Augmented Reality and Indoors Wi-Fi Positioning for Conducting Fire Evacuation Drills Using Mobile Phones

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Abstract

The new challenges posed by society are bringing Ambient Intelligence into the scene. Ambient Intelligence can help to improve common tasks through the use of electronic devices that interact with the user in a transparent way, automatically extracting information and performing data analytics to help into a better understanding of the environment around the user. In this paper we describe an experimental mobile augmented reality system, AVANTI, which uses as a testbed the Computer Science School of the Complutense University It makes use of WiFi positioning techniques for indoors and accelerometer sensors to predict speed and position. With those techniques, AVANTI allows computer-aid drills of fire evacuation, decreases costs and encourages the motivation of the users. By using an augmented reality interface we enrich the user perception of the environment, so the evacuation drill data can be easily accessed and the training process quality can experience a major increase. In addition, the use of Augmented Reality provides a more realistic simulation, with fire outbreaks into the phone screen, rather than the process of moving statically from one floor to the exit.

1. Motivation

The need for periodic fire evacuation drills in public buildings is universally accepted as a basic safety measure. These drills are intended to familiarize the occupants of a building with the procedure for evacuation, the exit routes, and meeting points. They usually involve a large coordinated effort where everybody in the building takes part at the same time, with a specific location for the hypothetical fire assigned overall and evacuation personnel guiding people. As these exercises involve a high financial cost [3] and in terms of disturbance of the daily routine of the building in question, they tend to be carried out with less frequency than would be desirable. To reduce this problem, serious games and virtual reality technology has been applied to allow simulations of fire drills in virtual environments [1,5,10]. These solutions allow users to exercise the procedure and explore the exit routes in a simulated space. However, Chittaro and Ranon [5] report that during debriefing of players who had tested their software it was discovered that players in a 3D simulation have a distorted perception of the speed at which they would move through real space. Players complained that the system allowed them to move at slower speeds than they would have achieved in real life. Chittaro and Ranon mention that this could be a combination of an observed tendency of people to underestimate overall evacuation time (especially time spent in stairwells) and unrealistic expectations concerning locomotion speeds acquired as a result of experience with recreational games.

The present paper proposes a solution that combines the advantages of virtual simulations – the ability to keep a log of the evacuation and the possibility of blocking specific exit routes – with the advantages of a real drill – the actual speed of movement of each user determines his progress with no intervening model of behavior, and the actual building is used instead of a 3D model. The proposed system combines wireless information for indoor positioning, and Augmented Reality to superimpose fire information on the environment as seen through the camera of the mobile phone. The accelerometer of the mobile phone is used to collect data for estimating by means of dead reckoning user speed and position when moving in 'black areas' (areas with fluctuations in the signal measurement, or with a significant signal loss).

2. Previous Work

This section reviews previous work in virtual simulation of fire drills, augmented reality, WiFi positioning, and the algorithms that have been implemented in the prototype.

2.1. Virtual Simulation of Fire Drills

Two basic approaches have been applied to improve fire drills using software simulations: virtual environments in which the user can move as a player representing a person that tries to evacuate the building [1,5], and software applications where the behavior of people during the evacuation of a building is simulated by means of a software model [7,10,17]. This paper concentrates on solutions of the first type.

One fundamental advantage proposed for virtual simulations of fire drills over real life drills is that in virtual simulations the results of the drill can be logged, which is useful for debriefing and assessment [5 ,10]. Another important advantage of virtual simulations identified by Johnson [10] is that to be effective drills must force occupants to find alternate forms of egress should these become blocked during an incident. This is not always possible in real drills, as it requires extra staff to be placed at the supposedly blocked route to deter people from using it.

2.2. Augmented Reality and Motivation

Augmented Reality (AR) is the process of overlaying and aligning computer-generated content over a view of the physical world. By using a transparent OpenGL layer over the render surface of a camera we can display virtual information over the reality. Some of the fields where AR can get involved are advertisement, architecture, entertainment [12] or music [4]. Augmented Reality can also show data analytics on the device screen, without interfering with the environment and enriching the user experience. The data can be automatically processed, like trajectory, information, fire locations, average time and escape direction, and the user can interact more dynamically.

