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Ad-hoc network positioning system for large scale disaster mitigation

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Human beings living on the earth always face with natural problem of disasters that are caused by both nature and human beings themselves. Actually, all of us do not like disasters to happen. But when they already happened, we have to mitigate their affects by rescuing people and precious things belonging to the cultural heritage of the world or a nation. In most disasters (from earthquakes to volcanoes, and even fires or explosions), we get difficulty in locating the people or things to rescue because they are somewhere in the ruin, we can not excavate the whole ruin of a city to find out them. So, it is very convenient to know their positions to reduce the finding time. This paper proposes a technical solution by using distributed GPS-free ad-hoc network SOM based positioning algorithm in such disaster cases. With the results from intensive simulations, it is showed that the algorithm can yield a good accuracy suitable in disaster situations.

Key Words : *Disaster, Ad-hoc network, GPS-free, positioning, distributed, SOM.*

1. Introduction

(1) The impact of the recent disasters

Recently, people around the world have been facing with many disasters caused by both the nature and by the human beings. These disasters can be categorized as natural disasters and technological disasters. Sometimes, the natural disasters are also caused by human being themselves indirectly, for example, floods caused by forest destructions. Japan is one of countries having many precious urban cultural heritages like Kyoto. Vietnam also has ancient cities like Hoi An or ancient Hanoi down town area, and faces many natural disasters mainly floods and storms. Inside these historic cities, there are many antiques belong to the cultural heritage of a country through out the history. Their size is ranging from small to very big, from easy to very difficult to observe. Many objects are sensitive to the outdoor environment like archaic paintings, imperial edicts in Hoi An, Hue or other cities of Vietnam. These objects may be held at the museums or owned by individuals. When a disaster occurs, their locations are changed in unpredictable manner. Japan is located in a geological area with many natural events like earthquakes or volcanoes. In general, all countries have to pay much attention to the disaster mitigation, but Japan has to pay much more consideration to the disaster mitigation of urban cultural heritage in particular. As shown in Table 1, we can see that in the last 3 decades, many Japanese people are affected by the natural disasters. Besides the affections on people, disasters also affect the economy with a huge value. Especially, the affection that can not be measured that is the affection on the cultural heritage of the society; many ancient houses damaged, many precious objects lost. It is obvious that many lost objects can not be recovered because they belong to the cultural legacy of a period in the history of the mankind.

(2) Technology investigation to the disaster mitigation

Nowadays, the advances in science and technology let us think a bout applying more ideal solutions in disaster prediction, control, and mitigation. Through out this paper, we will focus on the technological aspect of the disaster mitigation problem. All of us have an imagination about the scenes after each disaster: houses damaged, people are injured or killed or got stuck somewhere in the ruin. At any cost, the more lucky people have the duty to help affected people from death or find out them.

To achieve the goal of locating the people or objects, there are many methods ranging from manually locating the people by the first aid men to modern technologies. But as the narration of the lucky rescued people in recent disasters, we can think about if they had high technological devices, then they would have been rescued immediately, and would not have suffered so much from thirst or pain.

In most large scale disasters, electricity is cut off, so when applying any method we will consider the power supply for such high technological devices. But, thanks to the advances in science and technology, many wireless devices now consume very little power, and they can last for 5 years of idle state, and several days to a week of active state. An example of such devices are the Zigbee 802.15.4 devices with cheap price, long range communication, and very little power consumption. We can think about the case when all people and precious objects equipped with these wearable devices together with the similar devices from the first aid men will form a wireless ad-hoc network as showed in Fig.1. Then we apply a positioning algorithm so that all devices can know their and others' location. At that time, the first aid men will easily find out the location of the people or object to rescue. Besides that, the people need help also know about the locations around them and are helped to escape from the danger.

