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Research paper

Design of an Indoor Disaster Routing Protocol

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Abstract

Background/Objectives: We suffer a lot of casualties every year from some disaster situations, such as fire or gas leaks that occur indoors. The research is needed to minimize the harm of disaster.
Methods/Statistical analysis: When the disaster happens, the evacuation route changes every minute due to obstacles or dangerous situations. To solve this problem, we must collect map data and sensor information periodically. Then this information is used to calculate the evacuation route. In addition, the sensor data of the node transfer to a server in order to utilize the prediction of evacuation path using the RNN.
Findings: In many developed countries, a lot of research are launched to prevent disasters rather than response when the disaster occurs. However, guiding evacuation routes in real situations is an aspect of the disaster response, which requires disaster sensor data. In addition, in a disaster situation, some areas cannot go through by people due to fire or gas leakage. In order to efficiently guide the evacuation route, techniques for producing a map in real time and sensor (actual and predicted) data are required. At this time, the map data is converted into the topology map by using the image obtained through the SLAM technology, and the sensor data predicts the next value based on the previous data through the RNN (using the sensor data to predict). Consequently, the proposed Routing Protocol in Indoor Disaster (RPID) guides the evacuator to a path with a short cumulative damage amount.
Improvements/Applications: Depending on the routing protocol used in the simulator or the technique of locating the user's location information, we can develop an evacuation system which can help victim find a safe way to escape as fast as possible from the dangerous situation.

Keywords: Indoor Disaster, IoT, Routing Protocol, Indoor Geospatial Information, SLAM, RNN

1. Introduction

Over the past century, millions of people have moved to larger cities as demand for better income and convenience has increased. The metropolis has developed architectural skills while meeting the needs of these people. In recent years, together with science and technology, a hybrid building has been constructed in which not only one type of residence but also a variety of shops are located in one building.

We spend 80-90% of our time indoors, and as more large buildings and complexes become available, the time spent indoors will increase[1]. As a result, the disaster situation in the building also occurs every year, leading to increase the damage of human and property.

In most countries, Public Protection and Disaster Relief(PPDR) have been operating in response to disasters that can cause numerous casualties[2]. Conventional PPDR have been using voice-oriented narrowband communication due to their technical limitations. Recently, disaster situations have become complicated and scientific technology has developed, they have evolved into broadband communication capable of transmitting not only voice but also moving images or messages[3]. However, it is still in the development stage and there is a shortage of commercialization terminals[4].

In order to apply PPDR in indoors, various related organizations such as police and hospitals and Field Command Post need to be constructed. In addition, in order to perform smooth rescue activities, the inside of the building should be grasped. Accordingly, it is very costly and time-consuming to directly apply the disaster communication infra to the indoor. As a result, the investigation of evacuation of disaster is necessary, that focuses on preventing and responding to disasters in the building itself is increasing, and evacuation drills and research are being conducted separately.

In the case of a fire incident, there is a lot of casualty damage caused by suffocation (more 2nd harm damage), rather than a human injury caused by a fire (1st harm damage)[5]. In developed countries such as the United States and the United Kingdom, the egress simulator, a computer application, is being studied to reduce casualties caused by these disasters[6]. This simulator is prepared for evacuation drills and disaster prevention. However, most simulators do not take into account information about the accident site when a disaster occurs, which can lead to many problems in guiding the evacuation route[7].

In a disaster situation, the evacuee can be mentally or psychologically disturbed by the evacuation fatigue. This causes delays in the evacuation process and accumulates disaster damage. This can result in casualties. An efficient evacuation path that minimizes this problem is a route that is fast from the current location of the evacuator to the destination and has a small cumulative damage.

In this paper, we introduce a disaster response routing protocol and a simulator that can guide a rapid and safe evacuation route, assuming that a disaster occurred in a building where IoT / WSN is built.

This paper is organized as follows. In Section 2, we discuss related works. In Section 3, we introduce the structure of the proposed system and the routing protocol that guide evacuation path. Finally, section 4 is conclusion.

