Dynamic Evacuation Guidance Considering Occupant Distribution

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Abstract. In most large buildings, pre-planned routes are being introduced to occupants for rapid evacuation. However, the pre-planned route does not reflect information such as occupant distribution and danger zone at the time of the disaster, so there is a limit to minimizing the casualties. This study suggests the dynamic evacuation guidance that evacuation route is changed according to the occupant distribution at the time of the disaster. Hardware and algorithm required for dynamic evacuation guidance are described and evacuation simulation using scenarios are performed.

Keywords. Indoor evacuation, Dynamic evacuation, Simulation

1. Introduction

When a disaster occurs in a building, the initial response is most important to minimize casualties. In a large building, the pre-planned route is guided to occupants through static evacuation sign, map and video for rapid evacuation. However, the pre-planned evacuation route has limitations in minimizing the casualties because it does not reflect information such as occupant distribution and danger zone at the time of the disaster. And it usually only guides people to the nearest exit.

Some studies based on the dynamic network flow theory deal with minimizing the total evacuation time taking into account occupant distribution in buildings (Hamacher & Tjandra 2001, Casadesús-Pursals & Garriga-Garzón 2013). The total evacuation time represents the time required for all occupants to evacuate to a safe area. These studies structure the target building
as a network model and search for the route that occupants can evacuate the fastest. But, there is a practical difficulty in using the dynamic network flow based evacuation algorithm to guide evacuation in the field. Because a number of people belonging to the same space (node) evacuate to different paths. This may be a method to minimize the total evacuation time, but it is not suitable for evacuation guidance considering generally evacuation sign indicating only one direction.

This study focuses dynamic evacuation guidance that evacuation route is changed according to the occupant distribution at the time of the disaster, assuming that a number of people in a node are evacuate to the same route. For dynamic evacuation guidance, sensors for indoor situation detection should be installed in the building, and an algorithm for calculating the optimal evacuation route based on the data acquired from sensors is needed. Also, evacuation signs are required to guide the evacuation route calculated by the algorithm to the occupant. Section 2 introduces sensors for people counting, evacuation signs for route guidance, and algorithm for evacuation path calculation. Section 3 describes simulation results using dynamic evacuation guidance based on scenarios and Section 4 contains the conclusions.

Figure 1. (a) indoor structure, (b) network model, (c) sensor and evacuation sign
2. Dynamic evacuation guidance

2.1. People counting sensor and dynamic evacuation sign
In order to perform the dynamic evacuation guidance considering the occupant distribution, the target space should be divided into subdivisions and a people counting sensor and a dynamic evacuation sign should be installed in the divided spaces. A dynamic evacuation sign refers to a device that guides evacuation direction variably according to a signal. Figure 1 (a) shows the indoor structure of the building selected as the test bed, and (b) shows it as the network model. Each node represents a subdivision. And (c) is an infrared beam type people counting sensor and dynamic evacuation sign installed in the subdivision area.

Figure 2. (a) Building network model of MEEA, (b) Exit assignment result

2.2. Multiple exits evacuation algorithm (MEEA)
This study used the MEEA (Lee et al. 2017) to minimize total evacuation time. Figure 2 (a) shows the building network model used in the MEEA. MEEA has similar data structure with EVACNET4 (Kisko & Francis). The difference is that MEEA approaches indoor evacuation problem through the exit assignment of nodes. The exit assigned to a node means that evacuees located at the node are evacuated to the assigned exit. And through this, the evacuation time at the exit is calculated.

Figure 3 shows the pseudo code of the MEEA using the nomenclature of Table 1. In the initialization phase of the algorithm, the closest exit is assigned to all nodes. Thereafter, each exit competitively absorbs nodes, repeating until evacuation times at exits are balanced and the total evacuation time is minimized. In other words, it repeatedly adjusts the exits assigned to nodes until it reaches a near optimization. Figure 2 (b) shows a balanced exit assignment for all nodes after the algorithm is terminated.
Table 1. Nomenclature of MEEA

