Development of a UAV-based Disaster Evacuation Support System: an Interim Report

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***Abstract*— We have developed a system that supports evacuation after disasters using Unmanned Aerial Vehicles (UAVs). We focus on addressing disasters in mountainous areas. We assume that the information infrastructure is paralyzed. We have two types of UAVs for this system. One type of UAVs, which we call monitoring UAVs, conducts road condition checks and collects information about affected individuals, while another type of UAVs, which we call guiding UAVs, guides the evacuees. The guided route is not simply the shortest path. The UAV selects the most suitable route based on the factors such as route safety and congestion levels. The monitoring UAV that grasps the situation informs the guiding UAVs of the route status as needed, allowing the guiding UAVs to dynamically adjust the evacuation route. Both UAVs share information by exchanging messages by way of a control server through ad hoc communication through an opportunistic network. We have developed a simulator to demonstrate the effectiveness of our system.**

Keywords- UAV Swarm ; Multi-Agent ; Swarm Robot.

I. INTRODUCTION

Japan faces a wide range of disasters, including earthquakes, typhoons, and tsunamis. Evacuation routes may become blocked due to river flooding, collapsed buildings, or landslides. Therefore, it is important to search for evacuation routes while considering these obstacles. In this paper, we propose an evacuation guidance system with the aim of preventing secondary disasters after the primary disaster. The reason why we focus on the secondary disasters is that evacuees may inadvertently go to the unpassable and dangerous area, resulting in delayed evacuation and exposing evacuees to secondary disasters. Particularly, in sparsely populated areas, such as mountainous regions, evacuees may not have access to information to assess the disaster situation due to the paralysis of communication infrastructure. Therefore, we have developed a system for evacuating using UAVs equipped with opportunistic networks, assuming situations where normal communication infrastructure is unavailable. Figure 1 illustrates the concept of our system.

As part of disaster preparedness, there are studies utilizing multiple UAVs for evacuation assistance. These studies assume that information infrastructure becomes paralyzed during disasters, and multiple UAVs equipped with agents collaborate to establish ad hoc communication networks, aiming to prevent secondary disasters. Efficient evacuation assistance using multiple UAVs in a Mobile Ad hoc Network (MANET) environment has been studied [1].We verified the evacuation assistance system through simulation, replicating the environment during actual disasters. In this study, each evacuee is treated as an independent object, enabling the simulation of individual behavior. This allows us to explore potential challenges that were previously undiscovered.

Figure 1. Conceptual diagram of the evacuation supports system.

In Section II, we review related research on UAV-based evacuation support systems. Section III details our proposed system, including its design and components. Section IV discusses the evacuation route algorithm. Section V covers the system's implementation in a simulator and its performance. Finally, Section VI concludes the paper and suggests future work directions.

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II. Related Research

Various evacuation support system researches have been conducted using mobile terminals and UAVs. Katayama et al. are pursuing one of the most notable projects that is an agent-based evacuation guidance support system using a UAV [1] [2]. Their system incorporated Internet of Things (IoT) devices and UAVs to monitor disaster situations and indicate the shortest evacuation route for evacuees while avoiding tsunami effects. Their UAVs mount visible light identification (ID) to guide evacuation routes. Even though the system is excellent, their system is specialized for coastal areas [3]. Our system is similar but is specialized for mountainous areas.

Taga et al. conducted another notable research project [4] [5]. They proposed a system that supports evacuation after the occurrence of a large-scale disaster using multi-agents built on a mobile ad hoc network (MANET). Their aim was to let the evacuees share information on MANET and to provide safe routes to their destinations based on the collected information. Their system is situated in rather crowded urban areas, and our system aims to provide evacuation support in a mountainous area.

Fujisawa and Miwa proposed a real-time disaster information sharing system based on an opportunistic communication for evacuation guidance [6]. We also plan to implement our system based on an opportunistic communication system. As Uno and Kashiyama stated, it is important to evaluate the evacuation behaviors of evacuees in the time of a disaster [7].