2.3. Wi-Fi Positioning System

There is body of research on how to use WiFi to achieve indoor location and positioning, like [8] and [9]. Still not as widely commercially spread as GPS, WiFi Positioning has been used in some other fields. Wi-Fi Positioning System (WPS) is a term pioneered by SkyHook Wireless, the first company which leads it into a commercial development. Skyhook maintains a huge database of WiFi maps of signal, access points and their precise location, enabling any user to access them and achieving a level of performance considered good where the GPS signal is not strong enough. However, the use of SkyHook in specific applications is only practical if the particular location is included in their databases.

WPS may be combined with cell phone tower triangulation and GPS to provide a more reliable and accurate position data under a wide range of conditions, like tall buildings or obstacles, which might induct GPS signal into intermittence or weakness. The inconvenient for the WPS is that we need to update the database constantly, and it will not work out of the range of Wi-Fi access points.

2.4. K-Closest Neighbors

This algorithm recovers from the positions database the K positions that best fit with the

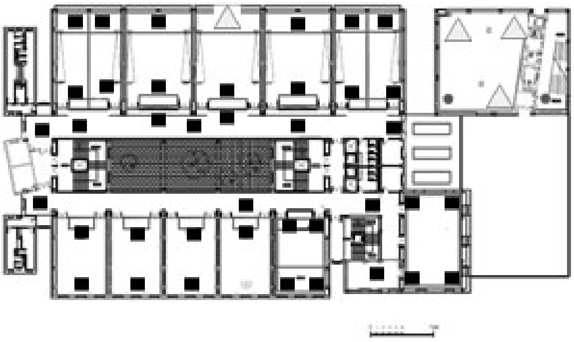

Figure 1. Our testbed for the WPS. The squares represent an access point with a good signal strength, the triangles represent an average signal strength and the dots represent a poor signal

signal tuple from the access points in the situation of the terminal. The criterion used for selecting the best positions is the Euclidean distance (measured as the power signal difference). If Z=(RSS1,...,RSSM) is the vector of observed signals from the device, composed by M access points in an unknown position X=(x,y) (the ones from the terminal we want to know) and Z_i are the registered signals in the database for the position $X_i=(x_i, y_i)$, then the Euclidean distance is:

$$d(Z,Z_i) = \frac{1}{M} \cdot \sqrt{\sum_{j=1}^{M} \left(\mathrm{RSS}_j(x,y) - \mathrm{RSS}_j\,(x_i,y_i)\right)^2},$$

Being:

1. $\mathrm{RSS}_j(x_i, y_i)$: the “Received Signal Strength” for the AP with the MAC j, located in x_i, y_i, recorded in the database.
2. M: number of different APs recorded in the database.

The set N_k of positions from the database which contains the small range of error in terms of RSS , is built as the following iterative process indicates:

$$N_k = \left\{ \operatorname*{argmin}_{X_i \in \mathfrak{L}} [d(Z,Z_i)] \setminus X_i \notin N_k \right.$$

This recovers the K positions from the database with a smaller error, and without any repetition (unique set).

L is the set of registered positions in the database. Finally, the position of the device will be calculated as the barycentre of the k positions:

$$X = \frac{\sum_{j=1}^{k} (1/d(Z,Z_i)) \cdot X_j}{\sum_{j=1}^{k} (1/d(Z,Z_i))} \quad \text{with } X_j \in$$

The main advantage of this algorithm is the simplicity of implementation and usage. However, the precision depends on the granularity of the reference database. The higher the whished precision, the bigger the database should be, what can mean a high access time, making the process to locate the device slower, which may lead into an unacceptable latency.

The selection of the size for the set N (variable k) can allow varying the number of points we are using to calculate the position of the terminal, allowing tuning to achieve the best possible accuracy. However, experience shows that there is no optimum value, and only the specifical needs of the application may determine the most efficient value for each case. [8]

2.5. Particle Filter

We have followed the description and methodology given in [8]. According to it, we introduce the definition of a particle filter:

The key idea of this algorithm is to combine the motion model and the map information in a filter to obtain a more realistic approximation of the position of the device.

The particle filter, based on a set of random weighted samples (i.e., the particles), represents the density function of the mobile position. Each particle explores the environment according to the motion model and map information.

Their weights are updated each time a new measurement is received.

The particle filter tries to estimate de probabilistic distribution Pr $[x_k \mid Z_{0:k}]$, where x_k is the state vector of the device at time step *k*, and $Z_{0:k}$ is the set of collected measurements until the (k + 1) measurement. When the number of particles is high, it can be assimilated to:

$$\Pr\left[x_k \mid Z_{0:k}\right] = \sum_{i=1}^{N_s} w_k^i \delta(x_k - x_k^i). \qquad [8]$$

This filter comprises 5 steps: prediction, correction, particle update, resampling and estimation.