2. Related Works

2.1. Egress Simulators

There are many egress simulators that guide evacuees on the inside of the building. Building EXODUS, which simulates the behavior of pedestrians and reproduces various situations (bottlenecks, congestion, etc.) in the event of a fire, and Pathfinder, which can represent the movement of pedestrians and analyze bottlenecks. Most of these disaster simulators are used for evacuation drills or bottleneck detection purposes for evacuation safety tests. Therefore, when an actual disaster situation occurs, there is no information on the disaster situation, and it is difficult or time-consuming to derive the evacuation route.

2.2 Indoor Map Data

2.2.1. System Structure

Recently, modern people have become able to do various activities indoors as the buildings become bigger and more complicated. Due to the demand for better convenience, many IT services are being developed for the purpose of helping people to perform activities indoors. One such research area is indoor spatial information service.

Unlike outdoor, the indoor environment is made up of various geometric spaces. In order for a person to move from one point to another, in most cases they cannot move directly. In other words, to calculate the travel distance between any two points, it should not be calculated by the Euclidean distance method. As shown in figure 1, when we move from arbitrary point A to point B, we have to go through a hallway or a door in the middle.

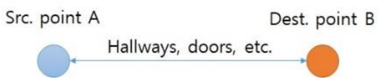

Figure 1. Moving path between two points

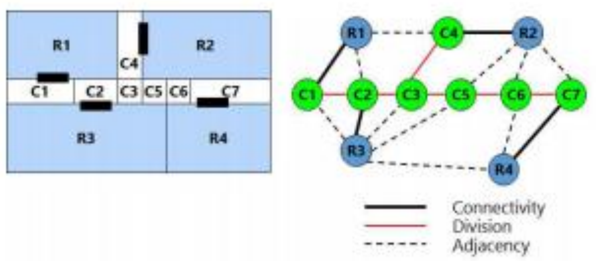

Figure 2: Example of Topology in Indoor Space

In figure 2, it shows a complex topological representation of the interior space[8]. This can simplify complex and enormous interior space through graph theory. The information about node V and edge E about the graph G = (V, E) can be expressed as follows.

$$\boldsymbol{V} = \{\boldsymbol{n} \mid \boldsymbol{n} = (\boldsymbol{C_{ID}}, \boldsymbol{p}, \boldsymbol{attr})\} \quad (1)$$

$$\boldsymbol{E} = \{(\boldsymbol{n_s}, \boldsymbol{n_e}, \boldsymbol{attr}) \mid \boldsymbol{attr}: \boldsymbol{distance}\} \quad (2)$$

Here, the node set V includes the node ID, represent coordinates, and attribute information indicating a wall or a door, a room number, a hallway, and the like. The edge set E includes IDs of a pair of adjacent nodes and distance. In this paper, we focus on hallways that can be used as evacuation routes.

2.2.2. Indoor Simultaneous Localization and Mapping

As our indoor activity time increases, it many studies on SLAM technology (unmanned cleaners, personal secretaries, etc.) as well as indoor spatial information services. In addition, research on disaster robots, which are placed in areas that are not accessible by human beings or are located before humans, are also to be conducted.

All paths exposed to the ever-changing disaster situation(obstacles and high gas concentration, etc.) can be used as an evacuation route or disappear according to the situation. This information is a factor that can have a lot of influence when guiding the evacuation route. Therefore, in order to efficiently derive the evacuation route, it is necessary to periodically collect the map data as well as the sensor data collected at each point.

In order to use the 2D image obtained through the SLAM technology in the disaster response simulator, it is necessary to convert it into the topology form through the graph theory. At this time, each area can be subdivided through Convex hull algorithm[9] or Voronoi diagram[10]. The partitioned segmentation sets that represent the coordinate as shown in Equation 1 and is assigned each attribute value. Then, by connecting all the adjacent segments according to Equation 2, the topology map on the right side of figure 2 is formed.