For efficient use of UAVs, it is important to provide evacuation routes as short as possible. Patel et al. proposed a Forward Backward Shortest Path (FBSP) evacuation routing algorithm that models the evacuation area as a graph with evacuation places as source nodes, shelter places as destination nodes, roads between places as edges, and evacuation routes as paths [8]. We employ a similar algorithm for our UAV flight planning. In order to achieve accurate and safe guidance for evacuees, we have to consider the moving speed of pedestrians. Rothkrantz and Popa provided efficient routing for pedestrians in a crowded city [9]. Even in mountainous areas, rushed evacuations can make crowded places along the evacuation route. We take into account this fact too.

III. Evacuation Support System

In this section, details our proposed evacuation support system, including its components.

A. System Overview

We conducted research on a system that assists in evacuation support by controlling a group of UAVs with agents to navigate autonomously. In the areas evacuation support is provided, we create a graph connecting points where people are present as nodes and connecting passable routes as edges. This graph represents the range of human activity. Each point is assigned a default priority for support. The derivation formula for priority is defined as equation (1).

$$priority = \alpha d + \beta t + \gamma U + \delta D \quad (1)$$

Here, α, β, γ, δ are empirically determined coefficients, d is the distance to the evacuation center, t is the average time to reach the destination from that point, U indicates the percentage of evacuees around that point, and D indicates the level of secondary disaster risk in and around that point. Thus, the impact of disasters on priority is considered.

In this study, wireless communication is assumed to be unusable during disasters. Multiple evacuation centers and points are provided in the area of operations, and an opportunistic communications network is established using UAVs. UAVs navigate between points, search for evacuees, and guide them to an evacuation center. Servers are installed at the evacuation centers to receive disaster information from UAVs visiting the centers and to calculate the optimal route.

The priority is updated each time a UAV reports on the disaster situation. UAVs have two roles: collecting information on disaster situations and guiding evacuees. Therefore, this system uses two types of UAVs for information gathering and evacuation guidance. UAVs for information gathering are referred to as UAV1 and those for evacuation guidance as UAV2.

B. UAV1

UAV1 is an information-gathering UAV that acquires information on disaster evacuees by flying in a width-priority exploratory flight over the graph, starting from the evacuation center. The data are conveyed through an opportunistic network and accumulated on a server located in the evacuation center. The server calculates an efficient evacuation route from the collected information on the evacuees. At that time, the priority of each point is updated, and the search is started again from the point with the highest priority. Therefore, there is a risk that once the priority has been lowered, the point may not be observed. However, UAV2 passes the information on evacuees found during evacuation guidance to UAV1, which can increase the priority.

C. UAV2

UAV2 is used for evacuee guidance. It receives the evacuation route generated by the server and guides the evacuees accordingly. It issues instructions for the evacuees to follow and provides guidance to the evacuation center. Simultaneously, if evacuees emitting signals from smartphones are detected, UAV2 transfers this information to UAV1, if it is in communication range. This helps prevent the disadvantage of points whose priority has decreased through not being observed again.

D. System Flow

UAV1 and UAV2 must coordinate their behaviors. The coordination is achieved through the information shared by them through the control server. Initially, UAV1 does not have information on the number of evacuees or the disaster situation. It first observes the overall situation by traversing all points in a breadth-first manner. The observed data are shared with the server installed at the evacuation center upon

UAV1's return. The server receives and stores information from the visited UAVs. Then, it generates and updates the priority score on the basis of this information, which is used to determine UAV1's subsequent movement routes. UAV1 focuses on navigating between points with high priority. During this process, if a UAV encounters another UAV, they exchange the information about the number of evacuees and the disaster situation.

