Optimal evacuation path search scheme for fire situations using 5G communication technology

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***Abstract*— This paper proposes an enhanced A* algorithm for optimizing evacuation routes within buildings during a fire outbreak. One important research topic is finding the safest and quickest evacuation route considering the structure of the building and the location of the fire when it occurs. The proposed technique employs a multisensor-based fire detection system facilitated by 5G communication technology, enabling not only fire detection but also assessment of potential evacuation routes considering various factors such as smoke, heat, and population density. Ultimately, it provides a route to safely evacuate to the destination. The technique proposed in this paper enhances the conventional path-finding A* algorithm by designating waypoints, setting optimal paths, and thus solving the problems resulting from the traditional A* algorithm, which simply designates a path from the starting point to a simple target. The proposed scheme leverages 5G communication technology to apply to building and fire map data, finding the optimal path from the starting point to the destination and selecting the path with the least cost from these routes. This approach provides a safe and efficient route for evacuees during a fire outbreak. In performance verification under simulation conditions, the proposed technique was validated to determine a route to the destination with a minimum cost, showing superiority over the conventional A* algorithm. The simulation results confirm that the proposed technique can process more data compared to the existing scheme.**

Keywords—Fire Detection and Evacuation, Multi-Sensor Based Systems, 5G Communication Technology

I. INTRODUCTION

Evacuation in a fire situation is of utmost importance, and research to find the safest and fastest evacuation routes has received much attention[1][2][3][4][5]. In this paper, we propose an enhanced A* algorithm to optimize the evacuation route within a building considering its structure and fire location during a fire. We employ a multi-sensor based fire detector that uses 5G communication technology for fire detection, and we provide a scheme to determine whether it can be set as an evacuation route due to various smoke and carbon dioxide, and ultimately, a safe route to evacuate to the destination. The most well-known optimal path search algorithm in the fields of data structures and algorithms for optimal path search in a fire situation is an algorithm that finds the shortest path from one point to another within a graph. The Dijkstra algorithm and the A* algorithm are representative examples. The Dijkstra algorithm finds the shortest path from the starting point to all other vertices, while the A* algorithm finds the path using heuristics. The Dijkstra algorithm has a problem that it takes a lot of time to calculate due to considering all vertices in emergency situations such as fire. The A* algorithm uses a heuristic method to find the path efficiently in a short time, but it does not always find the path with the minimum cost within the path. Since both algorithms need to adapt to dynamically changing environments in a fire situation, there are limitations with the existing optimal location search algorithms, and the development of an algorithm that can adapt to a dynamic environment is required as an alternative. In this paper, we propose a new approach to solve these problems. The technique proposed in this paper offers a new algorithm for finding the optimal evacuation path using fire detection sensors installed within the building. Based on the existing optimal location search algorithm, the A* algorithm, we propose a new algorithm that finds the optimal evacuation path suitable for dynamically changing fire situations by utilizing data from fire detection sensors.

II. PROPOSED SCHEME

The scheme proposed in this paper introduces an algorithm that leverages 5G communication technology to detect the ignition point and progression of a fire in a dynamic environment, and determine the optimal evacuation path in real time. This is achieved by utilizing data from real-time fire detection sensors installed within the building. The proposed scheme is composed of two main parts. The first part involves tracking and mapping the location of the fire and smoke concentration inside the building in real time, utilizing 5G-based fire detection sensors. The second part involves calculating the optimal evacuation route based on a real-time

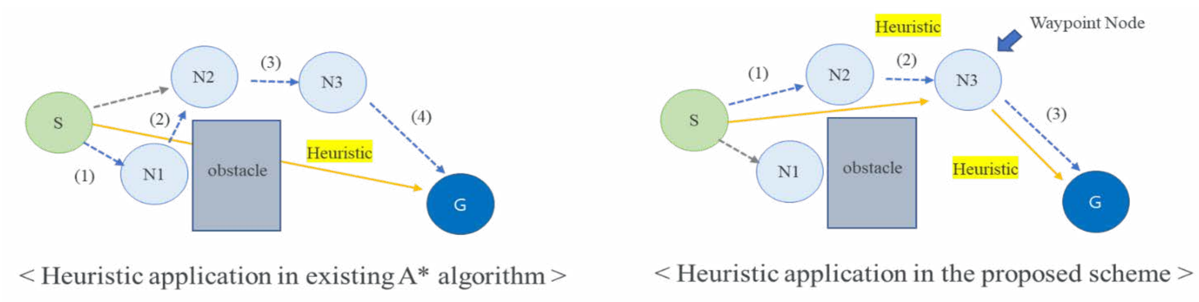

Fig. 1. Comparison between the proposed method and the search method of the existing A* algorithm

