An Evacuation Route Planning for Safety Route Guidance System after Natural Disaster Using Multi-Objective Genetic Algorithm

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Abstract

When a natural disaster occurred, some roads cannot be used anymore and sometimes blocked. Also, survivors and refugees cannot follow the evacuation procedures by just using default maps after disaster. A previous study proposed a safety route guidance system that can be used after natural disasters by using participatory sensing. The system estimates safe routes and generates an evacuation map by collecting GPS data and accelerometer data from pedestrians’ smartphone. However, the system does not base on default map data. After that, the system evaluates the safety of each route. However, the previous study did not propose a method of finding evacuation routes from the users’ current location to their destination. Therefore, in this study, we proposed a method of evacuation route planning. We have implemented Multi-Objective Genetic Algorithm (MOGA) into the route planning methodology. The proposed system has three objective functions, which are: evacuation distance, evacuation time and safety of evacuation route. Also, we proposed a new safety evaluation method. As a result, this study gives a better reflection of the change of road conditions. Also, the safety evaluation values are more useful than the previous study’s evaluation method of the route. Moreover, the system can provide evacuation routes with different characteristics to users. As a result, the users can select a route which is suitable for their situation.

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1. Introduction

Throughout the ages natural disasters (i.e. earthquake, tsunami and eruption) are unavoidable casualties in the history of mankind. In many occasions after the earthquakes, people die due to lack of data such as evacuation routes. When natural disasters occurred, some roads are blocked and cannot be used. Survivors and refugees cannot follow the evacuation procedures by just using default maps after disaster. In addition, survivors can go to evacuation area by using any route or even they can walk through gardens, collapsed buildings, fields, houses and so on. Hence, collecting the road safety conditions and providing useful routes for refugees are very beneficial after natural disaster occurrence.

1.1. Previous Study

A Previous study [1] proposed a safety route guidance system which can be used after a natural disaster by using participatory sensing. The system collects GPS data and accelerometer data from pedestrians’ handsets, uploads the data and assigns them as a safe route. Moreover, the previous study proposed a method of generating nodes and links from the collected information. A three-axis composite acceleration exceeds a threshold value when accidents occurred, such as tumbles and stumbles. For this reason, the system has a capability of detecting the risky locations and safe locations by the value of accelerometer and positioning that have been provided by handsets’ GPS. Furthermore, the previous study proposed a safety evaluation method that evaluates safety of each link based on pedestrian traffic and average walking speed. In this method, if the average walking speed was fast and the pedestrian traffic was heavy, the system increases the safety evaluation value. Also, the system provides a safe map which will be sketched by using color for each useful route. When the system generates the safe map, the system does not use data of default maps. Moreover, another previous study has proposed a new safety evaluation method. This previous study solved an issue that the safety evaluation value doesn't decrease.

However, the previous studies did not propose a method for finding evacuation routes from a current location of the user to the user’s destination. The users do not know which route should they take to reach their destination. There is also an issue associated with the safety evaluation method. If roads with many pedestrians become impassable, decreasing of pedestrian traffic will be recorded on the system. In such a case, the safety evaluation values must also decrease as well since the roads are not safe anymore. However, in previous study, the evaluation values have not been decreased and the roads are still displayed as safe roads on the safety map.

Fig. 1. (a) Safety route guidance system using participatory sensing; (b)An example of generated map

1.2. Purpose

The purpose of this study is to propose an evacuation route planning method. The method can provide several evacuation routes having different characteristics to users. Moreover, we propose a new method of safety evaluation which can properly reflect the change of road safety conditions on the safety evaluation values.
2. System Overview

An overview of the proposed system is demonstrated in Figure 2. There are three phases in this system: collecting information phase, analyzing and evaluating phase and providing an evacuation map phase. These phases are repeated for generating the evacuation map.

• Collecting information phase
  The system collects GPS data and acceleration data from pedestrians’ smartphone. When the user starts walking, smartphone starts collecting these data. In case if the user stops walking, the smartphone stops the data collection. The smartphone sends the collected data to a cloud server at regular intervals. The server receives and stores the data as safety routes. When network connections are disabled, the smartphone waits to send the data until the smartphone connects to the network.

• Analyzing and evaluating phase
  The system generates an evacuation map by analyzing the collected data from the smartphones. Then, the system won’t use road information based on the default map data. Firstly, the system calculates intersection points of the safety routes. The positions are saved as node data in the server. Secondly, every route is separated by nodes and the separated routes are saved as link data in the server. Thirdly, the system calculates the walking distance, the average walking speed and the pedestrian traffic for all of the links. Finally, the system evaluates the safety of each link based on the calculation results.

