additional georeferencing point to be added manually to the image currently shown on the application window. The user needs to select a point on the window as the location on the image for the georeferencing point. After this a window appears and the user must insert the geographical coordinates to be associated with that point. In a similar manner, the “Novo (Receptor)” command allows for an additional georeferencing point to be added to an image but instead of inserting the geographical coordinates manually, the application uses the coordinates gathered from the GPS receiver at the time. The “Enviar para a rede” command sends every georeferencing point other than the two compulsory points (upper left and lower right corner) to the network. The information is sent to the server which in turn sends to every user online. The last command in this sub-menu, “Mostrar Pontos”, shows all the georeferencing points associated with the image on the application window with yellow markers, except the two points used to calculate the representation of the user’s position on the image, which are colored orange. To determine which points to use, the application selects every possible combination of two georeferencing points, creating a rectangle between them and then calculates the center of the rectangles every time the user is inside a rectangle. After that, it measures the distance from the center of the rectangles to the user’s geographical coordinates and whichever has the shortest distance is selected and used to calculate the representation of the user’s position. Fig.16 shows an image with the georeferencing coordinates marked and Fig.17 illustrates the rectangles created internally by the application.

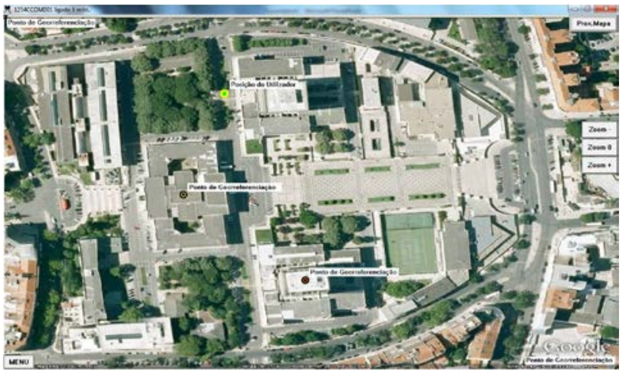


Figure 16. Image with georeferencing points marked.

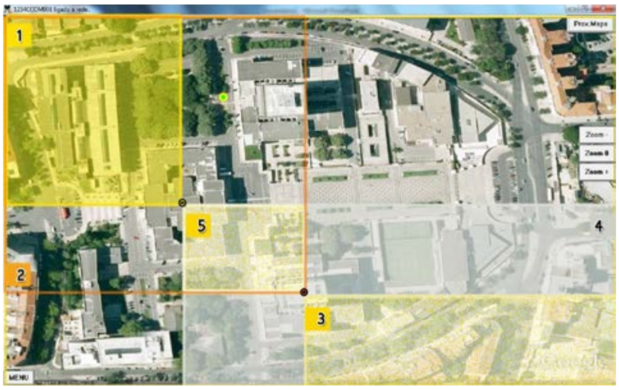


Figure 17. Rectangles created with the georeferencing points, as done internally by the application.

The number of rectangles created, $N_{\square}$, is given by (5), where n is the number of georeferencing points associated with the image. This only works if all the georeferencing points have distinct values for latitude and longitude.

$$N_{\square} = n(n-1) / 2 \qquad (5)$$

The use of a larger number of georeferencing points helps to reduce the errors associated with the georeferencing process. These errors can come from image distortions, in which the value of latitude or longitude per pixel is not always the same throughout the image. The projection used can also be associated with these errors, since it is assumed that the latitude is the same in an horizontal line and that the longitude is the same in a vertical line, which is false in most cases, where those values are the same in curves and not in lines.

D. Application for Stationary Devices

This application was designed to be used in civil protection operations' management centers. It was assumed that the computers that use it have access to the Internet and to a user database. After properly configured, the application is able to process data autonomously, unless if new maps or georeferencing information need to be added to the network. The main window is presented in Fig. 18.