Table 1. *Summarized data of natural disasters in Japan from 1979 to 2008 (source EM-DAT[9]).*

Category	Sub-category	# of Events	Killed	Total Affected	Damage US$ (000's)
Earthquake	Earthquake	29	5,755	3,298,448	144,994,400
	ave. per event		198	113,740	4,999,807
Wind Storm	Typhoon	58	1,022	1,483,772	49,633,100
	ave. per event		18	25,582	855,743

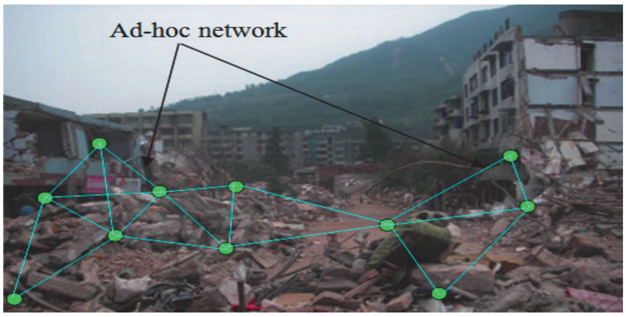


Fig.1 Ad-hoc network implementation (background photo from www.GRMcat.com[10]).

As we know that GPS positioning system is not effective in indoor and environments having obstacles. Obstacles interfere the radio propagations. So in our work, we considered the GPS-free ad-hoc network positioning system which can be applied to the circumstances with obstacles like disaster cases.

2. Distributed GPS-free SOM based positioning algorithm

(1) Related works

Recently, ad-hoc network positioning has been received attention from many researchers. Many algorithms and solutions have been presented so far. These algorithms are ranging from simple to complicated schemes, but they can be categorized as range-based and range-free algorithms. In the range-free algorithms, they utilize only the connectivity information and the number of hops between nodes. The others utilize the distances measured between nodes by using either Time-Of-Arrival (TOA), Time-Differential-Of-Arrival (TDOA), Angle-Of-Arrival, or Received-Signal-Strength-Indicator (RSSI) technologies. The latter category usually needs extra hardware to achieve such measurement. Besides that, when calculating the absolute location, most algorithms will need at least three landmarks that are nodes equipped with Global Positioning System (GPS). In our solution, we use some access points that we already know their location.

In the first category, we can mention the DV-HOP algorithm proposed by Niculescu and Nath1) as an Ad-hoc Positioning System (APS). DV-HOP uses distance-vector flooding technique to get the minimum hop count and average hop-distance from a node to known anchors' locations. By using corrections calculated by anchors (average hop-distance between anchors), nodes will calculate their location by using lateration (triangulation) method. The second category utilizes of some additional measurements. An example for this category such as DV-Distance.

In the contrary, some other algorithms seem to be more complicated but has better accuracy. An example is the Multi-Dimensional Scaling Map (MDS-MAP) proposed by Yi Shang et al2). MDS-MAP is originated from a data analysis technique by displaying distance-like data in geometrical visualization. It computes the shortest path between all pairs of nodes to build a distance matrix then apply the classical MDS to this matrix to retain the first 2 largest eigenvalues and eigenvectors to a 2-D relative map. After that, given 3 known anchors, it transforms the relative map to an absolute map based on absolute location of anchors. This method is implemented centrally.

(2) Self-Organizing Maps

The Self-Organizing Maps (SOM) was invented by T. Kohonen4). SOM provides a technique to represent multidimensional data into much lower dimensional spaces usually one or two dimensions. It uses a process known as vector quantization. In fact, SOM is a neural network working in un-supervised learning manner. Fig.2 illustrates a SOM network of 4 by 4 nodes lattice, each node has a specific topological location (x, y coordinates in the lattice) contains a weight vector. The SOM learning process is summarized as follows.

a) Assign a random weight vector to each node, $w_{i,j}$.
b) Present an input pattern, x, to the input layer of SOM.
c) Calculate the distance between input, x, and the weight vector of each neuron w_j to identify the winning neuron as $d = \| x - w_j \|$ with ||.|| is Euclidean norm.
d) Adjust the weights of all nodes in the neighborhood of the winning node as,

$$w_{i,j}(n+1) = w_{i,j}(n) + \gamma(n) h_i(n) (x_i(n) - w_{i,j}(n))$$

where $h_i(n)$ is the value of the neighborhood function and $0 < \gamma(n)$ is the learning rate.

e) Repeat step a) to d) until the convergence criterion is satisfied.

