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Voronoi diagram with fuzzy number and sensor data in an indoor navigation for emergency situation

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ABSTRACT

Finding shortest and safest path during emergency situation is critical. In this paper, an indoor navigation during an emergency time is investigated using the combination of Voronoi Diagram and fuzzy number. The challenge in indoor navigation is to analyses the network when the shortest path algorithm does not work as always expected. There are some existing methods to generate the network model. First, this paper will discuss the feasibility and accuracy of each method when it is implemented on building environment. Next, this paper will discuss selected algorithms that determine the selection of the best route during an emergency situation. The algorithm has to make sure that the selected route is the shortest and the safest route to the destination. During a disaster, there are many uncertainties to deal with in determining the shortest and safest route. Fuzzy logic can be hardly called for to deal with these uncertainties. Based on sensor data, this paper will also discuss how to solve shortest path problem using a fuzzy number.

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1. INTRODUCTION

Offices and public buildings in many ways are vulnerable to disasters. Fire and earthquake may happen anytime without prior notice. In such a situation, excellent support in decision-making is of critical importance to react accurately, fast and effectively [1] in finding the safe exits. The ultimate purpose of the support system is to avoid any casualties, either the inhabitants or the rescuers. For instance, in case of a fire, some people may be trapped and have difficulties in finding emergency exits to a safe place. This scenario becomes apparent that there is a critical necessity to find a solution to this challenging task and an indoor navigation model that provides routes to safe paths is the best solution.

There are two main research areas when working on indoor navigation; tools and methods. The former concentrates on the hardware such as facilities and sensors to provide position information in the disaster areas. The facilities include the signages and special landmarks that could help the victims to find the directions to safe exits through observation. Meanwhile, navigation sensors such as radar [2-4], inertial measurement units [5] or wireless positioning technologies [6] provide details information to the victims or rescuers about their current positions with respect to defined reference in the building. The latter focuses on the navigation models which study the optimal waypoints to the nearest or the fastest ways to the safe exits.

This work normally integrates intelligent systems such as Bayesian filter [7-9] or fuzzy to obtain the best solution for specific conditions.

In this paper, an indoor navigation model to find the safe exits has been proposed based on the network model known as Voronoi diagram with fuzzy number. The existing network models have been studied and the comparison showed the Voronoi Diagram was best suited for the emergency situations. Then, the most suitable shortest path algorithm was picked. Since there is a lack of literature which discussed indoor navigation for an emergency with the network model and the shortest path algorithm, the aim of this study is to build and test indoor navigation for an emergency with the Voronoi diagram and the shortest path algorithm. Our proposed combination of network model and the shortest path algorithm has achieved the intended goals, that to find the shortest and safest routes during emergency evacuation. The resident is supposed to obtain appropriate information which could lead them from one area into other spots up to they attain the refer secure place through this model. The route direction idea on indoor navigation shall examine several elements [10] including a particular building map database model, the human redeployment movement and any typical requirement to a user.

2. 3D GRAPHICAL MODELS

Design plan inherited by mainly the map databases build upon 2D graphical visualization [10]. X3D for 3D visualisation which is 3D graphics standard or its predecessor virtual reality modelling language (VRML) is another way to represent the map databases [11]. Yet this model has a shortcoming which it could not specify the semantics of a given building. Solid learning of map objects is needed than only their topological relationship to propose a navigation view of a building [10]. CityGML, industry foundation classes, and green building XML models may resolve this problem. Explained by [12], these models combination may be used to represent the building fabric into deeper model, which include a geometrical model and a logical model. Extraction of a clear path to guide the route is hard if only applying a geometrical model. Consequently, since the logical model may be projected with ease, then this model is selected to use from a route node to another node [12]. Likewise, the map depiction shall be in the 2-dimension model to produce route guidance shortly. To make a decision in exigence circumstances is not adequate if only employed the building spatial information. Several supplementary deliberations shall be highlighted in the process to assist well decision-making.