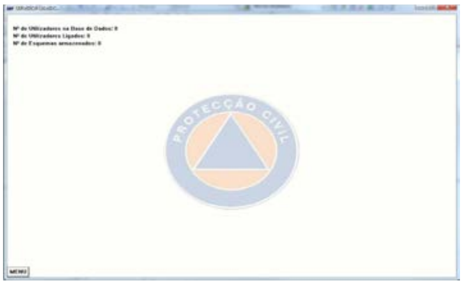

Nº de Utilizadores na Base de Dados: 0
Nº de Utilizadores Ligados: 0
Nº de Esquemas armazenados: 0

Figure 18. Server application window.

The only interface button available to the user is "Menu". Like the Client application, this opens another menu with other options, which are "Envia Mapa", "Coords Extra" and "Google Earth". This menu is shown in Fig. 19.

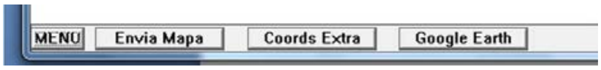


Figure 19. Server application's menu.

- The command "Envia Mapa" is used to transmit new images to the network. It starts by transmitting the image, then its information and compulsory georeferencing points and finally, any other georeferencing points associated with the image. If the receiving client has an image with the same name, the operation fails.

- "Coords Extra" is used when new georeferencing information is available for an image and works exactly like the "Enviar para a rede" command in the client application, under "Pontos Georreferenc". When a client updates this information, the server sends it to every online user which means some of the users may not receive it. With this command the server can broadcast this information to make sure every user in the network has access to the latest georeferencing information.

- Since the Server application doesn't have a visual interface able to show the position of the users in the network, the "Google Earth" command serves as a way to show users and sketches on this Earth browser. The application periodically creates KML files and when the button is pressed, opens Google Earth with the file and then updates it once a minute. Fig. 21 illustrates how the network elements are shown to the user.

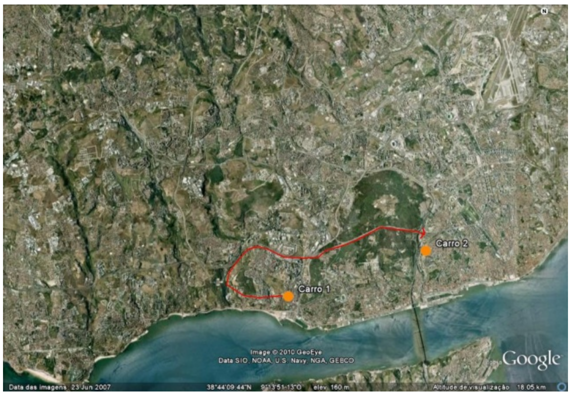


Figure 21. Google Earth window showing two users and a sketch.

In addition to the features described, the Server is also connected to a database, where permissions are managed. In this database, users are grouped according to levels of hierarchy. Each level is able to send different kinds of information to levels above and below. Each user is also given authorization to connect to the network in the database and to which operation they belong. Users are only able to see the position of others users on the same operation. Fig. 22 shows a diagram of the database, which consists of two tables, connected through the hierarchy groups.

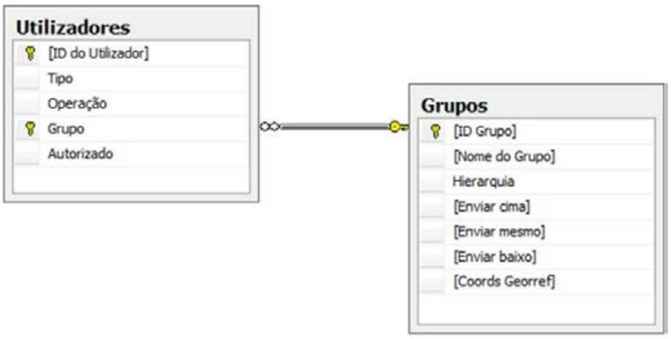


Figure 22. Database tables.

IV. APPLICATION TESTS

The applications developed were tested to assess the system's capabilities in terms of number of georeferencing points to be used, data transmission rates, window painting times, calculations of user's orientation precision and traffic consumption.