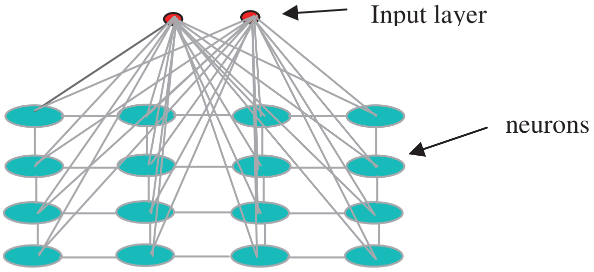


Fig.2 Two-dimensional SOM network.

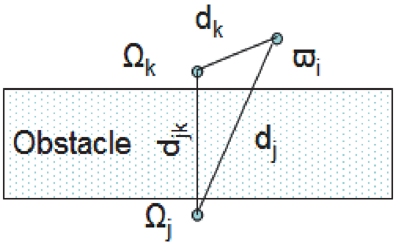


Fig.3 Obstacle illustration.

(3) Our proposed distributed GPS-free SOM based positioning algorithm

We propose a novel distributed SOM based positioning algorithm that takes the impact of obstacles into account with some modification to our past work3). Because most positioning algorithms presented so far do not pay much attention about this aspect. But in the disaster scenarios, many obstacles exist like ruin and buildings. To simplify the calculation, we assume that nodes will have the same radio range (r). The algorithm detail can be divided into 2 stages.

The first stage is the initialization stage. At this stage, anchors with known location broadcast their locations over the network. After this stage, each node determines the shortest path to each anchor in the hop count manner. The following terminologies are used throughout the paper,

The target ad-hoc network formed by G anchors with known locations Ω_i (i=1,2, …,G) and N nodes with unknown actual locations ω_i (i=1, 2,…, N), and we have to calculate the estimated locations of nodes as ϖ_i (i=1,2,…,N). The criterion from a node to the anchor with location Ω_i is calculated as follows.

$$cor = \frac{d}{hop.r.\theta} - 1 \tag{1}$$

Where d is the distance between supposed location of a node to an anchor, hop is the number of hops from that node to that anchor, and θ is a correction from a node to the anchor. By using intensive simulation, the distribution of θ is around 0.71. We also denote the number of nodes that a node i can communicate directly as N_i, and those estimated locations of its neighbors as $\varpi_{i,j}$ (j=1,2,…, N_i). A node i also hears G_i anchors with locations $\Omega_{i,j}$ (j=1,2,…, G_i).

At the end of this stage, we also apply our newly proposed obstacle avoidance algorithm. Let's consider the case when obstacles are inside the topology (as illustrated in Fig.3). Consider the triangle formed by node i and two anchors j and k. In this triangle we have the inequality $\mathbf{d_j \le d_k + d_{j,k}}$. If $\mathbf{d_j > d_k + d_{j,k}}$, we can conclude that there must be obstacles or holes between these two anchors. In that case, $\mathbf{d_j}$ needs correcting.
We propose a simple and robust algorithm to correct the distance from a node i to the anchor j as follows.

<u>Algorithm 1: Obstacle avoidance</u>

```
minhop← hop(j)
for i=1 to Gi
    mhop←hop(i)+ |Ωj - Ωi|.sqrt(2)/r
    if (hop(j) > mhop) and (mhop<minHop)
        minhop←mhop
    end if
end for
corj←|ϖi-Ωj|/(r.minhop).sqrt(2) -1
```

In the second stage, nodes will repetitively calculate their locations based on following phases at each SOM learning step.

a) Phase 1: Each node forwards its estimated location to all of its neighbors, so it also knows locations of all neighbors as $\varpi_{i,j}$ (j=1,2,…, N_i). At the first step of SOM, nodes also calculate their initial locations based on simple DV-HOP algorithm.

b) Phase 2: A node i updates its neighbors' estimated locations based on some constraints about connectivity. First, we define a set of nodes satisfy $|\varpi_i - \varpi_{i,j}| > r$ as $\{ j_\ell \mid \ell = 1,2,...,U_i \} \subseteq \{1,2,...,N_i\}$, then node i calculates a revising vector Vi as (2),

$$V_i = \frac{1}{U_i} \sum_{\ell=1}^{U_i} \frac{r - |\varpi_i - \varpi_{i,j_l}|}{|\varpi_i - \varpi_{i,j_l}|} (\varpi_i - \varpi_{i,j_l}) \tag{2}$$

