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Motion algorithm for autonomous rescue agents based on information assistance system

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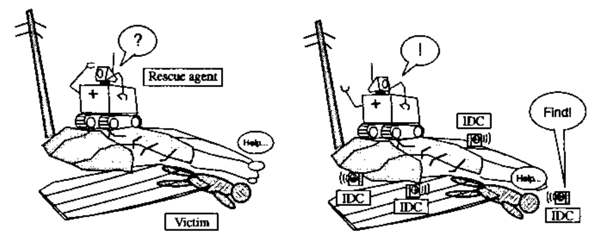
Abstract

In this paper, we propose an information assistance system and an algorithm for distributed rescue agents to improve their rescue activities. To save victims, finding them is quite important. We introduce a small intelligent device called "intelligent data carrier for rescue (IDC-R)" and a mediator blimp in order to search victims. Then, we propose an algorithm for distributed rescue agents to visit them, which needs few calcluation cost. We verify the effectiveness by carrying out simulations.



(a) Only rescue agent (b) Proposed approach

Figure 1: *Approach of information assistance in rescue*

1 Introduction

In 1995, the Hanshin-Awaji Earthquake killed more than 6,500 people and collapsed 80,000 wooden houses in Kobe. Contribution of robotics and information technologies is highly expected to mitigate such disaster damage. Now some researchers start to establish problems and solutions of information support system against such disasters [1]-[3]. Additionally, contest of rescue robots is proposed to encourage researches of rescue robotics [4]. In the case of earthquake disasters, one of the most important issues is providing information for action planning of disaster mitigation, search and rescue. However, information transmission may not work well because of breakdown of telecommunication networks.

So, we propose a system as infrastructure to find victims in disastrous area. The system works highly autonomously and independently in order to survive under disasters. As the basic concept, we realize "intelligent environment (Fig. 1)" such that it find and communicate people (victims) via local communication and information processing. We have already developed a device to find victims named "Intelligent Data Carrier for Rescue (IDC-R)".

In this paper, we propose a navigation algorithm for autonomous rescue agents according to the proposed victim search system.

The layout of this paper is as follows. In section 2, we describe system configuration of information assistance system. In section 3, we depict developed information assistance system and its working procedure. We denote navigation algorithms for autonomous rescue agents by using of the information assistance in section 4. Section 5 provides a summary of the paper.

2 Scope of this study

2.1 Approach and system configuration

On rescue activities, searching victims as soon as possible is quite important but very tough task. Usually, rescue agents (human rescue team, dogs, etc.) move around (sweep) suffered area. Although agents must be quite sensitive to find a victim, they have to walk around for long time.

Because sensing ability of a rescue agent is limited

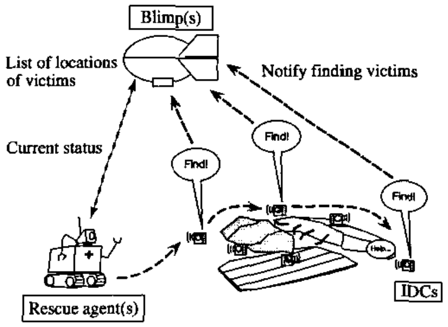


Figure 2: Overview of information assistance system

although victims are widely distributed. It is feasible to apply "distributed" way to find victims. So we propose a method to give "intelligence" onto an environment so that an environment itself find victims, specify their location, and notify rescue agents.

We apply local information management system, intelligent data carriers (IDC)[5]-[9], to find victims. Each IDC unit has its own CPU, memory and radio communication module. Because each IDC finds victims in distributed way, the proposed system can reduce load of rescue agent. We have added an IDC tag a function to find victims around it. We assume that IDCs are attached in advance on ceilings or walls in houses.

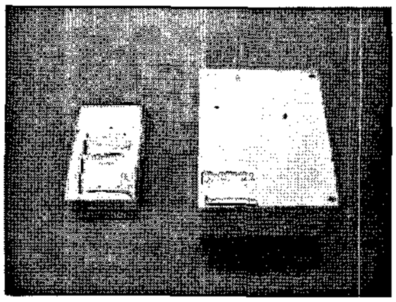
Then, rescue agent(s) should gather information of victims, especially locations of them, in order to plan to save them effectively. In other words, we have to calculate (semi) optimal path to visit victims. So, we have constructed our information assistance system as Fig. 2. We introduce a mediator blimp as an agent that moves around suffered area to sending wake up signal to and retrieve data from IDC, because an earthquake often destroys roads.