2.3. Routing Protocols for Indoor Disaster Situation

The basic algorithm of the proposed RPID considers the keywords "indoor" and "indoor disaster"; IoT / WSN routing protocol used in indoor environment and Routing protocols used in previous studies of indoor disaster situations;

There are many routing protocols studied for IoT or WSN environments. However, most routing protocols are designed with free space assumed. Therefore, a routing protocol considering indoor environment is needed. In addition, the nodes used in IoT / WSN have limited resources (computing power, low memory, etc.), thus establishing a low-power and lossy network environment with poor communication link quality. In order to build a network constructed with these resource-constrained wireless nodes in indoor, IETF has announced RPL[11].

In a disaster situation, based on bidirectional communication link, communication between the Field Command Post and rescue personnel, communication among rescuers, and communication with the evacuees should be considered. In this case, as the communication structure, a communication node established near the field command post is set as a root node, and each rescue person forms a topology as a terminal node[12, 13].

All nodes capable of communicating in the WSN periodically transmit the collected information to the base station. Even in a disaster situation, a sensor node other than a node exposed to a disaster situation or unable to communicate should can transmit data toward a base station. Similarly, in disaster situations, evacuees should be guided to the fastest and the least damaging route. Therefore, the route to send the sensor data to the base station can be regarded as a route to guide evacuees to the escape path.

In consideration of the indoor environment and the disaster environment, we selected a tree-based routing protocol and a proactive routing protocol as types of routing protocols. Also, considering the characteristics of the WSN to be transmitted to the base station (ROOT) node to connect with the external network, we form a topology that regards the destination EXIT node as the root node.

2.3. Predicting Indoor Disaster Information

RNN, one of the deep learning fields, is being adopted in various fields as a predictable model for time series data (sensor data, speech, languages) whose current value is influenced by the previous value. The RNN has previous results and is easy to learn sequential data. However, since the initial RNN has an activation function (sigmoid) having a value between 0 and 1, it has a disadvantage that previous data cannot be efficiently learned as time passes. A variety of modified RNN models have been studied. Recently, Long-Short Term Memory (LSTM) and Gated Recurrent Units (GRU) have attracted attention[14].

To guide the evacuee to a fast, low-risk route, you need to identify disaster information for all (relay) nodes that need to travel from their current location to their destination. However, collecting the sensor data every moment and deriving the evacuation route has many problems in terms of time. Therefore, if a future value is predicted based on previously collected sensor data, it should can be used to derive the evacuation path.

3. Proposed Indoor Disaster Response Simulator

3.1. Overview

In this paper, in figure 3 shows the overall structure of the system proposed. The system consists of three subsystems.

The real - time indoor map production system forms a topology map based on the images collected from the robot as mentioned above. The topology map consists of information about each vertex and edges information about adjacent vertices. Based on the map information, it is converted into JSON format and transmit to DATABASE through the web server.

The disaster data collection system refers to a WSN network having a hierarchical topology in which a node installed at an entrance is a ROOT node. Information collected from each node is periodically transmitted to the DATABASE through the EXIT node through the Web server.

An indoor disaster response simulator is an evacuation route guidance simulator that guides evacuation routes based on indoor map data and sensor information stored in DATABASE. A graph is formed based on indoor map data as well the topology map. In figure 4, it is a design drawing for an arbitrary target building, and figure 5 is a topology map formed hallways that can be used as an evacuation routes.