A. Number of Georeferencing Points

As explained in section III.C, the process of assigning geographical information to an image, also called georeferencing, has errors associated with image distortions and the projection used. To achieve a more precise representation of a user's coordinates on a georeferenced image, the distance between the corners of the square used must be shorter, which means the square used must be smaller and therefore, the number of points needed to cover the entire image must be higher. To study the size of the grid needed to achieve an acceptable accuracy for the representation of a user's coordinates, a group of georeferencing points was marked on an image. Each pair of points simulates a grid of a different size. In the tests, a Google Earth image of the University campus was used, covering an area of approximately 18’’ in longitude and 8.25’’ in latitude (approximately 440m x 258m). It is shown in Fig. 23. The image was used four times in the application, and each time, the distance between the extra georeferencing points used to calculate the pixel coordinates was shortened to simulate the use of a tighter grid. Also, a user with known coordinates was marked on the image and his coordinates were incorporated into the application as if they were obtained by a GPS receiver. With these conditions, for every map used, the accuracy of the given coordinates’ representation on the image is increased.

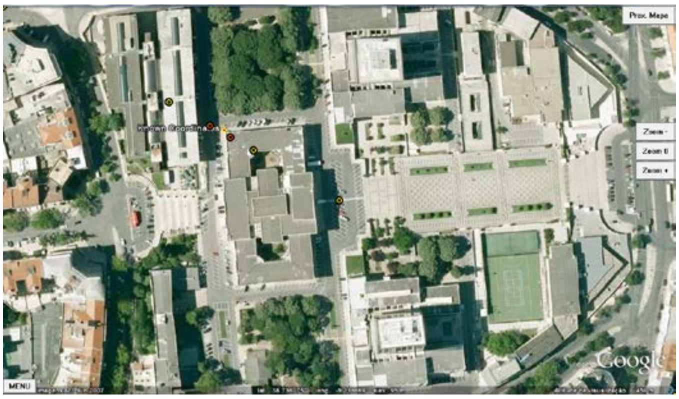


Figure 23. Test image used.

With the first pair of points, which simulates a grid of 5 points, the error between the calculated representation of the user and the real position was around 3m. Using georeferencing points with half that distance, meaning a grid of 13 points, the error was approximately 1m and, again, with that distance halved (41 points grid), it dropped to less than 0.5m. With that distance halved one last time, which simulates a grid of 145 points, the error wasn’t reduced. This last case is shown in Fig.24.

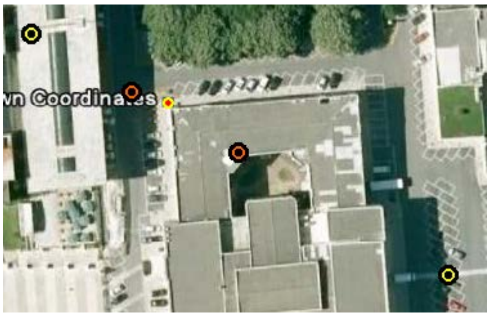


Figure 24. Case of a 145 points grid.

Due to the practical use of the application, using 13 points of georeferencing for this image is the best option. In this case the square created by the georeferencing points has approximately 4.51’’ in longitude and 2.07’’ of latitude (approximately 110m x 40m). To obtain an almost perfect accuracy, the case of the 41 points grid is needed which implies an area of 2.75’’ in longitude and 1.03’’ in latitude (approximately 55m x 20m).

B. Data transmissions rates

To test the rates of transmission in the network, an image was sent from the Server to an increasing number of users. The image used had a size of 346.181 bytes. The time was taken into account since the first message was sent by the Server until the last user received the last part of information about the image. The results are shown in Fig. 25.

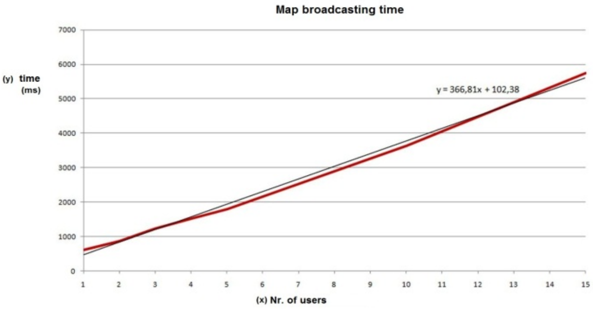


Figure 25. Transmission time from the Server to the network.