3 Information assistance system

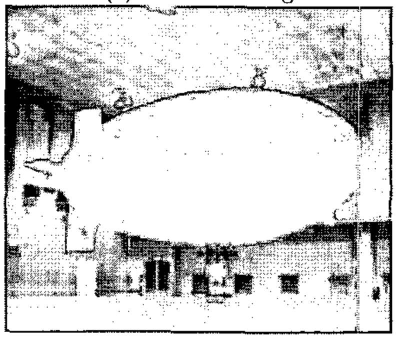
We propose novel information assistance system for rescue activities. The system is composed two devices. One is an intelligent data carrier for rescue (IDC-R) and the other is a mediator blimp.

3.1 IDC-R

We developed enhanced intelligent data carrier system for Rescue, named "IDC-R". Figure 3 depicts an IDC-R tag. Table 1 and Figure 4 illustrate the specifications of an IDC-R and its block diagram, respectively. It consists of two parts: core chip and voice management module. The core chip can work without any battery because the RF module generates enough electric power to drive its 12bit CPU and 1kbit memory. The core chip activates power manager and voice management module. The voice management module contains 16bit CPU, a voice generator, a speaker, a microphone, and 128 Kbytes memory. It can record 4[sec] × 8[times] voices.



(a) An IDC-R tag



(b) A mediator blimp

Figure 3: Photograph of an information assistance system

Table 1: Specifications of an IDC-R

CPU	16bit
Memory	1kbit (for location data) 128Kbytes (for voice recording)
Battery	Four NiMH batteries (1600mAH)
Size [mm]	118 x 95 x 61
Weight [g]	650
Frequency	125 [kHz]
Modulation	FSK, PSK

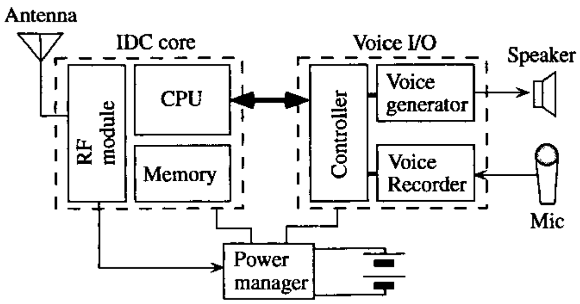


Figure 4: Block diagram of an IDC-R

Table 2: Specifications of a mediator blimp

Length	6.5 [m]
Width	3.0 [m]
Volume	30.6 [m^3]
Payload	8.0 [kg]
Max. speed	1.5 [m/s]
CPU	Intel DX4-66Mhz

3.2 A mediator blimp

In a suffered area, locomotion on the surface may be restricted because there is so much debris. So, we have developed a blimp that is equipped communication facilities among IDC-Rs and rescue agents. We call this blimp as a mediator blimp. It activates IDC-Rs and retrieves data from them. Figure 3(b) shows the developed blimp. The specifications of a mediator blimp are described in table 2. A mediator blimp is equipped with six fans (four for propelling, two for stabilizing), an antenna of IDC-R system, and a computer to control itself and to drive a reader/writer of IDC-R system on its gondola.

3.3 Searching procedure of an IDC-R

Here, we describe the procedure of finding victims by IDC-Re.

In order to search victims, we have added auditory functional feature to an IDC. An IDC-R is attached on wall or seal in advance. When a building or a house is collapsed, an IDC-R starts speaking "Is anybody here?" If a victim answers, an IDC-R records his voice. When we communicate an IDC-R that has voice data, we can see that there is at least a victim

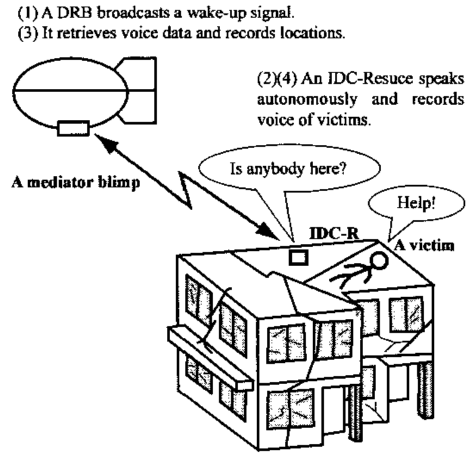


Figure 5: The procedure of searching victims by IDC-R

within few meters from the IDC-R.

Victim search process is as following (Fig. 5).

1. A mediator blimp flying over suffered area broadcasts wake-up signal to IDC-Rs that are buried with victims. An IDC-R receives the RF signal and starts its main CPU and voice I/O system up.
2. An IDC-R repeats speaking message to victims and recording their voice in certain interval.
3. A mediator blimp flying over suffered area broadcasts asking signal to IDC-Rs whether it has already recorded any voice or not. If an IDC-R has voice records, it sends its location data and the voice records to the mediator blimp.
4. After sending voice records, an IDC-R clear its memory and start speaking message and recording voices again.
5. A mediator blimp stores obtained information about victims and provide a black-board communication system among mobile rescue agents.

