Mobile building evacuation application

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ABSTRACT
Modern VR/AR technologies are more and more appropriate for civil engineering and facility management purposes, but most of the existing solutions are proprietary. The current paper introduces a mobile application built only with free and open-source technologies and services for indoor positioning and building evacuation using elements of augmented reality.

Author Keywords
indoor positioning systems; building evacuation; BIM; augmented reality; open-source;

ACM Classification Keywords
H.5.1. Information interfaces and presentation (e.g., HCI): Multimedia Information Systems. F.2.2. Theory of Computation: Nonnumerical Algorithms and Problems (E.2, E.3, E.4, E.5, G.2, H.2, H.3).

General Terms
Design; Measurement.

INTRODUCTION

The technological advance enhanced in the past years the development of innovative algorithms, hardware equipment and programming techniques. Both economic and academic fields are currently focused on integrating disruptive technologies to provide feasible solutions for problems that could not be addressed so far.

Declassified military technology like MISB – Motion Imagery Standards Board [1] and NATO STANAG 4609 – NATO Digital Motion Imagery Standard [2] provide interoperability between various surveillance equipment and geographical information systems, providing the stakeholders the ability to emulate recorded metadata over a detailed map of an area with strong valences into warfare and accurate target location. These technical improvements are not specific only to the military, but also to the mass consumer, where applications like Waze, Uber, Google Maps or Snapchat rely on dense networks of satellites and efficient path finding algorithms to provide real-time precise location services using trilateration.

Moreover, augmented reality has recently emerged as a disruptive technology, great potential being expected especially regarding teaching and learning. Several successful implementations can capture images from the interior of a building and compare them with previously stored building information models using convolutional neural networks to identify water pipes inside the walls [3].

Such initiatives involve deep learning techniques and trained neural networks, capable of correctly distinguishing between objects and identifying the most representative features of an image [4] [5]. Other fields where augmented reality has become more and more relevant is civil engineering and environmental planning, the following article introducing an AR flood simulator [6].

INDOOR LOCATION

While most of the outdoor location related issues have been addressed in recent years, the trend is to provide similar functionalities for indoor location, aiming better facility management solutions and more reliable emergency management systems.

In comparison to outdoor positioning systems, indoor positioning requires a more in-depth analysis of the structure where the localization is desired to take place. There are two main acknowledged approaches for indoor positioning.

The first one is relying on physical hardware installation within the building, the localization process requiring networks of sensors and beacons which acquire information about the target when in proximity. In this scenario, the limitations come from the physical features of the building, construction materials and degree of congestion, wave distribution patterns and refraction levels.

The second one is making the target responsible for the data acquisition, while the localization service is accountable for identifying the target's context regarding a much broader environment, often more complex and characterized by many similarities.

The former approach depends on what specialty literature calls artificial markers and it must be stated that such hardware installation is the building owner's responsibility and it usually is both expensive and complex, as it may interfere with already existing networks.

The latter is more convenient financially speaking, as it avoids the sensors' acquisition, but faces new challenges as this model is far more sensitive to information accuracy. Although precise building information models (BIMs) are mandatory, they must accurately reflect the reality to properly provide geo-location. Consequently, the reference representation needs to synchronize with every change that might occur. Otherwise, just a small change like a painted wall or a disbanded or newly added markers – marketing posters, for example, might confuse the recognition algorithm leading to incorrect results due to wrong model assumptions.

Nevertheless, while the hardware-dependent approach is influenced by physical radio communication principles between devices, the other one requires an intermediate layer amongst the end-user (the target) and the building ecosystem. This abstract layer involves effective and efficient software solutions that can communicate and exchange information with both the end-user and the building's information system. Studies have proved that a 3D rendered model is different in terms of visual features from an image captured inside an indoor environment; therefore, a cross-domain comparison between them is quite difficult to achieve [7] - to solve the issue complex neural networks carefully trained for image processing being required.

Last but not least, the following study [8] identified some other challenges that must be considered for such initiatives. Among them, the high-power consumption such infrastructure might need, the system robustness, the scalability – how well the process can handle a large number of requests are just some worth mentioning.

PROPOSED SOLUTION

In the hereby paper I define a prototype application for building evacuation scenarios. Several enterprise solutions that serve a similar purpose are already designed by Esri and Google, the most eloquent exponents being Google Indoor API and ArcGIS Indoor. What differentiates this initiative from them is the fact it is designed using only free and open-source technologies and requires no additional hardware infrastructure, like sensors or beacons.
The general architecture of the application and the most relevant components are detailed in Figure 1.

