A Map Construction System for Disaster Areas Based on Ant Colony Systems

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Abstract

This paper proposes a map construction system for disturbed disaster areas based on ant colony systems. In our system, evacuees with mobile devices record roads they take while evacuating to a shelter as data collection agents. Then, at the shelter, recorded road information is gathered and restructured into a safe-road map. In this restructuring, information is weighted in accordance with the ant colony system. By this mechanism, we treat the reliability of information on road segments with respect to their safeness for evacuation. In the simulation experiment, we can observe that our system can follow a changing situation and provide an up-to-minute safe-road map to a shelter in a disaster area.

1. Introduction

Recently, mobile ad-hoc network (MANET) technologies have received great amounts of attention for alternative communication systems in disaster situations such as a big earthquake [1, 2]. In a MANET, communication networks are constructed and maintained by the only a collection of mobile devices. Mobile devices play roles of network routers and exchange data packets with other devices. In other words, the MANET is managed autonomously by mobile devices. Thus, no infrastructure supports such as base stations for mobile phones, public access points for WiFi network, and so on, are required [3, 4]. This feature is suitable for communication systems in disasters, since network infrastructures may break or malfunction in such situations.

We have already proposed a map information sharing system for disaster areas in order to help evacuees to evacuate to shelters [5]. In this system, evacuees’ mobile terminals record roads taken by using GPS and map matching technologies while evacuees move to shelters. Then, mobile terminals within a communication range exchange the stored road information in an ad-hoc network manner. With this system, evacuees can gather information on a safe-road map and evacuate to appropriate shelters safely. However, in order to evacuate to shelters more safely, we have to consider correctness and recentness of information on a road network more
seriously. In disaster areas, the situation changes from moment to moment. In such areas, the condition of roads changes particularly drastically. For example, roads may become impassable due to the spread of fire, increased amounts of rubble from collapsed buildings, and so on.

In this paper, we propose a system for constructing a safe-road map of disaster areas. In order to take recentness and correctness of information on a road network into account, we introduce the concept of ant colony systems [6, 7]. Recentness of information is measured by using the amount of left pheromones in ant colony systems. By this method, we can weight information of a road network with respect to its recentness and thus highlight safer paths to shelters.

The rest of the paper is organized as follows. Section 2 introduces ant colony systems and describes their application to map construction systems. Section 3 describes our proposed system. Section 4 details our simulation experiments. Finally, Section 5 concludes this paper and explains our future work.

2. Ant Colony Systems

In order to solve the traveling salesman problem (TSP), the ant colony system (ACS) was proposed [8, 9]. It is a kind of a distributed algorithm in which a set of agents called ants cooperate to find good solutions. In the ACS, agents communicate indirectly by pheromones.

2.1. Ecology of Ants

In order to find food, ants initially move randomly around their colony. When ants find food, they move back to their colony while they lay pheromones down on the ground. When other ants find pheromone trails, they are likely to follow the path and can find food. In the same way, they drop pheromones and accumulated pheromones emphasize this path. A pheromone is a volatile liquid and thus evaporates as time advances. Since more pheromones are left on shorter path, ants can find the shortest path from their colony to food by following the pheromones.

Figure 1 shows an example of finding the shortest path. In this example, four paths go from a colony to a food resource: \(<a, c>, <b, c>, <a, d>, \text{ and } <b, d>\). Ants select a path randomly and reach to the food. While going back to the colony, pheromones are laid down on the path. More pheromones are left at \(a\) and \(c\) than \(b\) and \(d\). Thus, many ants use the path \(<a, c>\), and then more and more pheromones are left on the path. By this positive feedback, the shortest path can be achieved.

2.2. Application to Map Construction

In our map construction system, evacuees who evacuate to the nearest shelter act as mobile agents. Each evacuee records roads taken by using a mobile terminal with GPS and a map matching system. When evacuees reach the shelters, the mobile terminals communicate with map construction servers and transfer information on the roads taken. By gathering this information, the map of roads that evacuees recently used to evacuate is constructed. Figure 2 shows an overview of our map construction system. Evacuees evacuate to the shelter through different routes. Thus, by gathering such routes in the shelter, we can obtain a safe-road map of the disaster area.

In order to enhance our map construction system with respect to data recentness, a pheromone mechanism is applied. In disaster areas, the condition of roads changes much more drastically than normal. For example, a road taken by an evacuee a short time before may not be taken by other evacuees because of the spread of fire, rubble of collapsed buildings, and so on in disaster situations. Thus, it is important to know when a road was used for evacuation as well as which road was used for evacuation.

We introduce ant colony systems to our map construction system in order to solve the above problem. When an evacuee takes a road, the mobile terminal records not only the roads taken but also time taken. The reliability of a road for evacuation decreases like pheromones as time advances. Figure 3 shows a comparative example. Figure 3(a) shows information on the road network in the original map construction system [5]. In the original system, all roads taken are stored and shared equivalently as passable paths in evacuation. On the other hand, Figure 3(b) shows the proposed map construction system with ant colony systems. In Figure 3(b), roads taken are
Fig. 1. Ant colony systems

shown in a grayscale ramp. This grayscale shows the reliability of information. If a road was used for evacuation in an earlier time, information about the road is relatively unreliable because the situation of the road may have changed drastically in disaster areas. Furthermore, if many evacuees use the same road for evacuation, that road may be safe for evacuation and thus the information about the road is highly reliable. For example, in Figure 3(b), when the road \( r_1 \) becomes impassable during evacuation, evacuees who have not reached the shelter yet use alternative paths. Thus, the pheromone concentration of the road \( r_1 \) is decreased and another evacuation path to the shelter can be achieved. By introducing the reliability of information on the basis of pheromones in the ant colony systems, we can acquire a more accurate evacuation map in disaster situations.