<table>
<thead>
<tr>
<th>Nomenclature</th>
<th>Description</th>
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<tbody>
<tr>
<td>$G(N, E)$</td>
<td>Building network, $N$: node set, $E$: edge set</td>
</tr>
<tr>
<td>$D$</td>
<td>Exit node set</td>
</tr>
<tr>
<td>$l_{ij}$</td>
<td>The shortest distance from node $i$ to exit node $j$</td>
</tr>
<tr>
<td>$d_i$</td>
<td>The exit node assigned to node $i$</td>
</tr>
<tr>
<td>$T_j$</td>
<td>Evacuation time at exit node $j$</td>
</tr>
<tr>
<td>$B_j$</td>
<td>Constraint group of exit node $j$</td>
</tr>
<tr>
<td>$C_j$</td>
<td>Candidate group of exit node $j$</td>
</tr>
<tr>
<td>$p_{ij}$</td>
<td>The travel time to evacuate through exit node $j$ at the node $i$</td>
</tr>
</tbody>
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Algorithm Multiple exits evacuation algorithm

Input: $G(N, E)$

Output: Total evacuation time, $N$ that exit nodes are assigned

For all $i \in (N - D)$
Find an exit node $j$ which $l_{ij} = \min\{l_{ij} | j \in D\}$ then $d_i \leftarrow j$
End for

Calculate $T_j$ each exit node $j \in D$

$Z_0 \leftarrow \infty$

$Z_1 \leftarrow \max\{T_j | j \in D\}$

While ($Z_0 > Z_1$)

$Z_0 \leftarrow Z_1$

For all $i \in D$ sorted in ascending order of $T_j$

$B_j \leftarrow \emptyset$

While ($C_j \leftarrow \text{FindNeighbors}(j, B_j) \neq \emptyset$)

$k \leftarrow \{k | k = d_i, i \in C_j\}$

$t_0 \leftarrow \max\{T_k | k \in K\}$

For all $i \in C_j$

$k \leftarrow d_i$

$d_i \leftarrow j$

Calculate $T_k$ each exit node $k \in K$

$t_1 \leftarrow \max\{T_k | k \in K\}$

If ($t_0 > t_1$) or ($t_0 = t_1$ and $p_{k,j} > p_{k,j}$) then $C_j \leftarrow C_j - \{i\}$

Else $d_i \leftarrow k$

End for

End while

End for

$Z_2 \leftarrow \max\{T_j | j \in D\}$

End while

Procedure FindNeighbors($j, B_j$)

$C_j \leftarrow \emptyset$

Find $C_0 \leftarrow \{n | (n, k) \in \text{E}; d_n = i; d_k = j; k \not\in B_j\}$

If $C_0 = \emptyset$ then return $\emptyset$

Else

For all $n \in C_0$

If $n$ is a source node then $C_j \leftarrow C_j \cup \{n\}$

End for

If $C_j = \emptyset$ then $d_n = j$ for each $n \in C_0$ and do FindNeighbors($j, B_j$)

Else return $C_j$

Figure 3. Pseudo code of MEEA
3. Evacuation simulation using EgresSIM

In this study, simulation using EgresSIM (Kwak et al. 2016), a cellular automata based evacuation simulator, was performed based on a scenario instead of a real evacuation experiment using sensors and dynamic evacuation signs. The experimental space is as shown in Figure 1 (a) and the scenario consists of two cases with different occupant distribution.

Figure 4 (a) is a graph showing the total evacuation time of the shortest exit and dynamic evacuation guidance for each case. (b) shows the exit located at the shortest distance based on each room. (c) and (d) show the exit where the occupants of each room move when the dynamic evacuation guidance is applied to Case 1 and 2.

In Case 1, 890 occupants are evenly distributed throughout the building. In this situation, when using the shortest exit, the total evacuation time was 527 ticks on average. When the dynamic evacuation guidance was applied, the
result was slightly shortened to 502 ticks. In Case 2, 380 occupants are concentrated around exit B. When the shortest exit is used, as can be seen in (b), a lot of people gather at exit B, causing a bottleneck. When the dynamic evacuation guidance was applied, evacuees concentrated at exit B diverted to exit A and exit C, reducing total evacuation time by approximately 120 ticks.

4. Conclusion

In this study, hardware and algorithm required for dynamic evacuation guidance considering occupant distribution are described and evacuation simulations are performed using hypothetical scenarios. It is necessary to verify the dynamic evacuation guidance by applying more complex building structure and various scenarios, and it is considered that risk factors such as fire spread should be reflected. It is also necessary to use real sensor data and a dynamic evacuation sign. If the mentioned points are improved, it is expected that the dynamic evacuation guidance proposed in this study will be more effective in minimizing the casualties than the general evacuation guiding method which guides the pre-planned route.

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References