• Providing an evacuation map phase
  The system provides an evacuation map to the user. If the user chooses, the system searches evacuation routes from the user’s current location to their destination. The results will be displayed on the map and provided to the user.

3. Evacuation route planning method

When user selects an evacuation route, that user considered not only the safety of route but also the distance and the walking time. In this study, the evacuation route planning is regarded as a multi-objectives optimization problem. The problem has three objective functions as follows: evacuation distance, evacuation time, safety of evacuation route. By using Multi-Objective Genetic Algorithm(MOGA) for solving the problem, the approximate solution of the optimal solution for simultaneously optimizing a plurality of the objective functions is obtained. As a result, the system can provide several evacuation routes which have different characteristics and the users can select a route which is suitable for their situation.

3.1. MOGA

A multi-objective optimization problem deals with a task of simultaneously optimizing two or more conflicting objectives with respect to a set of certain constrains [2]. Multi-objective optimization problems usually have a set of
Pareto optimal solutions. Generic algorithms (GA) are the heuristic and optimization techniques that mimic the process of natural evaluation for solving complex optimization problems. MOGA is an approach to multi-objective optimization using GA. This approach can get the Pareto optimal solutions at the same time because GA work simultaneously with multiple points.

3.2. Proposed route planning method

Evacuation route planning procedures are described below.

(1) Obtaining node information, adjacent node information and link information
The smartphone application obtains node information and link information from the cloud server. The node information holds node ID and location of nodes. The adjacent information holds adjacent node ID of each node and inter-connection information between a node and an adjacent node. The inter-connection information is represented as link ID. The link information holds specific information for each link such as link ID, distance, average walking speed, pedestrian traffic and current safety evaluation value.

(2) Setting a departure point and a destination point
The users can input a departure node and a destination node on the smartphone’s application. Then the system start evacuation route planning based on them.

(3) Initialize the population
Initial population is generated by creating a number of route from the departure node to the destination node as individuals. The number of individuals in population is called population size. The population size is set to 200 in this study. Each individual represents the order of nodes in a route connecting from a departure node and destination node. Thus, the individuals are represented by using a departure node ID, via node IDs and a destination node ID. The length of the individuals is variable. For example, if departure node ID is 1, destination node ID is 7 and the order of via nodes ID is 2-4-5, the individual is expressed as follow: \([1,2,4,5,7]\).

![Fig. 3. Individual of route planning method](image)

(4) Evaluate fitness
The fitness of every individual in the population is evaluated. Each evaluation function is described as following.

- Evacuation distance

An evaluation function of evacuation distance is defined in Equation 1. The total distance of evacuation route, which is calculated the sum of all distances of links that compose the evacuation route, is used as an evaluation value.

\[
f_i(x) = \sum_{k=0}^{n-1} d_k
\]

where \( n \) represents total number of links inside the individual \( x \) and \( d_k \) represents the distance of link \( k \).
- Evacuation time

An evaluation function of evacuation time is defined in Equation 2. Required time to destination of evacuation route, which is calculated by adding all average walking time of links that compose the route, is used as an evaluation value.

\[
f_j(x) = \sum_{k=0}^{n-1} \frac{d_k}{v_k}
\]  

(2)

where \( n \) represents total number of links inside the individual \( x \). \( d_k \) represents the distance of link \( k \). \( v_k \) represents the average walking speed of link \( k \).

- Safety of evacuation route

An evaluation function of safety of evacuation route is defined in Equation 3. The average safety evaluation value of links that compose the route is used as an evaluation value. The evaluation value is calculated by dividing the sum of safety evaluation values of links by the number of links. A method of calculating safety evaluation value is described in Section 3.3. The sum of safety evaluation values of links is not used as evaluation value. Because if the sum of safety evaluation is used as an evaluation value, long distance route will have the higher evaluation value.

\[
f_j(x) = \sum_{k=0}^{n-1} \frac{P_k}{n}
\]  

(3)

where \( n \) represents total number of links inside the individual \( x \). \( P_k \) is the safety evaluation value of link \( k \).