Prediction

As argued in [14], during this step, the particles propagate across the building given an evolution law that assigns a new position for each particle with an acceleration measured from the acceleration sensors of the mobile. The new particle position can be obtained from the following transition function:

$$\begin{bmatrix} x^i(k+1) \\ y^i(k+1) \\ v^i{}_x(k+1) \\ v^i{}_y(k+1) \end{bmatrix} = \begin{bmatrix} 1 & 0 & \Delta t & 0 \\ 0 & 1 & 0 & \Delta t \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x^i(k) \\ y^i(k) \\ v^i{}_x(k) \\ v^i{}_y(k) \end{bmatrix} + \begin{bmatrix} \frac{\Delta t^2}{2} & 0 \\ 0 & \frac{\Delta t^2}{2} \\ \Delta t & 0 \\ 0 & \Delta t \end{bmatrix} \begin{bmatrix} a_x(k) \\ a_y(k) \end{bmatrix}$$

Where $[x^i(k), y^i(k), v^i{}_x(k), v^i{}_y(k)]$ is the position and velocity of a particle at time step *k* , Δt is the time difference between the two measurement moments and $[a_x(k), a_y(k)]$ is the acceleration of the device at time step k.

In [8] the acceleration is considered as an iterative process for simulation, but [8] proposes the use of accelerometers, so we used this last reference.

At this point we include the map information, in order to remove the particles having an impossible move, like crossing a wall.

$$Pr[x_k|x_{k-1}] = \begin{cases} 0 & \text{if a particle crossed a wall,} \\ 1 & \text{if a particle did not cross a wall.} \end{cases}$$

Correction

It is possible to estimate Pr $[Z_k \mid x_k]$ with this equation:

$$\Pr\left[Z_k \mid x_k^i\right] = \frac{1}{\sqrt{2\pi}\sigma} \exp\left[- \frac{\left\|X_{z_k} - X_{x_k^i}\right\|^2}{2 \cdot \sigma^2} \right]$$

[8]

Where X_{zk} is the position the mobile device returned by the k-closest neighbors algorithm, $X_{xk}{}^i$ the position of the i-th particle and *σ* the measurement confidence. The smaller *σ* is, the more precise the measurement is.

Particle update

This is the used particle weight update:

$$w_k^i = w_{k-1}^i \cdot \Pr\left[x_k \mid x_{k-1}\right] \cdot \Pr\left[z_k \mid x_k\right].$$

[8]

After a few iterations, the weights of the particles can be very low, because many of them can have crossed a wall. To prevent this phenomenon, a resampling step is needed.

Resampling

The criterion to trigger a resampling is given by:

$$\frac{1}{\sum_{i=0}^{N_s} \left(w_k^i\right)^2} \leq \text{Threshold.}$$

If a resampling step is needed, this algorithm copies half of the particles, and discards the other half which contains the particles with the lowest weights. Now we just need to combine the calculated probabilities to find the new position distribution.

Estimation

In this step, the algorithm uses the following equation to estimate the new position of the device:

$$E[X|Z] = \sum_{x_i \varepsilon L} x_i * Pr[x_i|Z]$$ [16]

Where L is the set of positions recorded in the database and $Pr[X_i|Z]$ is the probabilistic distribution which can be calculated using the equation placed in 3.1.2.

3. AVANTI: A Prototype for Fire Drill Conduction over Mobile Phones

AVANTI is a tool developed in the NIL (Natural Interaction based on Language) research group, which aims to bring together the trends from AmI and other technologies like Augmented Reality in order to provide an immersive scenario to motivate users in order to improve their performance in fire evacuation drills. It has been developed over Android, and uses OpenGL ES 1.0 (equivalent to OpenGL 1.3). The API is similar to J2ME JSR239.

Augmented reality allows us to display virtual fires on a simulation context. Thus, we can benefit from a virtual fire environment without the risks of moving around a real fire, as well as the implied engagement and motivation derived from a simulation. Mobile platforms allow movement and interaction without the need of being connected to a desktop computer but they require a specific solution for indoor positioning.

The program follows the client-server architecture paradigm. After the login, the client establishes a connection with the server and the sessions is created. This means that all the profile data from the server is retrieved. The client is permanently connected to the server, sending information from the reachable APs in order to receive the coordinates corresponding to the area where it is located. The server stores the databases to perform the positioning: strengths of APs and coordinates. Also the information related to the user profile, such as personal information, old trajectories, current trajectories, success in previous evacuations and required time.