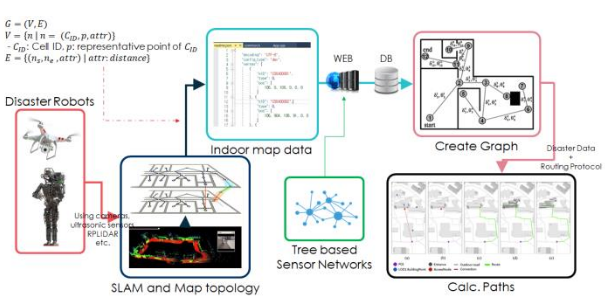

Figure 3: Overall structure of the proposed system

Figure 4: Design drawing for any target building

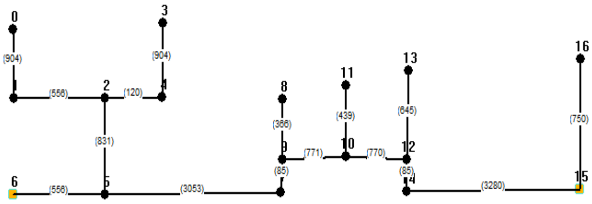

Figure 5: The topology map about the target building

3.2. Routing Metrics Considering Real-Time Disaster Environment

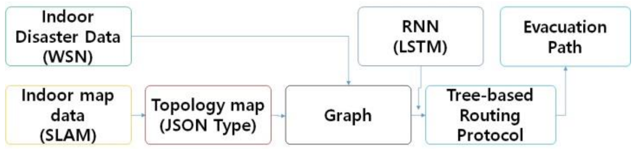

Figure 6: Flowchart of Indoor Disaster Response Routing Protocol

In figure 6, it shows a flowchart of the proposed RPID focusing on the disaster environment. The research on most routing protocols proposes the concept of routing protocols through graph theory, and compares them with existing routing protocols using the metrics. On the other hand, the routing protocol proposed in this paper that derives the evacuation path considering the real-time environment based on indoor map information and sensor data.

In the proposed routing protocol, the value of the sensor data is predicted through the RNN technique and it is decided whether the adjacent route can be performed (possible, impossible, temporary) as the evacuation route. In this case, temperature and gas concentration data used in Indoor Air Quality[15] are used for each node.

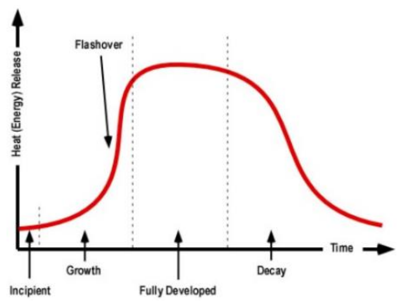

Figure 7: Fire Development in a Compartment

In figure 7, it shows the growth pattern of fire according to time[16]. At this time, evacuation must be done before Flash-Over occurs. Fire temperatures are much lower in open areas than in enclosed areas, but reach as low as 320 degrees[17]. However, most temperature sensors can only detect temperatures up to 60 to 90 degrees, and people over 40 degrees cause health problems due to heat stroke and the like[18]. Therefore, it can be applied to derive the evacuation route by changing the weight for the path according to the temperature as shown in figure 8.

In figure 9, it shows the effect on the human body according to the usual CO2 concentration[19]. In some countries, it follows the recommended indoor concentration (1000ppm) by ASHRAE and WHO. However, since disaster conditions increase the temperature and humidity information and fatigue, they also have to be weighted according to the concentration.

W.	Temp.	Description	Note
.1	~ 25.6	23.3℃ ~ 25.6℃ (Standard 55)	ASHRAE
.2	~ 40	Temperature at which heat stroke can occur	
.5	~ 60	Early in the fire or nearby fire	
.9	60 ~	Max. temperature the temperature sensor can collect	

Figure 8: Metric weights according to temperature

W.	PPM	Symptom	Note
.1	~450	Level with healthy ventilation management	Korea, Japan, WHO Europe, ASHRAE, Singapore
.2	~700	Indoor level that does not have health problems even though it is a long time	
.5	~1000	Level with people who do not have health damage but feel uncomfortable	
.5	~2000	Level at which the condition changes such as feeling drowsy	USA
.75	~3000	Levels at which health problems begin to occur, such as people experiencing shoulder stiffness or headaches.	
1	3000~	Headache, dizziness and symptoms such as the emergence of long-term health level	

Figure 9.: Influence on human body by CO2 concentration and metric weights

$$\boldsymbol{min} \sum_{i=0}^{m} (N(\widehat{T}_i) * N(\widehat{G}_i) + E_i^x) \quad (3)$$

Here, m represents the number of hop count from the current position of the evacuees to the EXIT node. Value $\widehat{T}_i$ and value $\widehat{G}_i$ are predicted temperature and gas concentration data, respectively. Temperature data and gas concentration data have values of different size. When calculating the evacuation route, the amount of change in the gas concentration data can be influenced more than the change in the temperature data.