3. NETWORK ANALYSIS

To choose the optimum route for emergency circumstances on indoor navigation in this study, we proposed a network design and developed although investigate and simulate existing shortest path algorithm. Three network models, i.e., adjusting line algorithm [13], Voronoi diagram [14], and Quadtree [15, 16] have been analysed as input for shortest path algorithm, combined with link cost, to generate evacuation guidance. Based on available network models, we have noticed, on the one hand, Quadtree has a drawback i.e. fall through in velocity consequence of peak complexity. However, it has good accuracy since this model is highly specified. Furthermore, "move into corridor" is adopted by adjusting line algorithm and Voronoi diagram is simpler and faster than Quadtree. Nevertheless, between all the networks, adjusting line algorithm has the worst network accuracy than the other. Hence, based on speed and accuracy, the Voronoi diagram is the prime selection for the network model. This diagram represents a subdivision of space into regions whose points are closer to a generating vertex than any other element. Centerline algorithms using the Voronoi diagram begin by sampling the polygon boundary and constructing the Voronoi diagram. The intersections between the Voronoi edges converge to the polygon centerline, as the boundary sampling rate is increased. One problem with this method is the difficulty in joining centerline segments from separate but adjacent hallway polygons.

4. SHORTEST PATH ALGORITHM

Having chosen the network diagram, the next logical step is to choose the best shortest path algorithm for this indoor navigation. Five algorithms, i.e., Dijkstra [17], Floyd-Warshall [18-20], A* Search [21], Bellman-Ford [22], and Johnson’s [23] have been taken into consideration in this project. A* Search is the best shortest path algorithm which could provide the top accuracy. It works mechanism based on Euclidean distance to the destination node sans forecasting the entire network. Hence, there possibly some cases whereupon the optimum route would be displaced. Furthermore, Floyd-Warshal algorithm is weak in consequence of n3 complexity. To calculate the optimum route, Dijkstra, Bellman-Ford and Johnson’s algorithm might be great preferences. Nevertheless, the Dijkstra algorithm has a better achievement than the others. We don't employ negative weights from Dijkstra in our study since it might collapse dealing on negative link cost.

5. RESEARCH MODELS

Figure 1 shows the research model on the safest and shortest route. The network model is produced by network analysis from a 2D building environment transformation. For producing the evacuation directive, on the shortest path algorithm, this network model conjoined with a link cost as an input. Based on the building form through the emergency period which is described with a fuzzy crisp number, the link cost is seriously influenced by this condition. This part of the paper discusses how the shortest and the safest route is defined. The main consideration of route guidance during the emergency time is speed and accuracy. In term of speed, the route guidance must be generated fast and very adaptive to network condition. Next, the shortest route is not always the safest route during emergency time. Therefore, in term of accuracy, the generated route must avoid dangerous places. Each edge of the network is represented by membership function that considers many factors during the disaster. It is generalised based on the canonical representation of operations on fuzzy triangular numbers to define the shortest route. This method is more efficient because the summing operation and the ranking of fuzzy numbers can be done in an easy and straight manner. Speed and accuracy are parameters that may be involved in determining the calculation of safest path. The selection is based on the reuses of the existing algorithm and as well as based on technical analysis and economic consideration.

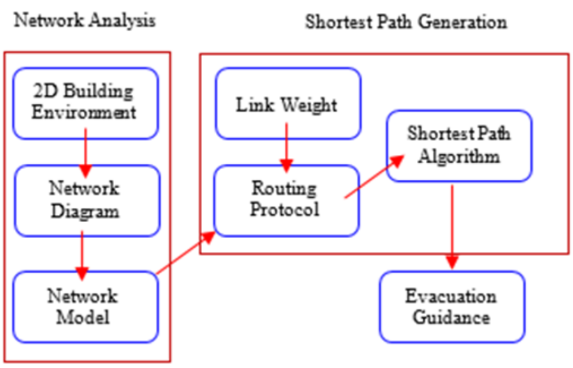

Figure 1. Effects of selecting different switching under dynamic condition

6. RESULTS

The following presents the results of our analysis and design which started from pre-processing building map, generating building network, and generating shortest path. This section is intended to provide insight into the whole processes of generating, facilitating and building the possible network topology including the possible network path. From this, it allows to develop a network topology table in which all different possible route or path analysis can be performed.