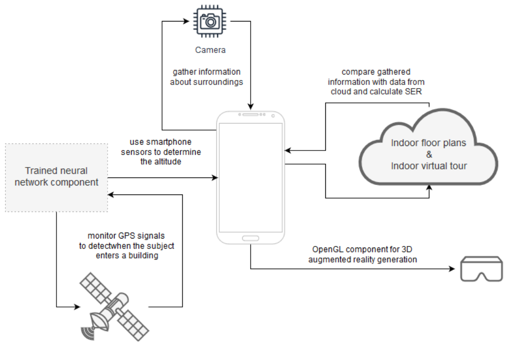

Figure 1. General Architecture

First, the application will integrate an external open-source service developed by Falcon and Schulzrinne [9] that installed on a smartphone uses a trained neural network to notice when someone enters or leaves a building, based on GPS signal intensity changes. Further, using the phone's barometer, the service can determine the exact floor level with almost 100% accuracy.

It is worth mentioning that the accuracy is strongly dependent on the way the machine learning module has been trained and the results are specific to the initial test environment and not necessarily common to a different structure, but for the moment the module is integrated as it is, future enhancements for my actual testing environment being considered.

Second, the development phase required for the architectural floor plans acquisition for the Cybernetics, Statistics and Economic Informatics (CSEI) building together with owners' approval for data manipulation and processing. As some of the information exposed in these plans either provide too many redundant details that only reduce legibility, or does not correspond with the actual room distribution, I have simplified the representation and updated the structure where necessary, using Autodesk AutoCAD, the result being detailed in the figure below.

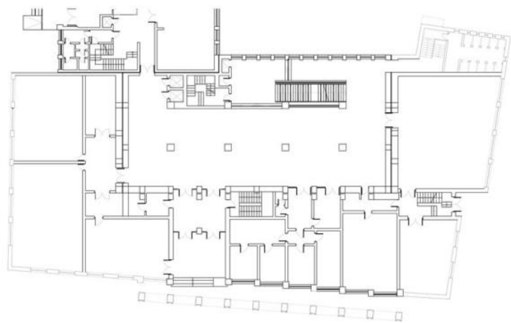

Figure 2. Architectural plan of CSEI ground floor

Starting from the simplified architectural plan, I have extruded the model, generating the building information model (BIM) - a tridimensional representation of the underlying layers that compose the structure. For this purpose, the education community version of Autodesk 3DS MAX facilitated a precise definition of the reference building, providing a comprehensive set of utility functions for creating stairs, windows and doors. The software application is strongly oriented towards modeling, providing a rich library of predefined objects, as well as a complex editing module for custom changes. Moreover, the features included in the educational license were more than enough for a complete definition of the building information model using the CSEI blueprints. In Figure 3 it is represented the BIM for the first floor of the reference structure.

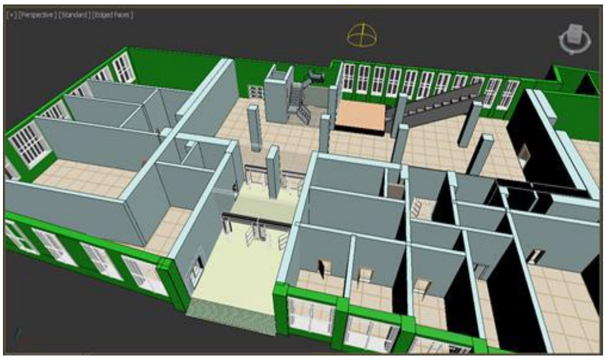

Figure 3. CSIE ground floor building information model

Once the BIM was defined, the next step involved the integration of an effective algorithm that could determine the shortest evacuation route relative to a random initial position. One sensitive detail that had to be considered was the presence of obstacles. The algorithm to be chosen should provide an optimum route without neglecting the walls, pillars or other pieces of furniture.

The research started from an initial hypothesis I have exploited - the floor in the Cybernetics, Statistics and Economic Informatics is divided into squares that are comparable in size with walls' width. This fact allowed me to define a matrix of squares that would overlay the actual BIM, the goal being to facilitate a movement strategy similar to the one in chess.