As expected and shown in Fig, 25, the time, y, increases with the number of users, x, and that increase can be approximated by the line given by (6).

$$y\ (\text{ms}) = 366.81x + 102.38 \tag{6}$$

This means that with enough users the network will be idle for a potentially long time when the server broadcasts new images. For this reason, this feature should be used when not in an operation. One option to solve this would be the use of an architecture hybrid of server-client and peer-to-peer, which was never considered for this project.

C. Application’s Window Painting Time

In order to measure the time needed to paint the Client’s window, two tests were performed: one only with the users’ positions and the other with the users’ orientations, since it involves more calculations to rotate the marker. Both tests were performed with a crescent number of users. The results can be seen in Fig. 26.

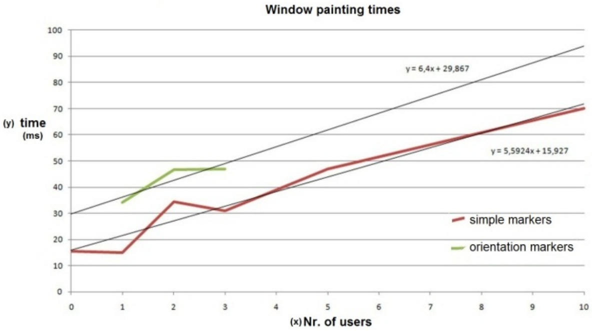


Figure 26. Window painting time.

The red line corresponds to the results with only simple markers used. The test was performed with a range from 0 to 15 users. The results can be approximated by a line given by (7).

$$y\ (\text{ms}) = 5.5924x + 15.927 \tag{7}$$

The green line corresponds to the second test case, with only orientation markers, from 1 to 3 users, and the results can be approximated by a line given by (8).

$$\text{y (ms)} = 6.4\text{x} + 29.867 \qquad (8)$$

As can be seen in Fig. 26, an increase in the number of users is translated into an increased time needed for the window to be painted. Also, if the application has to paint the orientation markers, it takes more time than to paint only simple ones. Using (7) and (8), the window's paint time can be estimated for a large number of users, for example, 100. For this number, the paint time only with simple markers is 575.167 ms and for orientation markers is 669.867 ms. Both these values are over half a second. This doesn't pose a problem if the image is manipulated (for example, with the pan feature) as the window is refreshed every 5 seconds. The problem is when the image is being manipulated because the window is repainted with very small intervals (300ms in the case of pan). A solution would be to only paint the users' markers when the image is stationary.

D. Precision of Orientation Calculations

To test the precision of the orientation feature of the client application, the values calculated were stored for a 10min interval and then the average and standard deviation were calculated and compared to a known value. In the time interval used, the number of points gathered was around 120 since the window is repainted every 5 seconds. The average value, $\bar{X}$, was calculated using (9), where x(t) are the gathered values and $\mathrm{n_x}$ the total number, and the standard deviation, σ, using (10).

$$\bar{X} = \frac{\sum[x(t)]}{n_x} \qquad (9)$$

$$\sigma = \frac{\sqrt{\sum[\mathrm{x(t)} - \bar{\mathrm{x}}]^2}}{\mathrm{n}_x - 1} \qquad (10)$$

Fig. 27 shows the image used on this test with the calculated orientation of the user and the real orientation marked.

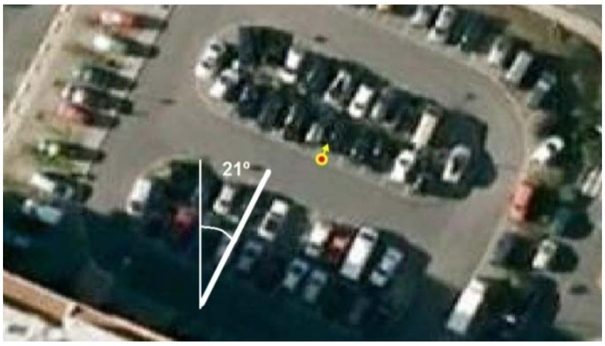


Figure 27. Real and calculated orientations marked on the application window.