4 Motion algorithm for distributed rescue agents

4.1 Problem settlement

When a rescue system knows locations of victims, it should visit them and rescue as soon as possible. It

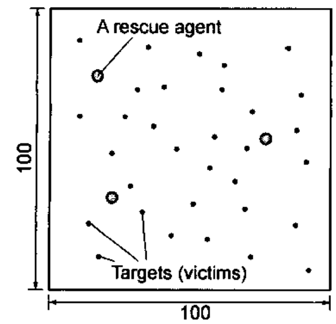


Figure 6: *A model of a suffered area.*

can be formulated as a multi-agent traveling salesman problem (m-TSP) when many distributed rescue agents compose a rescue system. Because a m-TSP is typical NP-Hard problem, we hardly obtain optimum solution by centralized computation within limited time. In this section, we propose a potential-added greedy algorithm that is suitable for distribute agents.

We assume a mobile robot as follows.

- A shape of a robot is a circle with radius r.
- A robot can move in any direction.
- Robots do not communicate each other.
- A robot knows positions and status of victims.

In this paper, we assume that a robot can know positions and status of victims by a black-board communication system on a mediator blimp. We set an environment for simulations as Fig. 6. The working area is a square with 100×100, in which several victims (targets) are located at random. A model of a robot is a circle with radius 2, and it can move at speed 1 per a step time.

4.2 A greedy-based algorithm

A greedy algorithm is quite simple. An agent always moves the nearest target from its current position. Although this algorithm requires quite few calculation cost, total traveling distance may be large. We improve a greedy algorithm by introducing potential functions.

One of causes the ineffectiveness of a greedy algorithm is concentration of robots. Because the algorithm is so simple, many robots may move toward to the same target. We introduce a potential function to the greedy algorithm in order to prevent concentration of robots. There are many researches on potential field for path planning algorithms [10]. Most of them make a potential field that generates repulsive force among robots and attractive force between a robot and its target. However, a robot driven by a potential field may move to open space where no target exists. We propose an algorithm that changes only order of targets to be visited by introducing potential-like functions to calculations of the distance between a robot and a target.

We propose two type potential functions. One is a function of distances from other robots. We call "distance potential." The other is that of order to be visited by other robots. We call "order potential."

Distance potential. Let us assume that robot i considers a potential of target k. There are n robots. The potential function is calculated by (1), where d_{jk} denotes the distance between robot j and target k, c_p is a static coefficient.

$$p_{ik} = \frac{1}{n-1}\sum_{j\neq i}^{n} exp\left(-c_p d_{jk}^2\right) \qquad (1)$$

Then, a robot regards $\hat{d}_{ik} = p_{ik}d_{ik}$ as a modified distance to decide "the nearest target" in the greedy algorithm.

Order potential. Let us assume, again, that robot i consider a potential of target k. The potential function is calculated by (2), where n_t and c_t are a static constant that indicate depth of order to estimate and a coefficient, respectively. n_j indicates number of other robots that are going to visit target k after $j-1$th visiting other targets.

$$q_{ik} = \frac{1}{\sum_{j=1}^{n_t} n_j}\sum_{j=1}^{n_t} n_j \exp(-c_t j^2) \qquad (2)$$

Then, a robot regards $\hat{d}_{ik} = (1+q_{ik})d_{ik}$ as a modified distance.

4.3 Simulation results

We have carried out simulations to verify the efficiency of the proposed algorithm. In the simulations we set $c_p = 2 \times 10^{-4}$, $n_t = 3$, $c_t = 10^{-5}$, number of victims are 120. We have compared following five conditions.

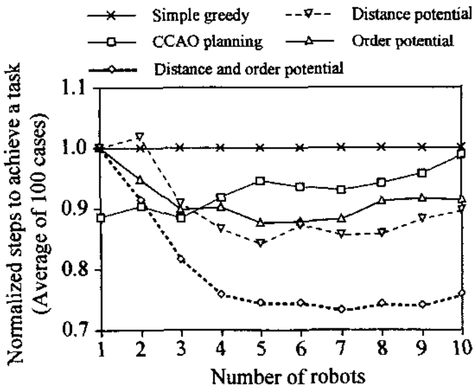


Figure 7: Performances of potential-added greedy algorithms

(a) Simple greedy algorithm.

(b) Planning by CCAO method [11].

(c) Distance potential only.

(d) Order potential only.

(e) Distance potential + Order potential.

We have carried out simulations by changing number of rescue agents. A line on the graph is normalized as the steps of the simple greedy algorithm become 1.0. By increasing number of agents, the proposed algorithm results about 25% less steps than that of the simple greedy algorithm.

4.4 Adaptation of potential function

Next, we denote an adaptation algorithm of potential function. By the results in Fig. 7, we verified effectiveness of the potential-added greedy algorithm. However, a parameter for potential function is designed by hand. Here, we denote a method to arrange the parameter autonomously by distributed agents.