The fire models are generated using a particle system [13]. A different approach, using just Collada[2] models on the application, was originally tried. However, the use of a particle system is within the bounds of affordable resource consumption for the system, and the effect is much more realistic. The particle system can be even adapted to reflect different fire intensities, therefore generating more particles, bigger and with a different launching speed.

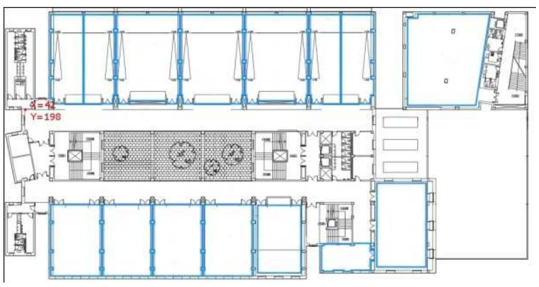

Figure 2. Location of the point (42,198,1) in our representation

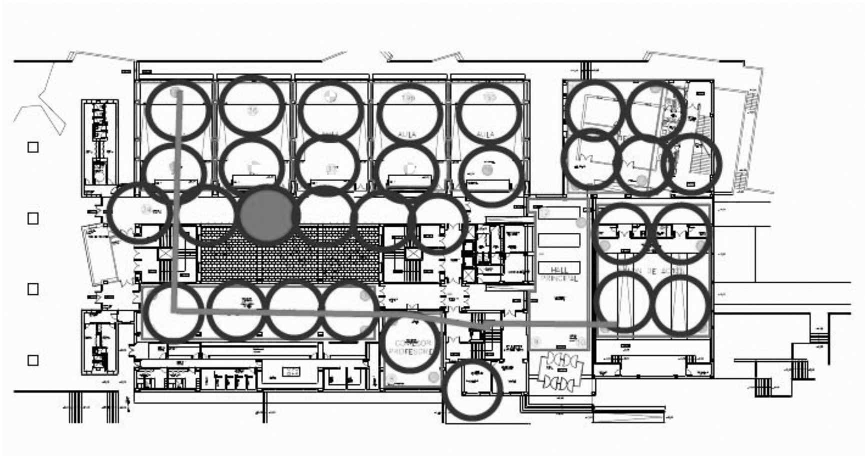

Figure 3. Generation of the route

3.1. Representation of the Building

AVANTI uses as a model the building of the Computer Science School from the Complutense University. to represent the scenario of the simulation. It uses a spatial Cartesian coordinates model, with the Z axis being discrete (floor 1, 2 or 3) and the X and Y axis using real coordinates. As an example, in Figure 2 we can see, on the dot, the location (42, 198,1). In our database we have recorded the positions in meters, but the maps are represented in pixels, which precise a scale of representation. In this case this scale meter-pixel is 1:10.904225532. For each entry of the database we have stored the coordinates of a certain point (x y,z) (measured in meters), and the strength of the signal received in every single access point, with a unique MAC number. Every time we show the positioning data on the device, there is a real time transformation from the stored units (meters) to the representation unit (pixels). As requesting the data of an external server in every single step would be very costly in terms of response times (a fast computation is needed), the database is temporally stored in the device while the application is running, which is carried out in the background. With this information, we can use the positions recorded in the database to estimate the position using the algorithms described in the next section.

3.2. Calculation of Exit Routes

The main purpose of AVANTI is to serve as a simulator to acquire the necessary knowledge to evacuate a building in case of fire. In order to do this, it is necessary to perform a calculation of routes to the safe areas, taking into account certain restrictions:

1. The elevator cannot be used.
2. Due to the risk of gas pockets, closed doors cannot be opened.
3. Moving to an upper floor must always be avoided, unless it is absolutely necessary. The primary target is to reach the bottom of the building (and consequently the exit).
4. If all the exits are blocked, the user has to reach an outdoor area (terrace, or windows).
5. Fire areas must be avoided.

The building has been divided into different nodes with a size of 3,6 x 3,6 meters, according to the actual accuracy of the positioning algorithm. However, if future improvements achieve a greater accuracy, this size will be reduced. In each node, a fire can be established. Some nodes are output nodes: that means, they have to be reached in order to accomplish the evacuation. The heuristic of the nodes (the value which indicates how good the node is) is provided by the shortest distance from this node to an exit. The main advantage of this model is the simplicity of the implementation and of the calculation of the routes. On the other hand, this simplicity may result in a lack of precision.