Then it updates the estimated neighbors' locations $\varpi_{i,j}$ (j=1,2,…, N_i) based on the following formulas,

$$\Delta_{i,j} = \frac{\alpha(m).(\varpi_i - \varpi_{i,j})}{F_i} \qquad \varpi_{i,j} \leftarrow \varpi_{i,j} + \left\{ \Delta_{i,j} + q(m).|\Delta_{i,j}|.\frac{V_i}{|V_i|} \right\}$$

$$q(m) = \left\{ 1 + \exp\left(\frac{uT - m}{vT} \right) \right\}^{-1} \qquad \alpha(m) = \exp\left(-\frac{m+1}{T} \right) \qquad F_i = \begin{cases} \dfrac{N_i}{U_i} & U_i \ne 0 \\ N_i + 1 & U_i = 0 \end{cases}$$

c) Phase 3: After receiving estimated locations from the neighbors, node i then calculates its new estimated location base on (3),

$$\varpi_i = \frac{1}{N_i + 1} \left(\sum_{j=1}^{N_i} \varpi_{j,i} + \varpi_i \right) \tag{3}$$

d) Phase 4: Each node then utilizes the locations from heard anchors to adjust its estimated location based on the following formulas,

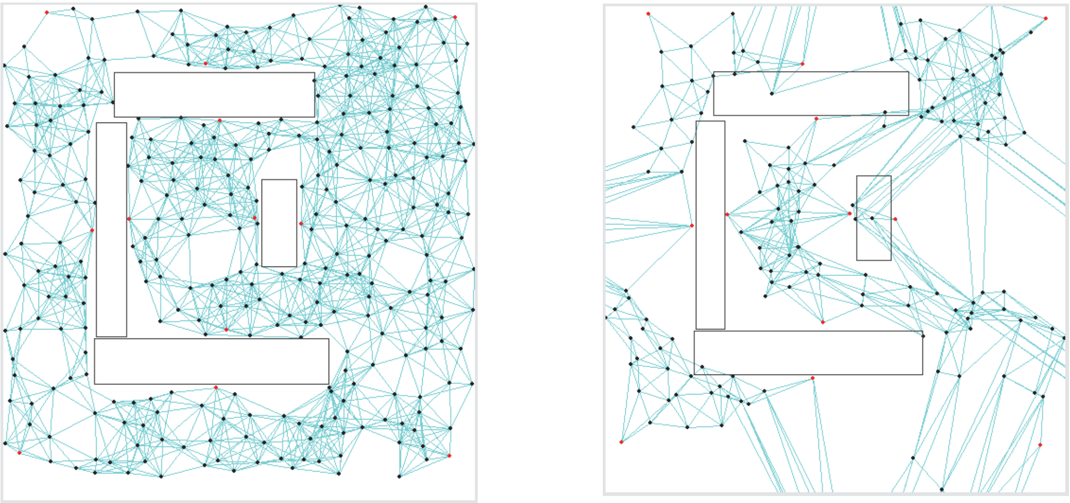
$$\Phi_i = \frac{1}{G_i}\sum_{j=1}^{G_i} W(cor_j)\frac{(\Omega_{i,j}-\varpi_i)}{|\Omega_{i,j}-\varpi_i|} \qquad \varpi_i \leftarrow \varpi_i + \Phi_i \qquad W(x)=\begin{cases}-a.x^2 & (-1 \le x \le 0)\\ a.x^2 & (0 \le x \le 1)\\ a & x > 1\end{cases}$$

(4) The simulation results

The algorithm is evaluated by using absolute error metric (ratio to the radio range) as described in (4),