3. System Overview

Our system consists of two components: mobile terminals with evacuees for recording roads taken, and a map construction server in the shelter. Each mobile terminal records the trajectory of an evacuee’s movement. When evacuees reach the shelter, recorded road information is transferred to the map construction server. In the map construction server, information on pheromones of each road segment is stored and up-to-date safe evacuation routes to the shelter are calculated on the basis of ant colony systems.

3.1. Mobile Terminal

In a mobile terminal, position information of an evacuee is measured by GPS, and a taken road segment is determined by map matching technologies. Generally, position information acquired from GPS has some errors. Specifically, error ratio is relatively large in urban areas, since the number of GPS satellites whose radio wave can reach to the GPS devices in mobile terminals is not enough due to high buildings. Thus, by using map matching technologies, the sequence of position information corresponds with the sequence of road segments [10, 11, 12]. We have already proposed the pedestrian-oriented map matching algorithm suitable for the mobile terminals of this system [13].

When an evacuee reaches an intersection of roads, the mobile terminal detects the road taken by using the map matching algorithm and records the road segment and the current time: \( < r_i, t_i > \). The mobile terminal stores the information on such pairs for all taken road segments.
3.2. Map Construction Server

The map construction server is located in the shelter and collects information on a road network from the mobile terminals in ad-hoc network communication. On the server, information collected about road networks is aggregated into the safe-road map on the basis of ant colony systems. Specifically, for all information \(< r_i, t_i >\), the quantity of residual pheromones is calculated and accumulated. When the current time is denoted as \(t_c\), the pheromone, pheromones for the road segment \(r_i\), are calculated as follows:

\[
\text{pheromone}_i = \text{pheromone}_i + \alpha - \beta \times (t_c - t_i),
\]

where \(\alpha\) stands for the initial value of pheromone and \(\beta\) stands for the decreased value of pheromones.

4. Experiments

In order to confirm the effectiveness of our proposed system based on ant colony systems, we conducted a simulation experiment.

4.1. Simulation Scenario

In the experiments, we provided a virtual disaster area 2.0 kilometers wide and 1.5 kilometers high around our university. Figure 4 shows the simulation area. In the experiments, 500 evacuees are deployed on roads randomly. Evacuees appear in 0.2 person/minute in accordance with a Poisson distribution. The area has one shelter, and all evacuees try to evacuate to the shelter on the basis of the mobility model we proposed previously [14]. The average speed of evacuees is 4 km/h. For pheromone parameters in the ant colony system, \(\alpha\) is set to 50 and \(\beta\) is set to 10, that is, pheromones evaporate and decrease by 10 in one minute. In order to confirm the ability of our system to follow changing situations, several roads become impassable when the simulation time reaches 20 minutes. Thus, evacuees have to change their evacuation routes to the shelter. We observe the constructed map of our system for 40 minutes.
4.2. Experimental Results

Experimental results are shown in Figures 5 to 7. In the figures, evacuees are denoted as blue dots, and collected map information is denoted as red lines. Color shade of lines expresses the density of pheromones, i.e., the safeness of roads. The roads with larger quantities of residual pheromones are displayed in darker red lines.

Figure 5 shows the constructed map after 5 minutes. We can observe that safe routes can accumulate near the shelter although no information is obtained in the far away areas because evacuees in these areas have not reached the shelter at this time. Figure 6 shows the map after 20 minutes. At this time, the safe-road map to the shelter is almost achieved. We can observe that main routes that many evacuees use for evacuation are dark red. Figure 7 shows the map at 40 minutes. In this simulation scenario, as mentioned above, several roads become impassable for evacuation at 20 minutes. By comparing Figure 6 with Figure 7, we can detect that the alternative route is found since impassable roads appear near the shelter. From the above observation, we can clarify that our proposed system can construct an up-to-minute safe-road map of the disturbed disaster area.

5. Conclusion

In this paper, we proposed a map construction system for disaster areas based on ant colony systems. In our system, evacuees in disaster areas record the roads taken while evacuating to the shelter as data collection agents. When evacuees reach the shelter, recorded road information is gathered and restructured into a safe-map on the basis of ant colony systems. From the experimental results, we can confirm that our system can construct an up-to-minute safe-road map to the shelter in response to the changing situation in disaster areas.

For our future work, we try to apply this mechanism to a map information sharing system among evacuees. By using this system, evacuees can acquire safe routes and move to shelters more safely.

References


Fig. 5. Experimental result: elapsed time = 5 minutes

Fig. 6. Experimental result: elapsed time = 20 minutes
Fig. 7. Experimental result: elapsed time = 40 minutes