We used a Pareto ranking method [3][4] as a method of fitness evaluation. The rank of an individual within the population depends on the number of individuals dominating this individual. All non-dominated individuals are assigned as rank 1. The rank closer to 1, the fitness will be higher.

\[
r_x = 1 + n_s
\]  

(4)

where \( r_x \) represents rank of individual \( x \) and \( n_s \) is the number of individuals dominating individual \( x \). The system decides the rank of each individual by comparing evaluation values that has been calculated by Equation 1, 2 and 3. In the following cases like: the evacuation distance of individual \( x_i \) is longer than the evacuation distance of individual \( x_j \), the evacuation time of individual \( x_i \) is longer than the evacuation time of individual \( x_j \) and the safety evaluation of individual \( x_i \) is longer than the safety evaluation of individual \( x_j \), individual \( x_i \) is dominated by individual \( x_j \).

\[
f_i(x_i) \geq f_j(x_j) \cap f_2(x_i) \geq f_2(x_j) \cap f_3(x_i) \leq f_3(x_j)
\]  

(5)

(5) Selection

Some individuals are selected from the population as parents for creating new individuals based on their fitness value. The new individuals are called offspring. We used an elitist strategy and a roulette wheel selection together as selection methods. Individuals with the highest fitness value are replicated to next generation by the elitist strategy. These individuals have rank 1 in this study. Moreover, the other individuals are selected by the roulette wheel selection method. In the roulette wheel selection, individuals are given a probability of being selected that is proportionate to their fitness. Some individuals are chosen randomly based on the probability and produce offspring.

(6) Crossover

We used a uniform crossover technique. An example of crossover operation is shown in Figure 4. Two individuals are selected randomly as parents. Node ID included one individual are compared with node ID included the other individual. If a same node ID is found, the position of the node is selected as a crossover
point. If there are more than one common node ID, the first common node is selected as the crossover point. The new individuals are generated by exchanging the parts of the back from the selected node by each other. When they do not have the same node ID, crossover operation will not be performed.

(7) Mutation

An example of mutation operation is illustrated in Figure 5. An individual is selected randomly from populations as parents. Firstly, one node ID, which consists of the selected individual, will be chosen randomly. Secondly, a connection path from the selected node to the destination is generated. Finally, a new individual is created by replacing the back from the selected node with the generated path.

(8) Termination

This algorithm is stopped when the predetermined number of generations has been created. Otherwise operation of (4) - (7) are repeated. In this study, the predetermined number is set to 200.

3.3. Safety evaluation method

The safety evaluation value $P$ is determined by using Equation 5. $v$ represents the average walking speed between two nodes, $m$ represents the pedestrian traffic per hour between these nodes and $d$ represents the distance between them. Each individual is evaluated based on the average walking speed and the pedestrian traffic every hour. In this equation, if the average walking speed was fast and the pedestrian traffic was heavy, the system increases the safety evaluation value of the link. Firstly, the system calculates a temporary evaluation value $p$. If the ratio of the temporary evaluation value and a current safety evaluation value are smaller than the threshold $\beta$, the system determines a suddenly decreasing of pedestrian traffic has been occurred. In this case, the current safety evaluation value is computed in accordance with the coefficient $\gamma$ to lower the temporary evaluation values. If the ratio is larger or equal to the threshold, the current value will be changed to the temporary evaluation value. In this study, we calculate the evaluation values by setting $\alpha=0.8$, $\beta=0.9$ and $\gamma=0.5$. However, we have to consider and decide which value of $\alpha$, $\beta$ and $\gamma$ will be best for the system.

$$p = \frac{100 \times v \times m}{d} + \alpha \times P(t)$$

$$P(t + 1) = \begin{cases} p, & \text{if } \frac{p}{P(t)} < \beta \\ p, & \text{otherwise} \end{cases}$$

(5)
4. Experiment

4.1. Purpose of these experiments

The purpose of this experiment is to confirm the followings:
- The proposed route planning method can find several evacuation routes with different characteristics.
- The proposed safety evaluation method can give a better reflection of the changes of road conditions on the safety evaluation value than the previous study.

4.2. Method of experiments

We created a route planning program and conducted route planning experiment on an actual map by running the program. Figure 6(a) shows the map that have been used in this experiment. The black circles indicate generated nodes and the number from 0 to 13 represent link ID. The distance of each link was set based on the actual distance between two nodes. However, the average walking speed and the pedestrian traffic of each link was set assumed values. Except link 1, the average walking speed of each link was set to 1.0 [m/s] as described in “Tsunami Evacuation Buildings Guidelines” [5]. The average walking speed of Link 1 was set to 0.8 [m/s]. Link 0 and link 5 have become impassable after five hours’ timeline starting from the system working point. Then the pedestrian traffic of link 0 and link 5 were decreasing sharply. Moreover, after that point, the average walking speed of Link 0 and link 5 was set to 0.8 [m/s]. Under this circumstance, we searched routes from the departure point to the destination point twice as shown in experiment 1 and experiment 2.