The function N is a normalization function with a value between 0 and 100. For example, it is a function that calculates the minimum and maximum values of the temperature data as 0 and 100, respectively, and converts the temperature data to a value between 0 and 100. With this normalization, temperature data and gas concentration data can be applied with equal weight when deriving the evacuation route.

Value E_i^x represents the risk for surrounding nodes that are x hops apart for each relay node. This value refers to the metric value that has undergone the normalization process mentioned above. The fire spreads due to several causes (conduction, convection, radiation, etc.). However, the farther away you are from the hazard area, the less damage you have to disaster. In other words, when a disaster occurs in a neighboring node, the nodes are also exposed to a disaster. Therefore, not only the prediction information of the nodes from the current position of the evacuator to the escape route but also surrounding information about all the nodes included in the route should be grasped and applied to the evacuation route as well. The metric value be expressed as Euclidean Distance Matrix as shown in figure 10 and the EXIT node with the lowest metric at the current position of the evacuees should be guided to the final destination.

0	904	2483	1460	1580	2291	5344	5429	5795	6200	6639	6970	7615	7055	10335	11085
904	0	1579	556	676	1387	4440	4525	4891	5296	5735	6066	6711	6151	9431	10181
2483	1579	0	1023	903	1854	4907	4992	5358	5763	6202	6533	7178	6618	9898	10648
1460	556	1023	0	120	831	3884	3969	4335	4740	5179	5510	6155	5595	8875	9625
1580	676	903	120	0	951	4004	4089	4455	4860	5299	5630	6275	5715	8995	9745
2291	1387	1854	831	951	0	3053	3138	3504	3909	4348	4679	5324	4764	8044	8794
5344	4440	4907	3884	4004	3053	0	85	451	856	1295	1626	2271	1711	4991	5741
5429	4525	4992	3969	4089	3138	85	0	366	771	1210	1541	2186	1626	4906	5656
5795	4891	5358	4335	4455	3504	451	366	0	1137	1576	1907	2552	1992	5272	6022
6200	5296	5763	4740	4860	3909	856	771	1137	0	439	770	1415	855	4135	4885
6639	5735	6202	5179	5299	4348	1295	1210	1576	439	0	1209	1854	1294	4574	5324
6970	6066	6533	5510	5630	4679	1626	1541	1907	770	1209	0	645	85	3365	4115
7615	6711	7178	6155	6275	5324	2271	2186	2552	1415	1854	645	0	730	4010	4760
7055	6151	6618	5595	5715	4764	1711	1626	1992	855	1294	85	730	0	3280	4030
10335	9431	9898	8875	8995	8044	4991	4906	5272	4135	4574	3365	4010	3280	0	750
11085	10181	10648	9625	9745	8794	5741	5656	6022	4885	5324	4115	4760	4030	750	0

Figure 10:. Routing metrics expressed as Euclidean Distance Matrix

4. Conclusion

With the development of architectural technology, buildings have become bigger and the damage of people has been constantly occurring. In the meantime, except for the government (local government), disaster was an indifferent field because of its technical limit and commercial merit. Recently, however, due to the development of related technologies such as disaster robots, communication, and image processing, interest in disaster safety is increasing. In this paper, we introduce an indoor disaster countermeasure simulator as a study to minimize human casualties. In addition, we designed a routing protocol for the disaster that can guide the evacuation route based on IOT disaster prediction data through RNN and map information through SLAM technology. The next research topic is to implement the design contents mentioned in this paper.

Acknowledgment

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