6.1. Pre-processing building map

For testing, we had used map of the ground floor of Zone A and B, Faculty of Information and Communication Technology, Universiti Teknikal Malaysia Melaka. The map was provided by Pejabat Pembangunan Universiti Teknikal Malaysia Melaka. The initial format of the map is in AutoCAD data. We had chosen PostgreSQL/PostGIS to store the data. To Test the data, we had used QGIS Desktop because it can store and retrieve data from PostgreSQL/PostGIS and used spatial analysis tools from PostGIS combined with pgRouting.

6.2. Generating building network

The building network can be generated by performing some steps. From the base map, we had created a polygon which represents rooms and accessible areas of the building as shown in Figure 2. After creating the polygon, we created a Voronoi diagram using ST_StraightSkeleton function from PostGIS. The result can be seen in Figure 3. Next, we created network path by cleaning up lines which have no intersection in one of their vertex (dead end) as shown in Figure 4. Lastly, we created a network topology in a database using the pgr_createTopology function from pgRouting. Network topology's table is shown in Figure 5. The cost and multiplier column will define the link cost. In the event of disaster, very unlikely that the victims have sufficient time to response in appropriate manners. Many cases the victims will not be able to assess their situations properly, in order to minimize the damage from the disaster. For examples, in the event of fire, victims should feel the doors with the back of hand before opening them, which if they are warm, then the fire is on the other side. In the actual situation, victims are rushed to find the safe exits, thereby there are possibilities that they endangered themselves by entering the fire area unintentionally. In this regard, there is a need to use sensors to sense the disaster's surroundings to manage the risk of injury or casualty.