Once the patrol of the points is complete, UAV1 returns to the departure evacuation center. It reports the number of evacuees and the disaster situation to the server at the evacuation center. The server updates the priority score and determines evacuation routes for each point based on the priority. The determined evacuation routes are then passed to UAV2 one by one.

When a UAV2 discovers evacuees, it sends a message to the evacuees to follow it. This message is transmitted to the evacuees' devices and emitted through flashing lights. UAV2 then guides them to the evacuation center.

If UAV2 confirms that a previously passable evacuation route observed by UAV1 is disrupted during guidance, making it impossible for evacuees to evacuate, it halts guidance, returns to the departure point, and informs the server accordingly. The server recalculates the new evacuation routes and relaunches UAV2. Additionally, UAV2 reports the number of evacuees, the disaster situation around the points, and its own status to other UAVs whenever they pass by. The server compiles this information. Consequently, the value of the priority scores necessary for UAV1's path generation changes in real time. This process repeats until all evacuees have completed evacuation.

IV. Algorithm for Determining Evacuation Routes

This system maps UAVs and human behavioral areas as a graph. Therefore, it can utilize evacuation route determination algorithms based on conventional shortest path algorithms. We took advantages of the algorithm of Patel et al [8].They invented an algorithm that simultaneously determines multiple routes in addition to the shortest path between the current location and destination (Figure 2).

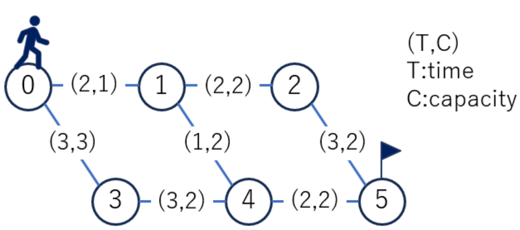

Figure 2. Graph example.

Consider the scenario in which an evacuee at node 0 evacuates to node 5. In this case, we select the shortest path from 0 to 5, which is 0-1-4-5. Then, the capacities of edges 0-1, 1-4, and 4-5 decrease by 1. The capacity becomes 0 for edge 0-1, while edges 1-4 and 4-5 become 1. Since the capacity of edge 0-1 becomes 0, it becomes impassable. Therefore, in the next step, we select an alternative shortest path that does not include edge 0-1, such as 0-3-4-5. This illustrates how multiple routes are selected simultaneously.

V. Implementation on a Simulator

In this study, to verify the evacuation support system, we developed a GUI simulator using Unity. Figure 3 and Figure 4 show the simulator in action. Unity is a game engine provided by Unity Technologies and is known for its versatility across various platforms. The development environment used was Unity 2020.3.27f1.

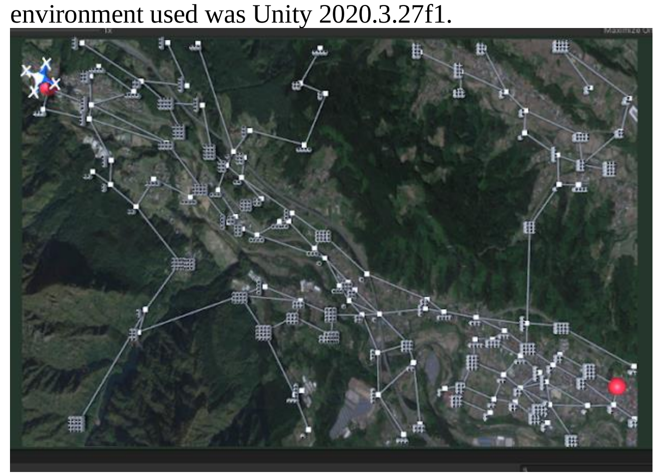

Figure 3. The GUI simulator.

The paths connecting points must allow UAVs to navigate and guide people that necessitate passable roads. In cases where neighboring points are connected by roads, linear movement is assumed between those points. Additionally, each point is assigned one of three levels of hazard: "Safe Point," "Disaster Alert Point," and "Impassable Point." The initial hazard level values were assigned as 0.25, 0.5, and 0.75, respectively. These hazard levels can be dynamically changed as the monitoring UAVs perceives the disaster situation.