With a real value of about 21º, the average value obtained was 20.57º with a standard deviation of 2.97º, which includes the real value. An acceptable orientation value is only achieved with very favorable conditions for the GPS system. The surrounding area must be clear to avoid excessive reflections so the receivers get clear signals and the signals must be stable so they don't vary too much. Also, it was assumed that both values obtained from the rear and front receivers vary in a similar manner. If this doesn't occur, the orientation may be very different from the real value.

E. Traffic Consumption Estimate

To get an estimate of the traffic consumed by the network a number of calculations were performed taking into account the most basic operation of the system: the transmission of geographical coordinates.

$	User ID	Message ID	Body size	#	Body	Checksum
1	variable	3	3	1	variable	2

Figure 28. Format of the messages transmitted in the network.

The body of a geographical coordinates' message is composed of the User ID of every user on the same operation as the receiver, along with their coordinates. All the information is separated by "*". The number of bytes used on every part of the message is as follows:

- Message header is composed of 18 bytes: 11 for the User ID, using firefighters vehicles' ID (4 numbers, 4 letters and 3 numbers), 3 for the Message ID, 3 for the Body size and 1 for "#";
- User information with one pair of coordinates is composed of 41 bytes: 11 bytes for the User ID, 1 for "*", 29 for the user's position (latitude between 0 and 90 with 10 decimal digits plus orientation and longitude between 0 and 180 with 10 decimal digits plus orientation);
- User information with two pairs of coordinates from two receivers is composed of 71 bytes: 41 bytes for the information explained above, 1 byte for "*" and 29 bytes for the coordinates of the second receiver.

Applying this number of bytes in a regular message with 10 users, half of them using two receivers, the total number of bytes is 587 (18 from the header, 5 times user information with one receiver and 5 times user information with two receivers). Having in mind that in a minute these messages are transmitted 12 times, this means that in an hour 720 messages are sent. This means a consumption of about 0.4 MB /h.

Assuming a very large number of users, 100, where 50 have access to two receivers these values would be 5717 bytes in a message and a consumption of 3.9 MB /h.

Most mobile Internet service providers provide users with 100 MB of consumption per month. This means, in the average case, around 250 hours and in the worst case scenario, 25 hours. Considering that the worst case will very rarely occur, the consumption is considered acceptable. No calculations were considered for the Server as it's assumed it will be stationary, where data consumption isn't an issue.

V. CONCLUSIONS AND CRITICS

As proposed, the system developed allows users to see the position and, in some cases, the orientation of other users in the same operation on the cartography used. This cartography may be any kind of image, from digitalized maps to aerial photographs, as long as geographical information is associated with it. The information associated with each image may be increased manually or through the GPS receivers, increasing the accuracy of users' representation's calculations. Every user can draw sketches directly on top of the cartography and select which users should receive it. A system of permissions on the server application selects which users can connect to the network and which information each user can send and receive. The system is able to differentiate between two types of users, adding diversity to the network.

With the user's orientation feature, the system allows for an expansion with cameras to be developed. By knowing the orientation of a user and using cameras able to rotate and zoom, the line of sight of each camera equipped vehicle can be shared with the network. With the permissions system, the network could allow selected users to control the cameras and the visual information to be shared.

Unlike previously developed applications in this field, this project doesn't use a map distribution system, as it was developed to be used with vehicle computers, which shouldn't have disk space problems and can store all the maps needed. These computers also have touch screens which means they can easily be handled in the middle of an operation without the need to use pens or markers like when using PDAs. The applications considered in section III.A need a lot of configuration time as all the parameters need to be inserted before connecting to the rest of the network (GPS receivers and Server). The application developed in this dissertation creates external files where all the configuration information is stored, reducing the time needed to start using it. The orientation feature, explained earlier, is also a new feature not present in previous projects.