A visual explanation is provided in Figure 3. The fulfilled node represents a node with a fire inside. The line is the calculated trajectory.

The easiest way would be to go across the corridor where the fire is located, but this is not possible. Therefore, the trajectory has to been modified, making it through the other corridor.

3.3. Server Model

To achieve a dynamic simulation, we provide a server which allows an instructor to change the location of the fire dynamically, in order to represent a more unexpected and chaotic behavior (as a real fire is likely to be).

The server shows dynamically information about where the users and the fires are located. The instructor can access data from the users: particularly, he can access actual trajectory and old trajectories, completed evacuations and fail evacuations and actual position. He can deploy as well fires in suitable locations: that means, fires cannot be located in areas such doors or walls, but free of obstacles. To accomplish this purpose we use a map of bits, representing the obstacle areas in black and the free areas in white. If at some point the instructor tries to set a fire onto a forbidden area, the system will reject the request. This is used as well for the visualization of the users: at some point, a misleading signal can establish that the user is located at a forbidden area. Using the map of bits we return the user to the closest valid position, which is as well close to its previous valid position.

This server manager has been developed with Google GWT. By using AJAX, the current user status is being updated in real time.

3.4. OpenGL 3D Objects and scenario representation

After the abovementioned concepts, we are ready to explain how our 3D model with the fires works. We use the following elements to determine the position where we have to paint a fire in the screen:

1. Device orientation (measured with the compass). A single mathematical operation (distance between two points) performed with the data from the database.
2. Distance to the virtual objects (fires)
3. Obstacle in the sight of vision

We provide now an example, to make it clear. For instance, consider the supposition the device is located at (101, 63, 1).This location in the map can be seen as a cylinder in the figure 4

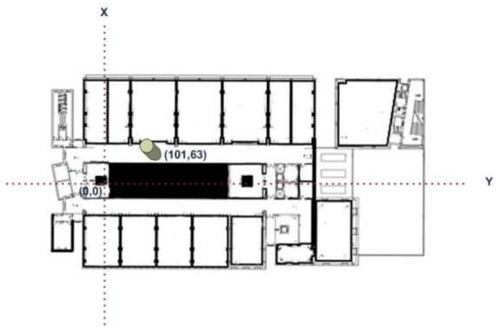

Figure 4. Position (101, 63 ,1)

Suppose that a fire (F1) is initiated in the location (304, 64, 1). According to our representation, this fire will be located in the same corridor as the terminal on a vertical distance of around 200 pixels on the X axis. A representation is given in the figure 5.

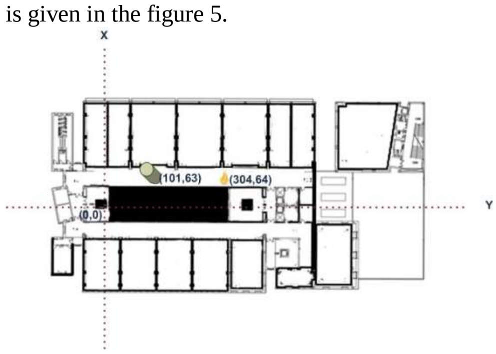

Figure 5. A new fire has appeared on the position (304, 64 ,1)

A straight line can be deployed from the terminal to the fire F1 without having a collision with any obstacle. Considering that we are located at the terminal location (101, 63, 1) and our camera is pointing into the direction of the normalized vector (0,1) – that means, watching at the end of the corridor- the camera will display an image as in the figure 6.

Figure 6. Watching the fire F1 at the same corridor

Now consider the following changes in the scenario. The device is moving from position (101, 63, 1) to position (211,63,1)), so now the user is closer to the fire. The closer the distance to an object is the bigger the size of the object will appear to the observer.

On the other hand, a new fire F2 will appear in position (334,121, 1). If we are still looking in the direction determined by the normalized vector (0,1), the object should appear within our field of view, but it is obscured by an obstacle. Drawing a line from our position to F2 will cross in the bits map a black line, which indicates us that we should not be able to watch it. The representation of the map can be seen in the figure 7. The vision through the camera is shown on the figure 8.

