Navigation Algorithm for the Evacuation of Hospitalized Patients

E. Iadanza, A. Luschi, T. Merli, and F. Terzaghi

Abstract

The paper presents a model to support evacuation plans design for fire emergency management in healthcare facilities. It relies on existing path analysis algorithms such as Dijkstra and fire propagation simulation, also evaluating the level of criticality typical of healthcare facilities such as patients' speed based upon their illness and admission and architectural structure of wards. The algorithm automatically evaluates the safest evacuation path (which may not coincide with the shortest) for single typology of patient (ambulating, partially-ambulating, completely non-ambulating, auto-sufficient or not) and inpatient unit (ICU, ordinary ward, short-observation unit) in relation to the position of the fire trigger. The results of the algorithm are shown by using SVG-rendered graphic of existing hospital's layout.

Keywords

Fire • Evacuation • Hospital • Care • Navigation

1 Introduction

When it comes to approach the safety evaluation for facilities, there are a series of events which must be considered to prevent workers from accidents and injuries. Prevention and protection in working environment is crucial and all the events which may cause damages to people (and to devices) must be identified, evaluated and eventually corrected. National and international regulations legislate on it and fire emergency is one of the highest and most dangerous aspect. Healthcare facilities like hospitals have a lot of technologies and procedures which involve combustible and oxidizing materials as well as ignition sources (MRI, CT, PET, bovies, thermos-ablation, etc.).

There are two main aspects of fire prevention: the first is about the technical and behavioral applications to prevent the ignition and to eventually detect and then extinguish the fire in its early stage (active protection); the second instead is toward the safe evacuation of the building once the fire has reached the flash-over and active protection has failed (passive protection). During this phase all the people inside the hospital must be safely evacuated, regardless of the reason they were in (physician, nurse, technicians, patients, visitors). However, while internal staff know the structure and how to move through, external people must be correctly led to the nearest emergency exit. Moreover, patients usually cannot walk properly and may need additional help during the evacuation according to their illness: this may imply the transportation of vital support systems and a subsequent decrease of evacuation speed. As a result, the interconnections among different users, speeds, spatial knowledge and spatial configuration lead to congestion issue.

This work aims to develop a consistent algorithm to evaluate the safest evacuation path in case of fire, according to the described factors: typology of user, speed, spatial position of ignition, fire and smoke propagation and congestion.

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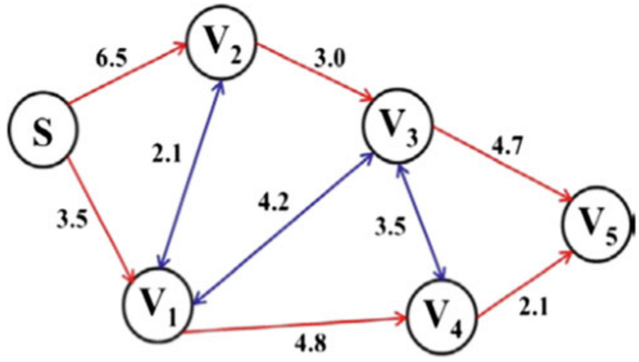

Fig. 1 Example of an interconnected weighted graph

2 Methods

2.1 Shortest and Safest Escaping Route

The first approach is to determine the shortest and safest route from a given point on the evaluated floor and the nearest emergency exit. This can be easily evaluated using a modified Dijkstra's algorithm [1]. An interconnected weighted graph is made on the CAD map of the floor: the weight represents the length of the path and the arrows between two different nodes indicate if the path can be travelled only toward or even backward. Then an adjacency matrix is implemented and used to evaluate the shortest path between a starting and an ending node (Fig. 1).

In case of multiple emergency exits the process is iterated among all the possible ending nodes (exits) and the shortest path among all the shortest paths to each exit is then chosen.

This approach does not take in consideration the spatial localization of the fire and how it is evolving. Therefore, it is crucial that a sensor system is installed on every node (each node represents a room o portion of an alley) and that it can communicate with all the other sensors along the possible escaping paths [2, 3]. The sensor must measure all the parameters that change during a fire such as temperature, humidity, air pressure and smoke density. If one of these measurements overcomes a threshold safety value, the node which the sensor is related to will be excluded from the graph. If the item was still in the group of the usable nodes, then the algorithm re-calculates to find another path which will now not include it. Therefore, the safest path might not be the same as the shortest, because it will result in the shortest path among all the safe nodes, i.e. the ones with all the values below the threshold.