We created a map based on actual road networks. Referring to maps provided by the Geospatial Information Authority of Japan, we set up road networks, as shown in Figure 3, focusing on roads designated for evacuation guidance.

When the simulation starts, the evacuees and UAVs are placed at each point. UAVs initiate evacuation support from the base, which is the evacuation shelter, where they are initially placed. Evacuees are assumed to move to the nearest intersection, and the simulation starts with evacuees placed at each intersection.

Evacuees are initially displayed as translucent objects before being discovered by UAVs. Once discovered by UAVs, they become opaque and visible. This allows for visual tracking of evacuees already discovered by UAVs during the simulation as shown in Figure 4. Additionally, observing the distribution of discovered evacuees provides insight into the progress of information gathering for evacuation support. Figure 5 shows the screen when the UAV for evacuation guidance (blue UAV) has completed eight attempts for guidance. The paths already traversed by the evacuation guidance UAV are colored green.

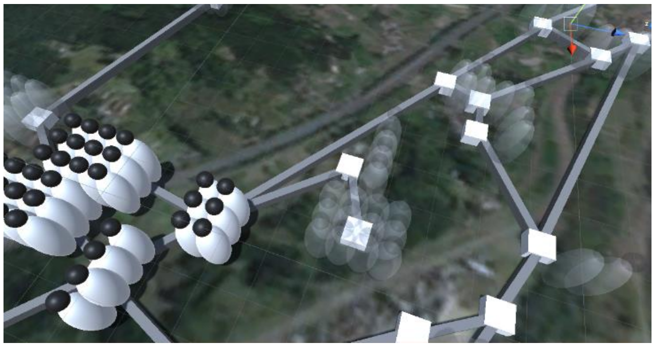

Figure 4. Representation of undiscovered evacuees as translucent.

Figure 5. UAV paths during evacuation guidance.

At this point, approximately half of the evacuees have been discovered, with their distribution observed to be biased toward the left side of the map. This bias is due to the monitoring UAVs initially follow a predetermined route to observe all points. Figure 5 also shows that UAVs guide evacuees in a situation where the distribution of evacuees remains unknown; because, at this time, not all the points have been observed yet, and UAVs are flying the predetermined routes.

Focusing on the flight paths of the displayed UAV2, we can observe that it has navigated points around the area relatively close to the evacuation shelter. Since guidance starts without information on the disaster situation, it is expected to begin from points relatively close to the shelter.

VI. CONCLUSION AND FUTURE WORK

We have developed a system that supports evacuation after disasters using UAVs. We focus on addressing disasters in mountainous areas. Since our assumption is a situation where the information infrastructure is paralyzed, we set two types of UAVs for this system. We created a simulator that displays the movement history of UAVs and people on a map so that we can observe their actions and discover problems. The map is based on Annaka City for a real-world scenario. As a result, we could observe the UAVs' actions and evacuees' behaviors as we predicted. We confirmed that this simulator can visually demonstrate UAV actions even to non-developer disaster experts.

As we proceed to build a better simulator, we must implement human behaviors more realistic than those of the current simulator. In actual disaster situations, it is presumed that evacuees autonomously undertake evacuation actions even when they are not guided by UAVs. For example, by applying ant colony optimization algorithms, it may be possible to mimic the actions of people avoiding dangerous areas and heading toward their destination. Simulating actions during periods when they are not guided by UAVs allows the verification of the impact of the evacuation support system on evacuation actions. In addition, we can focus on the people who failed to evacuate. Then, we must analyze their behavioral history to analyze whether they received adequate evacuation assistance. We believe our attempt to build this evacuation support system to create a new method to save people living in mountainous areas that are previously rather neglected in Japan.

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