The only drawbacks of the application, which could be corrected if it was to be commercialized, are the absence of a user password, meaning that anyone with the application and a valid User ID can connect to the network if that user is not connected already. This could be bypassed by using a password system when connecting to the network and by having the Server transmit a unique code-key to the users and have them sending it back when they need to reconnect. This was not developed because part of the communication protocols would have to be changed, which would be a lengthy process. Also, some unexplained cases of Server crashes occurred, that couldn't be reproduced at will, which means that it could not be completely resolved.

The applications developed meets the objectives proposed from the start, and having been tested in terms of performance, it's considered that with a little more development in some areas it could be commercialized.

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REFERENCES

[1] - Navigation Center, "NAVSTAR User Equipment Introduction, Public Release Version", 1996.

[2] - Scott Prater, "Airmen Upgrade GPS Constellation", 50th Space Wing Public Affairs Schriever AFB CO (AFNS) Jun 03, 2010.

[3] - Will Lumpkins, Sr. Member IEEE, Sr. FAE, "GPS and WiFi Technology", presentation from the company Wi2Wi, 12th May 2009.

[4] - Kowoma.de, "Control Segment (Monitor Stations)", 2009.

[5] - Bluetooth website (http://www.bluetooth.com).

[6] - Usha Communications Technology, "GPRS General Packet Radio Service", white paper, 2000.

[7] - Nokia, "Enhanced Data Rates for GSM Evolution, EDGE", white paper, 1999.

[8] - Ericsson, "The evolution of EDGE", white paper, 2009.

[9] - Peter Rysavy, "Data Capabilities: GPRS to HSDPA", white paper for 3G Americas, 2004.

[10] - Pablo Tapia, Jun Liu, Yasmin Karimli, Martin J. Feuerstein, "HSPA Performance and Evolution", John Wiley & Sons Ltd, 2009.

[11] - E.F. Codd, "A Relational Model of Data for Large Shared Data Banks", Communications of the ACM, 1970.

[12] - Donald D. Chamberlin & Raymond F. Boyce, "SEQUEL: A Structured English Query Language", Proceedings of the 1974 ACM SIGFIDET (now SIGMOD) workshop on Data description, access and control, 1974.

[13] - Chris Collins, "History of the SQL", author's blog article, 2007.

[14] - Dr. Herong Yang, "MySQL Tutorials - Herong's Tutorial Notes", book from the author's website, 2009.

[15] - ANSI/ISO/IEC International Standard (IS), "DatabaseLanguageSQL—Part2: Foundation (SQL/Foundation)", SQL standard, 1999.

[16] - SQL Tutorial from www.w3schools.com.

[17] - Google's KML website.

[18] - Nuno Carvalho, "I-Garment Case Study: Location and Monitoring Applications Through Satellite Communications", I-Garment project presentation, 2005.

[19] - R. Matos, D. Santos, J. Sanguino, A. Rodrigues, "A GPS-based Mobile Coordinated Positioning System for Firefighting Scenarios," Proc. of the 1st International Conference on Mobile Computing and Wireless Communications (MCWC 2006), Amman, Jordan, 17-20 September 2006, pp.209-214.

[20] - Filipe Tocha, "Sistema de posicionamento coordenado baseado em GPS: Geocommunicator", Msc Thesis, Instituto Superior Técnico, Technical University of Lisbon, 2008.

[21] - D. Santos, R. Matos, J. Sanguino, A. Rodrigues, "Automatic Location-based Map Distribution Service for Mobile Coordinated Positioning System," IADIS International Conference, WWW/Internet 2006, Murcia, Spain, 6-7 October 2006, vol. 2, pp. 305-309.

[22] - Robin Jan Maly, "Comparison of Centralized (Client-Server) and Decentralized (Peer-to-Peer) Networking", semester thesis, May 2003.

[23] - NMEA, "The NMEA 0183 Protocol" v3.0 of the standard.

[24] - José Sanguino, support material for the course Navigation Systems, of the Integrated MSc in Aerospace Engineering curricular plan, Instituto Superior Técnico, Technical University of Lisbon, 2010.