2.2 Speeds

As mentioned above, different users inside a hospital may have different movement speeds according to their illness and therapy they are undergoing. According to the destination of use of a room, together with the activity area of the department which the room belongs to, it is possible to determine the typology of patient and if it is plausible that he could be connected to a vital support system. All these factors affect the average speed of evacuation for that given room which is an input to the designed algorithm according to the following table (Table 1).

2.3 Congestion

The evacuation time increases with the number of persons that must be evacuated and can be assimilable to the flow of a fluid in a hydraulic model [4] according to the formula:

$$t = \frac{N}{D \cdot V \cdot W} \tag{1}$$

where N is the number of people, D is the density of people, V is the speed evaluated at 2.2 and W is the width of the alleys crossed during the evacuation. The time t is in seconds. The total time of evacuation is given as a sum up between the escaping time of the first evacuated person and the rest of the people and must be less than the maximum admitted law values [5].

3 Results

The algorithm has been implemented on the San Luca Nuovo building of the Careggi Hospital in Florence (Italy) [6, 7]. Information about the destination of use and activity for single rooms, together with the expected number of persons (deduced from the number of beds, the time of the day and the scheduled visit program) is taken from the hospital WMS [8, 9, 10]. Pyrosim [11] has been used to simulate the propagation of a fire event and the evolution of the measurement parameters presented in 2.1 (Fig. 2).

Table 1 Different speeds for different types of patient

Subject group (number)	Mean (m/s)	Standard deviation range (m/s)	Range (m/s)	Interquartile range (m/s)
All disabled (*n* = 107)	1.00	0.42	0.10–1.77	0.71–1.28
With locomotion disability (*n* = 101)	0.80	0.37	0.10–1.68	0.57–1.02
No aid (*n* = 52)	0.95	0.32	0.24–1.68	0.70–1.02
Crutches (*n* = 6)	0.94	0.30	0.63–1.35	0.67–1.24
Walking stick (*n* = 33)	0.81	0.38	0.26–1.60	0.49–1.08
Walking frame or rollator (*n* = 10)	0.57	0.29	0.10–1.02	0.34–0.83
With out locomotion diability (*n* = 6)	1.25	0.32	0.82–1.77	1.05–1.34
Electric Wheelchair (*n* = 2)	0.89	–	0.85–0.93	–
manual wheelchair (*n* = 12)	0.69	0.35	0.13–1.35	0.38–0.94
Assisted manual wheelchair (*n* = 16)	1.30	0.34	0.84–1.98	1.02–1.59
Assisted ambuiant (*n* = 18)	0.78	0.34	0.21–1.40	0.58–0.92