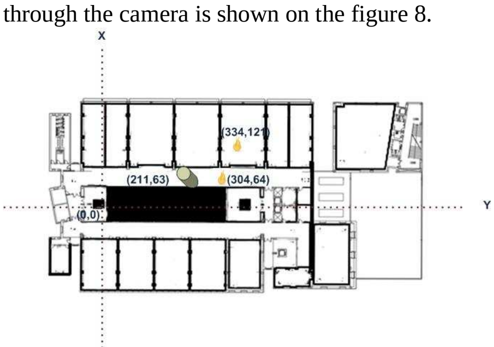

Figure 7. Second scenario of the described example

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Figure 8. What the camera will see in the second configuration

We rely on the *gluLookAt()* function of OpenGLto solve the problem. We can position the desired objects (fires) in certain locations, and rely on *gluLookAt()* to locate the camera center in the coordinates specified by the device, and the eyePosition in the coordinates specified by the compass sensor.

4. Discussion

The proposed solution of using mobile phones coordinated from a central server to conduct a simulated fire drill over the actual building brings together the advantages of a virtual solution and the advantages of a real life drill. The use of WiFi positioning allows the system to track the movement of the user over the building so a log of the evacuation can be generated. The use of augmented reality provides the means of overlaying simulated fires at specific locations in the building. The WiFi positioning makes it possible for the system to detect users trying to step into danger areas, so warnings can be sent. At the same time, the fact that the user is actually moving through the real building ensures that the speed of movement is realistic, and that no mismatches are possible between the virtual representation and the reality of the building at any given moment in time.

After the finalization of the first prototype of AVANTI, the main conclusion among the developers was that the part involving the WiFi positioning, and more accurately the collecting process of data from the access points, needs some more refinement and improvement to extend the availability of this approach to commercial process. We can consider that this was the main bottleneck of the development. The automatization of this process is still far from being a reality, and thus the human supervision of the data collecting is nowadays compulsory. SkyHook Inc. is actually leading the commercial WiFi positioning and increasing the reputation around the community, so more automatic tools are expected to be developed in the next years.

The use of the Android platform was one of the adequate choices from the beginning of the development. A vast community of developers and resources in the Internet makes application development much easier. It is our belief that Android has reached the maturity only a few years after being released, and it can be considered for professional developments.

However, our feeling is bittersweet with the hardware manufacturers for Android. The application was tested on a HTC Hero, which sometimes lacks of full compatibility with the Android Operative System. We had some problems trying to combine the view from the camera and the OpenGL view, problem which was not happening in other phones with the same Android version. The last version of Android was not always available for the device, so our development was mainly done with an older one, specifically 1.6. Nevertheless, the Nexus One device was released some time before our development finish, and the valorations were very positive, so we expect that the Android Hardware could be competitive in the future against some other platforms as iPhone.

There are some known shortcomings of augmented reality that should be taken into account [15]: it is not yet suitable for real time performance, and its use in mobile devices is still under development. Under these circumstances the proposal is intended as a proof-of-concept. Further developments can be expected as the technology evolves.

Another important issue is the possible effect of the augmented reality included in the prototype as an aid for motivating building occupants to carry out the fire drills. The use of simulations to improve motivation is an accepted procedure in educational contexts [6]. Marc Prensky points out in his book Digital Game-Based Learning [13] some successful stories where he applied serious games and simulations to help a certain collective to get involved in the learning process. Augmented reality has also been used with a similar purpose [11].

5. Conclusions and Future work

The conduction of fire drills using mobile devices coordinated from a central server and relying on WiFi indoor positioning and augmented reality is a feasible possibility. Such a solution would combine the advantages of virtual simulations with those of real fire drills, while avoiding some important disadvantages of each one of them.

The next step in AVANTI would be to extend it to reflect different type of fires and its effects. The representation can mostly be done by adapting the particle system. Another idea is to develop a system where the fire extinguishers are relevant, are they can be used in order to mitigate the fire. This will require a previous research stage to analyze the different type of fires, different type of fire extinguishers, and suitability of one for the other (i.e, water should not be used against an electrical fire). This could be further extended by locating sensors on extinguishers or fire alarms. Being able to track which of these elements have been activated or are being used during the simulation could provide a new level of realism, leading into more accurate calculation of evacuation routes, and improving the training process (simulated fires could be extinguished by the action of the emergency crews, as may happen in a real situation).

Due to the cost of generating a complete map of signals for the entire building, we use for the representation only the second floor. A future version would include the entire building as well, so the algorithms might be refined to include problematic sectors such as the stairs (switching between the different floors).

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