updated map of the fire and smoke spread. The proposed scheme operates as follows: initially, a map representing the building structure, along with a map indicating the location and concentration of fire and smoke, are prepared. Then, the A* search algorithm is utilized to find the optimal path from the starting point to the endpoint. The A* algorithm is a greedy algorithm that selects the most efficient next node based on the estimated cost (heuristic) from each node to the destination. However, as the fire changes dynamically, the safe route also needs to be continuously updated. Therefore, the fire and smoke map is updated at every time unit, and the A* algorithm is re-executed based on this updated map to recalculate the optimal evacuation route. By doing so, the algorithm consistently provides an optimal evacuation path that reflects the most recent fire information. The proposed scheme also identifies common points between the path from the starting point to the endpoint and the path from the endpoint to the starting point. It then calculates the cost of the route that includes these common points. Fig. 1 depicts the existing A* algorithm and the path finding method of the proposed method. In Fig. 1, S is the starting point, G is the target point, and N1, N2, and N3 are points that can be moved. In the case of the existing A* algorithm, as the next moving point is selected by applying heuristics to the destination, it has an inefficient problem in searching for the optimal path when there are obstacles on the path. However, in the case of the proposed method, inefficient paths can be avoided by selecting waypoint nodes and applying heuristics to the waypoint nodes to the destination.. In this way, the most optimal path can be selected among the routes calculated in both directions. The path-setting method for fire detection in the proposed scheme can be represented as follows:

$$p = Algorithm\ (F, G)$$
$$Fi = \{0, 1, 2, 3\}\ for\ all\ I\ in\ Sensors \qquad (1)$$

In the proposed scheme, the data obtained from 5G communication-based fire detection sensors can be categorized into four distinct levels, as illustrated in Table 1.

TABLE I. DEFINITIONS AND WEIGHTS FOR RISK LEVELS

Level	State Description	Weight
0	Normal state	0
1	Possible danger within 10 minutes	5
2	Smoke detected	10
3	Uninhabitable condition	20

Based on this data, the optimal evacuation path in a dynamic environment can be determined. The scheme proposed in this paper can be expressed as follows:

$$f(n) = g(n) + h(n, direction) \qquad (2)$$

In the formula (2), g(n) represents the actual cost from the start node to node n, while h(n, direction) symbolizes the estimated cost (heuristic) from node n to the target node. In this context, "direction" could be from the starting point to the target point, the target point to the starting point, or along a shared route. Thus, when compared to the conventional A* algorithm, the proposed scheme incorporates directionality into the heuristic function h(n), enabling it to pinpoint an even more optimized route among various pathways. In the suggested technique, the risk level of a space can be expressed as follows based on smoke density, temperature, and population density:

$$R(n) = F(smoke(n),\ toxic\ gas(n), temp(n)) \qquad (3)$$

For each node n located on the path, 'smoke' represents the degree of smoke, 'toxic gas' indicates the level of harmful gases to the human body, and 'temp' represents the temperature. The overall operation of the proposed scheme can be described as follows:

(1) Risk calculation: Compute the risk level considering smoke sensor readings and temperature values for each node's risk R(n).

(2) Weight update: Apply weights to the path for each node's R(n) based on the risk assessment.

(3) Finding the optimal evacuation route: Set up the optimal evacuation route using the A* algorithm based on the updated weights.

(4) Responding to changes in multiple sensors: When the output values of the sensors change, repeat the process to update weights and recalculate the optimal evacuation path.

The proposed scheme employs systems like 5G CPE to collect and incorporate real-time fire sensor data. The multi-sensors for fire detection deliver individual sensing data to the 5G CPE within a mesh network structure, and the 5G CPE transmits the aggregated sensor data to the server. The server calculates the optimal evacuation route and interfaces it with digital signage and mobile apps for evacuation guidance, allowing for the minimization of casualties and property damage.