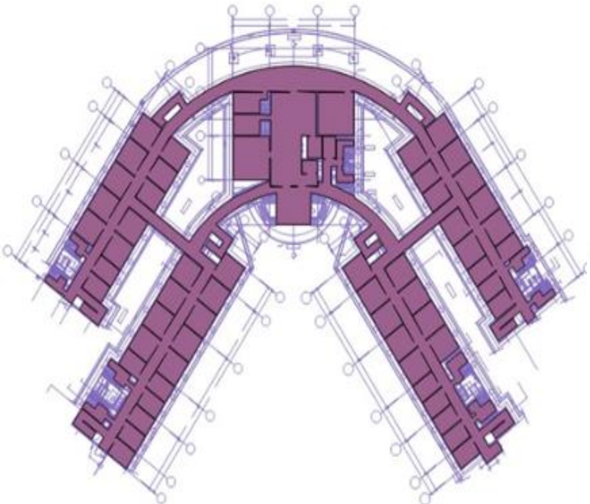

Figure 2. Building polygon

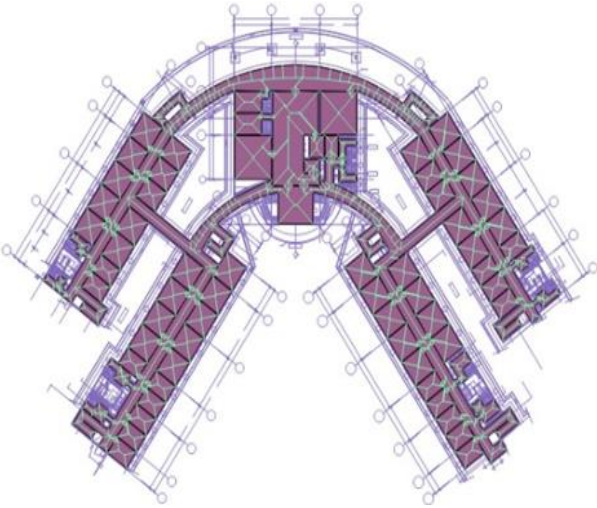

Figure 3. Voronoi diagram

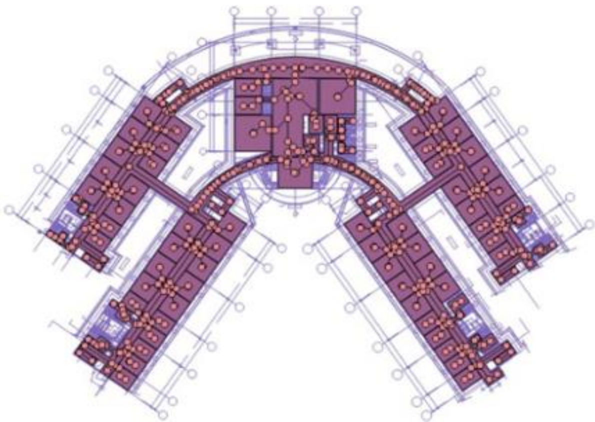

Figure 4. Network path

	gid [PK] serial	lines geometry(LineString,4326)	source integer	target integer	cost double precision	multiplier double precision
1	1	0102000020E61000000200000049564AA8251B35C109F8C1838E9335416006790BD51F35C15C257B20DF8E3541	1	2	1696.1902320802	1
2	2	0102000020E6100000020000003CE774BD251B35C1D7F6C4838E933541F63809D2D51F35C15ADA07E7DF8E3541	3	4	1696.13215562875	1
3	3	0102000020E610000002000000ECF9A9C8032234C10C3D15F012313541D07D9FD30A2234C15EC8F30A22313541	5	6	16.6661609013465	1
4	4	0102000020E610000002000000D07D9FD30A2234C15EC8F30A22313541E681FCC51B2234C13C8F54181A313541	6	7	18.7178610639647	1
5	5	0102000020E610000002000000D07D9FD30A2234C15EC8F30A22313541D07D9FD30A2234C15EC8F30A22313541	6	6	0	1
6	6	0102000020E6100000020000002E29FA8D01EB34C1D0529B2B54DB35413CD054BA3EED34C1DCFC77F452DB3541	8	9	573.174546823727	1
7	7	0102000020E610000002000000E681FCC51B2234C13C8F54181A3135414453760F7A2534C1EC44295B1B323541	7	10	899.845624745564	1

Figure 5. Network topology table

The use of suitable sensors will provide a better evacuation guidance. In an indoor environment, among possible disasters to dealt with are fire and explosion. In explosion, there is a high chance that it will cause a fire as well. Therefore, in both events, smoke and heat sensors can be installed to check the surrounding. In a compact version, both sensors can be enclosed together as a single unit, called as a node, with wireless connectivity such as Wi-Fi, Bluetooth or IEEE 802.15.4 standard. In this work, IEEE 802.15.4 is preferred because of the low power consumption. These nodes can be connected in a mesh network with a gateway to the internet. Each node will check the presence of smoke and measure the surrounding temperature (in Celsius), in 30 seconds interval. Every interval elapsed, the data will propagate until it reaches the gateway, which will send the data to the cloud. The data payload is 1 byte as shown in Figure 6.

Bit-7	Bit-6	Bit-5	Bit-4	Bit-3	Bit-2	Bit-1	Bit-0
0: no smoke 1: smoke detected	Upper decimal value of temperature. Range from 0-7.			Lower decimal value of the temperature. Range from 0-9.			

Figure 6. Data payload

For instance, at ambient temperature (27C) without presence of smoke, the payload will be 27h (0010 0111) and if smoke was presence, and temperature rise to 45C, the payload will be C5h (1100 0101). The timestamp will take 8 bytes and another 1 byte is for the location ID. In overall, the payload has a size of 10 bytes. The data propagates from the source to the destination, gateway, through Ad Hoc on-demand distance vector (AODV) routing protocol. One of the advantages in using AODV is it can respond very quickly to the topological changes that affect the active routes. This is crucial especially if the nodes happened to damage during the disaster, the communication between other nodes to the gateway will not be interrupted.