The larger potential causes the more distribution of robots. So, we propose an algorithm to change a coefficient in the potential function based on the state of distribution both of targets and of them.

A mediator blimp examines standard deviation of targets and robots by (3), respectively. A mediator blimp divides a suffered area into $N \times N$ cells, and it counts number of cells that contains i targets (or robots). Then, average (expected number) μ_n and deviation σ_n are calculated by (4) and (5) respectively.

$$P_n(i) = \frac{n(i)}{N^2} \quad i = 1, 2, \cdots, m \tag{3}$$

$$\mu_n = \sum_{i=0}^{m} P(i)i = \frac{m}{N^2} \tag{4}$$

$$\sigma_n^2 = \sum_{i=0}^{m} (i - u_n)^2 P_n(i) \tag{5}$$

We introduce Poisson distribution as a criterion to evaluate deviations of targets and robots in a suffered area. The average and deviation of Poisson distribution are derived by (7) and (8) respectively, where $\lambda = m/N^2$.

$$P_p(i) = \frac{e^{-\lambda}\lambda^i}{i!} \quad i = 1, 2, \cdots, m \tag{6}$$

$$\mu_p = \lambda \tag{7}$$

$$\sigma_p^2 = \lambda \tag{8}$$

We normalize the distributions by m^2 as (9).

$$\tilde{\sigma}_n^2 = \frac{\sigma_n^2}{m^2} \quad \tilde{\sigma}_p^2 = \frac{\sigma_p^2}{m^2} \tag{9}$$

We represent distributions of targets and robots as ${}^T\tilde{\sigma}_n^2$ and ${}^R\tilde{\sigma}_n^2$ respectively.

To equalize distributions of targets and robots, we formulate (10) feedback.

$$\begin{aligned} e &= {}^T\tilde{\sigma}_n^2 - ({}^R\tilde{\sigma}_p^2 - {}^R\tilde{\sigma_n}^2) \\ c_p(t+1) &= c_p(t) - Ke \end{aligned} \tag{10}$$

where K denotes a constant gain.

Because the size of a suffered area is limited, a huge c_p reduces effectiveness of the proposed system. We design maximum c_p by (11), where d_{max} represents the maximum possible distance in a suffered area.

$$\begin{aligned} exp(-c_{max}d_{max}) &\geq 0.5 \\ \frac{\log 0.5}{-d_{max}} &= c_{max} \end{aligned} \tag{11}$$

We add a constraint $0 \leq c_p(t) \leq c_{max}$ to (10).

We have carried out simulations to verify the adaptability of the proposed algorithm. We have compared following four conditions.

(a) Simple greedy algorithm.

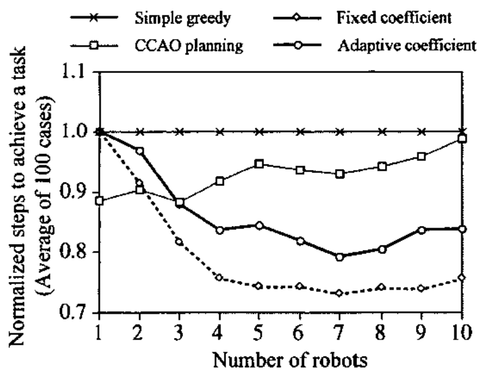


***Figure 8:** Comparison of fixed/adjusted coefficient in a potential function*

(b) Planning by CCAO method.

(c) Potential-added (fixed coefficient).

(d) Potential-added (Autonomous adjustment).

Figure 8 shows simulation results for 120 targets. We execute 100 time simulations for each condition. The vertical axis indicates normalized steps to finish a rescue task. Lines in a simulation results show the average of 100 results. The performace of the proposed algorithm (d) is about 15% better than that of the simple greedy algorithm, but about 10% worse than that of (c). The algorithm of autonomous adjustment cannot result supreme performance, but it is still much better than the simple greedy algorithm. By the results, we can say that the proposed algorithm adapts task conditions autonomously and can work effectively.

5 Conclusion

In this paper, we propose an information assistance system and an algorithm for distributed rescue agents to improve their rescue activities. We introduce a small intelligent device called "intelligent data carrier for rescue (IDC-R)" and a mediator blimp in order to search victims. An IDC-R is equipped auditory functionality to detect voices of victims. A mediator blimp can fly over a suffered area and can retrieve information about detected victims. We have actually developed the devices. Then, we propose an algorithm for distributed rescue agents to visit them. A task to visit all detected victims is a multi-agent traveling salesman problem that is classified to NP-Hard class. By introducing novel potential functions to a greedy algorithm, we have proposed an algorithm which needs few calculation cost. We also construct autonomous adaptation algorithm to a task condition. We have verified the effectiveness by carrying out simulations.

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