III. Simulation Result

To evaluate the performance of the proposed algorithm, we conducted a performance evaluation by applying the A* algorithm and the proposed algorithm respectively in a simulation environment, where a fire occurs randomly

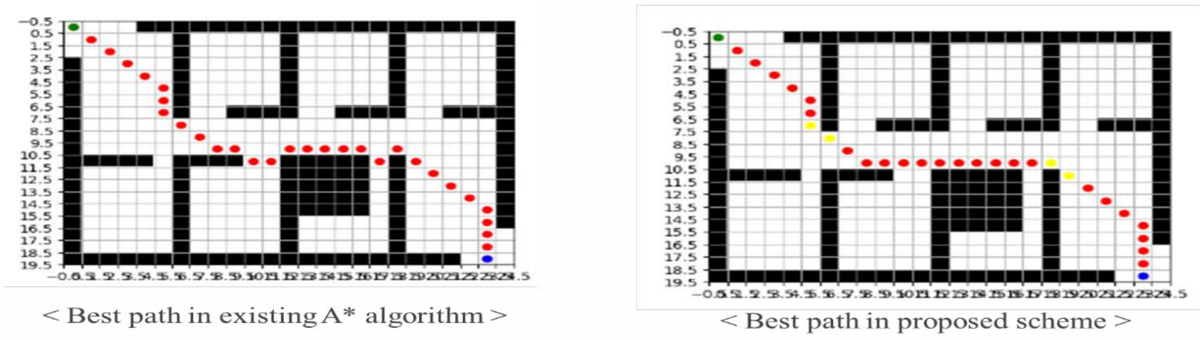

Fig. 2. Comparison between the proposed scheme and the search method of the existing A* algorithm

in a virtual building structure, to find the optimal path and calculate the cost and time. Table 2 illustrates the simulation environment used to evaluate the performance of the proposed scheme.

TABLE II. SIMULATION ENVIRONMENT

Category	Detailed Information
Simulation Grid	25 × 20
Risk Level weight	level 0 : 0, level 1: 5, level 2: 10, level 3: 20
Risk Area Generation	1 points(25 Grid), Random
Starting Point	0, 0 or Random
Emergency Exit	25, 20
Simulation Runs	1000 times

The simulation environment was set to designated arbitrary points within the grid. In the event of a fire, a grid of 25 squares was constructed centered on the ignition point, and the risk level was set to levels 1-3. Based on this, a fire map was generated and the proposed method was compared with the existing A* algorithm. The simulation was performed 1000 times each using the proposed technique and the existing A* algorithm, and the cost and time for finding the optimal path were derived respectively. The system for the simulation operation was conducted in a Win 11 64bit environment with a CPU i7 3.0GHz and GPU GTX 1660. In the simulation environment, it was confirmed that the proposed method more efficiently searches for the optimal path by applying a heuristic algorithm using Waypoint nodes, compared to the existing A* algorithm in identifying evacuation routes.

TABLE III. THE PERFORMANCE OF THE PROPOSED SCHEME WITH THE EXISTING A* ALRORITHM

Start Point	End Point	Best Path Weight Cost		Delay Time for Finding Best Path (sec)	
		Proposed Scheme	Existing A* algorism	Proposed Scheme	Existing A* algorism
Fixed (0,0)	Fixed (25,20)	37.91	39.52	0.1151	0.095
Random	Fixed (25,20)	22.33	23.22	0.1043	0.090

In Figure 2, green represents the starting point, blue represents the target point, and yellow in the proposed method indicates the Waypoint path. The performance of the proposed scheme compared with the existing A* algorithm in Table III. The start point conditions were fixed at (0,0) and random, while the end point was fixed at (25,20). The best path weight cost and delay time for finding the best path are reported for both the proposed scheme and the existing A* algorithm. As shown, the proposed scheme consistently outperforms the existing A* algorithm in terms of path cost, albeit with slightly longer delay times for identifying the optimal path.

IV. CONCLUSION

In this paper, we proposed an algorithm for finding the optimal evacuation route in dynamic environments using fire detection sensors. The proposed algorithm classifies the fire risk into four levels to dynamically determine the evacuation route from the fire. Simulation results demonstrated that this approach could identify more effective evacuation routes. These results provide significant insights for research into fire evacuation algorithms in dynamic environments. Further research is needed to explore the applicability of the proposed algorithm in various environments and scenarios.

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