The data that reached the gateway will be stored in the global server such as cloud. The server will detect any anomaly and send emergency notification to the affected users. At the same time, the server will request the sensor data more frequent from the nodes, in every 10 seconds. This is another practical justification to adopt the AODV which the main advantage of this protocol is that routes are established on demand. The emergency notification contains information of level of disaster and location of disaster. In the Figure 1, the building equips with a number of nodes that are connected in mesh. Every node will report to the gateway at the specified interval and the gateway sends the information to the server. In case of fire, in the proximity of node 1, as illustrates in the figure, the server detects the disaster by observing a rise in temperature. The server sends emergency notification to the users in the building to leave and avoid that particular area. The presence of smoke and high heat will give a red alert and can represent as constraint value in order to determine the shortest and safe path based on Dijkstra algorithm.

6.3. Generating shortest path

– Shortest path without constraint

We use Dijkstra algorithm to find the shortest path to the exit. Dijkstra shortest path is performed by calling the PGR Dijkstra function from pgRouting. The parameter for this function is source node, target node and cost. Link cost is calculated by multiplying cost and multiplier field. The result is presented in Figure 7.

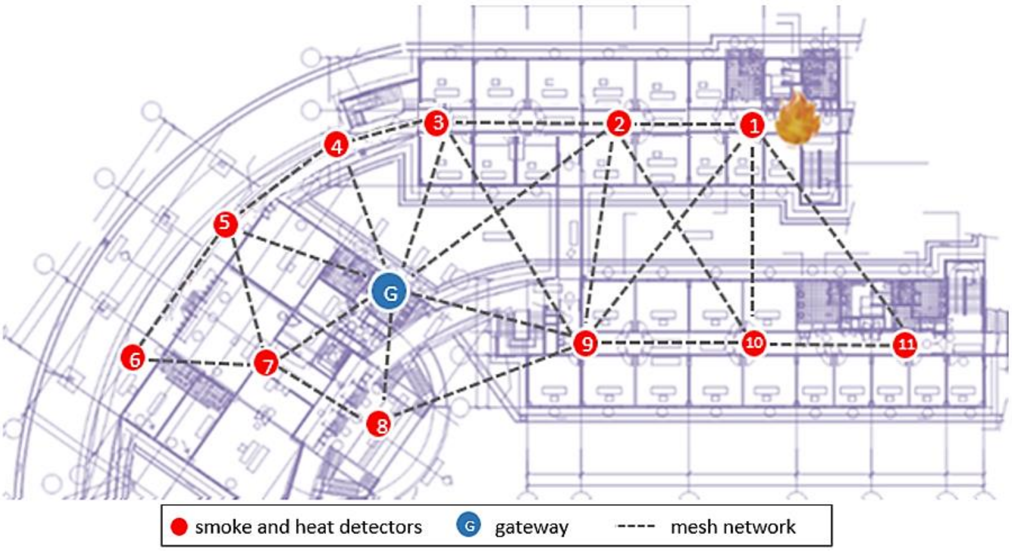

Figure 7. Fire at an established disaster management setup

– Shortest path with constraint

To set constraint, we set multiplier field on the database. To define the hazard area, the multiplier value is set to 99999, as shown in Figure 8. Next, we performed the Dijkstra shortest path to select the best exit as we did without constraint. The result can be seen in Figure 9.