- Experiment 1: Route planning was performed an hour before the changing of road conditions.
- Experiment 2: Route planning was performed six hours after the changing of road conditions.

4.3. Experiment results

4.3.1 Experiment 1: Route planning was performed an hour before the changing of road conditions.

The result of route planning performed an hour before the changing of road conditions is shown in Table 1. Figure 7 shows the results was drawn on a map. It was found from the results that the program was able to find and provide three evacuation routes which have different characteristics. As a result, users can evacuate by selecting a route which is suitable for their situation. Moreover, it is assumed that users can estimate risks by comparing provided routes. For example, in this case, users can estimate that link 1 has dangerous places where are difficult to walk through. Because link 1 is included in the shortest distance route (Route 2), but not in the shortest time route.
(Route 3). Thus the system becomes more convenient for users than the previous study by using the proposed route planning method.

Table 1. Pareto optimal solutions

<table>
<thead>
<tr>
<th></th>
<th>Evacuation distance[m]</th>
<th>Evacuation time[s]</th>
<th>Safety of evacuation route[traffic’s value/s]</th>
<th>Via link</th>
</tr>
</thead>
<tbody>
<tr>
<td>Route1</td>
<td>416</td>
<td>416</td>
<td>349</td>
<td>13-12-9-5-14-0</td>
</tr>
<tr>
<td>Route2</td>
<td>398</td>
<td>440</td>
<td>212</td>
<td>6-1-0</td>
</tr>
<tr>
<td>Route3</td>
<td>407</td>
<td>407</td>
<td>240</td>
<td>6-3-14-0</td>
</tr>
</tbody>
</table>

![Diagram of evacuation routes](image)

Fig. 7. Results of evacuation route planning

4.3.2 Experiment 2: Route planning was performed six hours after the changing of road conditions.

The result of route planning performed six hours after the changing of road conditions is shown in table 2. Figure 8 shows a part of the results was drawn on a map. The shortest distance route was same as experiment 1. However, the shortest time route and the safest route was changed in experiment 2. It was found from the results that the program was able to provide evacuation routes that reflect the changes of link information. Moreover, when the system used the safety evaluation method proposed by the previous study, link 5 included in the safest route. However, when the system used the safety evaluation method proposed by this study, link 5 was not increased in the safest route. The safety evaluation method proposed by this study is better in case of changing in the status of the routes, based on safety values comparing to the previous study.

Table 2. Pareto optimal solutions when using the new safety evaluation method

<table>
<thead>
<tr>
<th></th>
<th>Evacuation distance[m]</th>
<th>Evacuation time[s]</th>
<th>Safety of evacuation route[traffic’s value/s]</th>
<th>Via link</th>
</tr>
</thead>
<tbody>
<tr>
<td>Route1</td>
<td>416</td>
<td>462</td>
<td>113</td>
<td>13-12-9-5-14-0</td>
</tr>
<tr>
<td>Route2</td>
<td>516</td>
<td>516</td>
<td>319</td>
<td>13-12-10-8-4</td>
</tr>
<tr>
<td>Route3</td>
<td>398</td>
<td>454</td>
<td>51</td>
<td>6-1-0</td>
</tr>
<tr>
<td>Route4</td>
<td>446</td>
<td>446</td>
<td>121</td>
<td>6-3-2</td>
</tr>
<tr>
<td>Route5</td>
<td>455</td>
<td>487</td>
<td>143</td>
<td>13-12-9-5-2</td>
</tr>
</tbody>
</table>
5. Conclusion

In this study, we proposed a route planning method for the safety route guidance system by using MOGA and a new safety evaluation method. As a result, the system becomes able to provide several evacuation routes which have different characteristics to the users. Thus the users can select a route which is suitable for their situation. Moreover, the system also becomes able to provide better reflections of the changes of road safety conditions on the evacuation route map. For the future work, we are planning to compare between other routing planning methods and decide which method is most suitable for the system. Moreover, we need to implement our proposed system to provide evacuation routes to users.

Acknowledgements

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References