A first viable solution for finding the shortest route in regards to obstacles is the "cone exit" algorithm defined by Biner and Brun [10]. This approach involves the division of the surface into rectangles and assignment of different weights for each resulting square, depending on the proximity to obstacles or points of interest. Through successive trials, the algorithm decides the optimum evacuation route choosing at each step an adjacent area with a lower or equal weight than the current. Several successful applications of the algorithm involve university amphitheater evacuation using agents in Netlogo. [11] [12]. Anyway, this option involved a detailed analysis of the surface to reasonably assign weights.

Therefore, a second option has been considered.
One of the most obvious choices for this purpose is the well-known Dijkstra algorithm, but the downside of Dijkstra is the lack of a heuristic function and the actual implementation that computes the distance between the current node and any other node in the graph. As our model is quite large, an algorithm that computes any possibility would be both time and resource consuming.

The approach of overlaying a 2D matrix over the actual BIM allowed me to assume a heuristic function of 0s for inaccessible areas and 1s for walkable patches (Figure 4).

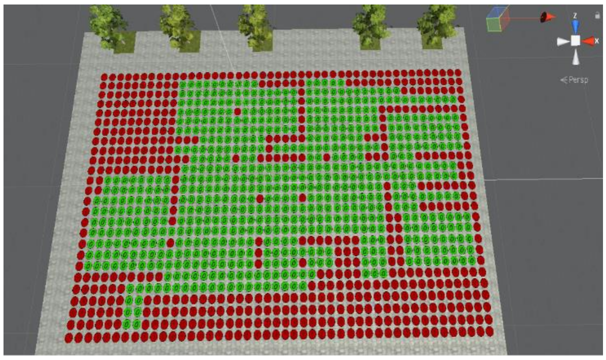

Figure 4. A star matrix

Further, the BIM and the A* matrix have been integrated into Unity 3D Personal – a cost-free platform used to develop games, but which also allows the developer to design virtual reality elements. In Figure 5 the building information model and the weights matrix are presented overlaid.

Figure 5. A* matrix - BIM integration

From Unity 3D the project allows the user to walk through the building and press a key for determining the shortest evacuation route relative to the actual position. The application keeps a hardcoded record of all the possible exits of the building, computes the optimum evacuation route for each exit and guides the user to the closest, instantiating navigation arrows in the right direction.

In the meantime, an extended version of the A* matrix, containing additional metadata about the model, has been deployed in a Firebase cloud database which is connected to an Android application. When the mobile application is launched the neural network service would provide precise geo-location and when the user taps a button, the algorithm would try to identify the current position inside the matrix. Using the stored metadata, the shortest evacuation route will be computed and an augmented reality image labeling system would display arrows on the screen, guiding the user to the nearest exit. To instantiate the guiding arrows, the service uses the camera application to spawn augmented reality objects, a function provided by the ARCore module, available in Android OS since version 27. Capture from an evacuation test performed with the application is detailed in Figure 6.

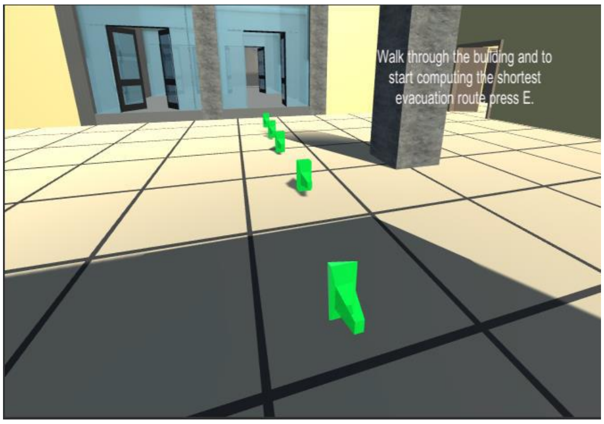

Figure 6. Evacuation demo

CONCLUSION

The current proposed architecture is founded on a comprehensive literature review about emergency mitigation practices and augmented reality solutions designed for such scenarios, particularly in Romania.
The study case, I performed on the Cybernetics, Statistics and Economic Informatics building, provides a step by step methodology for defining an effective evacuation system without acquiring expensive infrastructure, using only mobile phone embedded sensors and open-source services and technologies.
The application might be adapted to also provide guidance to lecture halls or libraries inside the faculty responding this way to a yearly recurrent issue among freshmen – where is my next lecture taking place?

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