Each node will check the presence of smoke and measure the surrounding temperature (in Celsius), in 30 seconds interval. Every interval elapsed, the data will propagate until it reaches the gateway, which will send the data to the cloud. The data payload is 1 byte as shown in Figure 10. The emergency notification contains information of level of disaster and location of disaster. In the Figure 7, the building equips with a number of nodes that are connected in mesh. Every node will report to the gateway at the specified interval and the gateway sends the information to the server. In case of fire, in the proximity of node 1, as illustrates in the figure, the server detects the disaster by observing a rise in temperature. The server sends emergency notification to the users in the building to leave and avoid that particular area as shown in Figure 11. The presence of smoke and high heat will give a red alert and can represent as constraint value in order to determine the shortest and safe path based on Dijkstra algorithm.

	gid [PK] serial	lines geometry(LineString,4326)	source integer	target integer	cost double precision	multiplier double precision
604	604	0102000020E61000000200000004C086998E5234C1F2ECA3A54EB6344104C086998E5234C1F2ECA3A54EB63441	453	453	0	1
605	605	0102000020E61000000200000008A19D0DE625234C14E4D16CBC6B634418A19D0DE625234C14E4D16CBC6B63441	25	25	0	1
606	606	0102000020E61000000200000008A19D0DE625234C14E4D16CBC6B634418005EA7DF35034C1B26E322AB8BA3441	25	254	1074.1498267446	99999
607	607	0102000020E61000000200000008005EA7DF35034C1B26E322AB8BA3441F03FB3CA124A34C178380AAF9DCD3441	254	244	5147.97571485107	1

Figure 8. Set multiplier to define hazard

Figure 9. Shortest path with constraint

Bit-7	Bit-6	Bit-5	Bit-4	Bit-3	Bit-2	Bit-1	Bit-0
0: no smoke 1: smoke detected	Upper decimal value of temperature. Range from 0-7.			Lower decimal value of the temperature. Range from 0-9.			

Figure 10. Data payload which send to the cloud

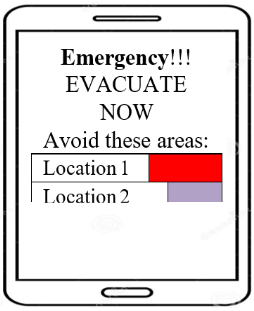

Figure 11. Emergency notification

7. DISCUSSION

From sub-section 3 and 4, it becomes apparent that the existing model and algorithm have pros and cons to produce the shortest and safest route. Based on this strength and weakness analysis, we propose a hybrid shortest and safest route algorithm which is a combination of Voronoi diagram and Dijkstra algorithm using a fuzzy number. The proposed indoor navigation model had successfully provided the shortest path to the safe place while considered the hazardous area such as fire. Currently the constraint that set as the hazard was fixed in the simulations. However, the value can be dynamically changed if more information from the surroundings were available. The potential hazards such as heat intensity can be sensed through temperature sensor that could provide spectrum of dangerous zones; low heat, medium heat and high heat. The humidity sensor also can be used to check the intensity of water vapour in particular areas. In the fire case, high humidity areas would engulf in flames slower compared to dry places. Therefore, with reference to the temperature and humidity spectrums, the algorithm could accommodate less risk situations when computing the shortest as well as the safest routes to exit. Apart than that, the model could integrate with navigation sensors to exactly determine one's position with respect to the building. This is imperative as wrong position would lead to fatal decision when determining the shortest path. One of the best options for positioning and tracking the victims is by using device free localization (DFL) technique [24]. This technique does not require the user to wear any tracking device on the body, which is essential in time-critical situations. One of DFL methods that could be applied is known as radio tomography imaging (RTI) [25]. The RTI system will determine the signal disturbance detected during radio transmission between the wireless nodes that are fixed along the corridors as the potential human presence. Through this model, occupants are expected to get accurate information that can guide them from one room to another until they reach designated place. More importantly, the route generated must be not only be short but also safe.

8. CONCLUSION

An indoor navigation model using sensor data has been proposed and aimed to standardise and investigate methods and algorithms for navigation in buildings. An inclusion of Voronoi diagram combined with a classic Dijkstra algorithm gives a significant early result especially in term of speed and accuracy. The combination is considered to be complementary to each other to produce a better result. Fuzzy numbers can be used to deal with the uncertain environment. However, this hypothetical conclusion needs to be validated with a set of experiment and testing. The criteria for generating membership function of the fuzzy set must be studied as well in future works.

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