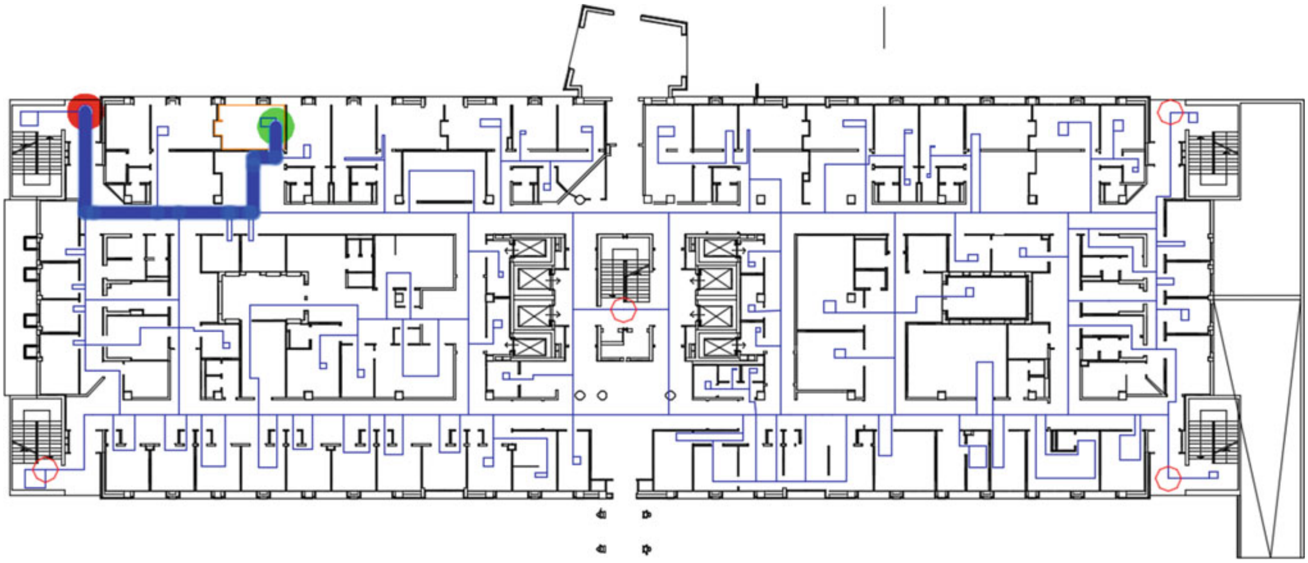

Fig. 2 Shortest route with no fire event in place

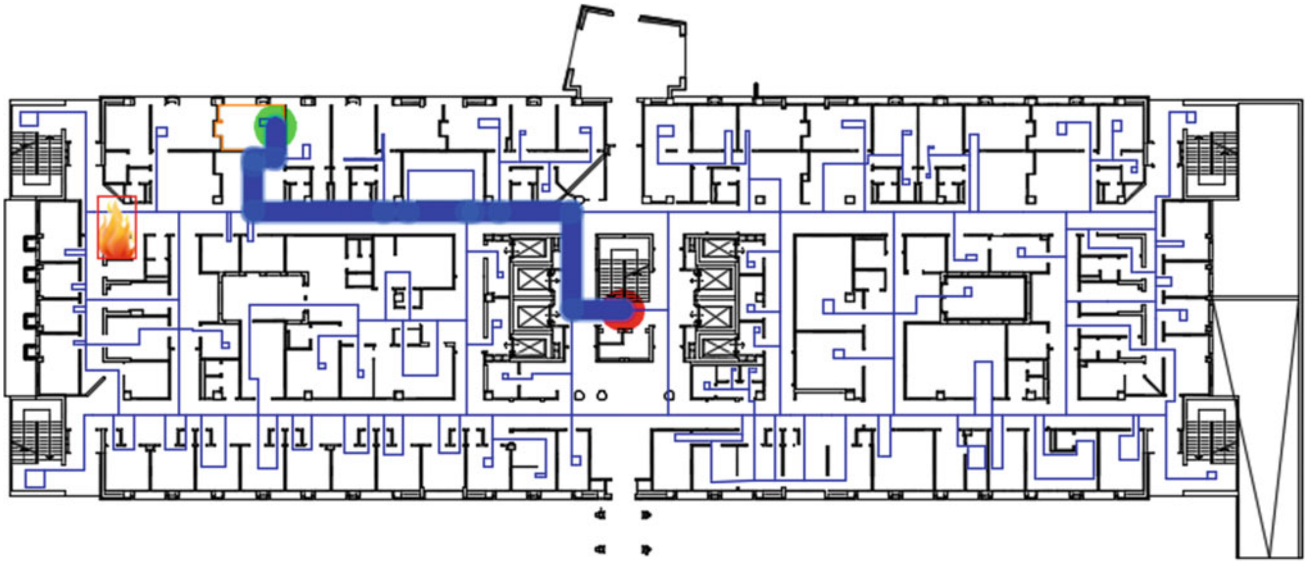

Fig. 3 Shortest safest route with a fire event in place

The starting node is a pulmonary outpatient. The WMS outputs a room surface of 19 sqm with a density of 0.2 person/sqm for the pulmonary ward. Thus, the number of people to evacuate is 4. The average speed is 1.2 m/s. The shortest route is about 30 meters long. According to (1) the average speed is reduced due to congestion to 0.98 m/s. The total escaping time is about 30 s (Fig. 3).

By introducing a fire event with an ignition in a nearby room, the algorithm re-calculates the escaping path because the fire would reach the nearest exiting mode before all the evacuated people (according to the example, all the 4 persons must safely reach the exit). Due to the longest and different path, the congestion parameter will be also recalculated. The new escaping time is about 47 s for a route of about 46 meters.

The escaping times can be compared to the maximum time admitted by the law [5] verifying their matching to the threshold (60 s for a path of 30 m and 300 s for a path of 46 m).

4 Conclusions

The algorithm finds its place of usability both for planning and verifying purposes. In fact, it can be used in development phases to design a correct layout for the emergency exits, and in later analysis to verify the accuracy and the compliance of the evacuation plans. However, the algorithm relies only on mathematical factors which by theirselves cannot fully describe all the human behaviors during a fire emergency. Therefore, the algorithm must be intended just as a decision support system because human validation of the obtained outputs is always needed.

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