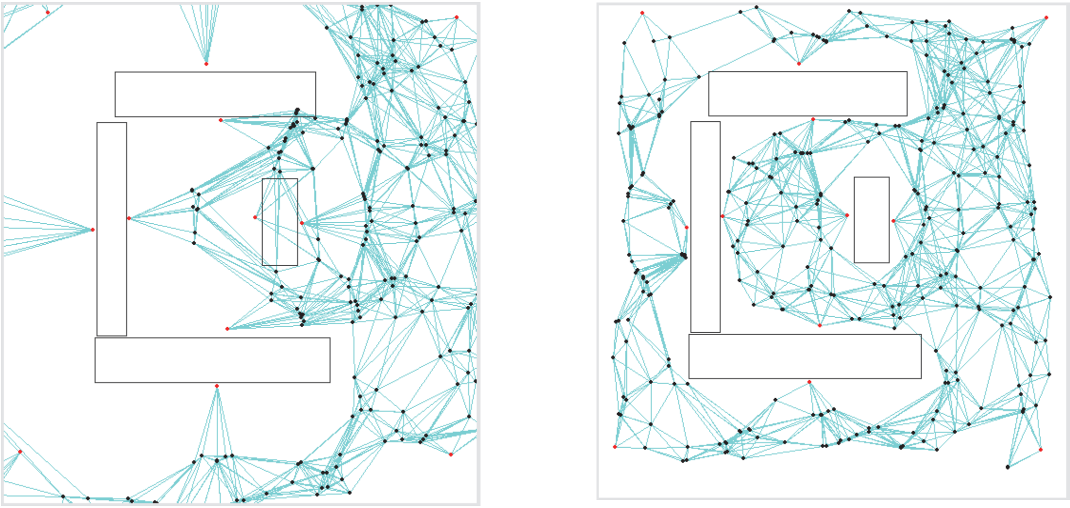
$$Err_{avg} = \frac{1}{N}\sum_{i=1}^{N}\frac{|\varpi_i - \omega_i|}{r} \tag{4}$$

The simulation is intensively conducted using our written Java application on many network topologies with nodes randomly distributed on an area of 1 by 1. Fig.4(a) shows one of original topologies. Fig.4(b), Fig.4(c) and Fig.4(d) show the estimated topologies with the DV-HOP, original and the proposed method, respectively. In these figures, rectangles, red dots, black dots, and cyan lines represent the obstacles, anchors, nodes, and one-hop connections between nodes, respectively. The average absolute error (ratio of r) with radio range variance (N.r^2) is showed in Fig.5.



(a) Actual topology.

(a) Estimated topology with DV-HOP.



(c) Estimated topology with original SOM method.

(d) Estimated topology with our proposed method.

Fig.4 Actual and estimated topologies.

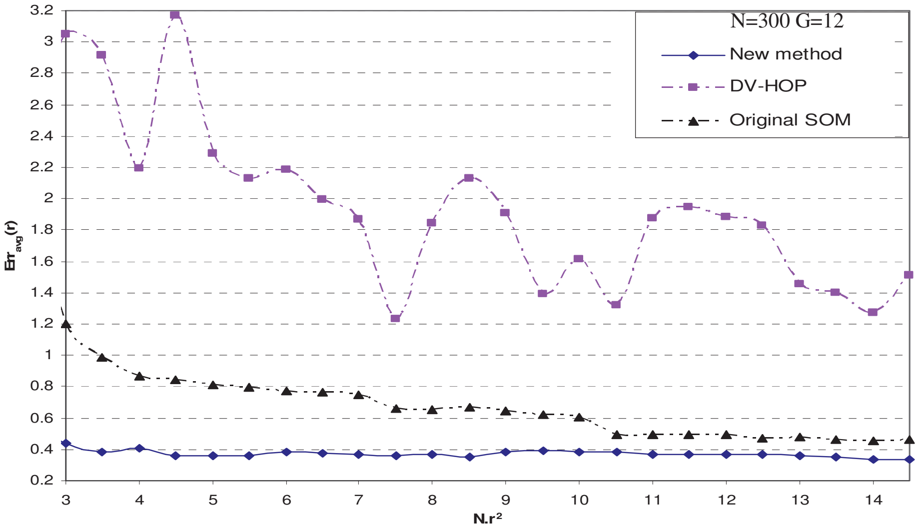


Fig.5 Performance evaluation.

From the results, it is clear that the proposed method has noticeable improvements over the original method and much better then the DV-HOP. Especially at lower connectivity level, the proposed method get rather good accuracy. For the disaster cases, we can think about the solution of locating objects by apply this method to the global area, then to the narrow area near the objects that we calculated in global area. By using step-by-step narrowing the area of searching, we will finally locate the exact location of objects.

3. Conclusions

Our proposed distributed GPS-free ad-hoc positioning algorithm based on SOM has gained improvements over the original SOM and the DV-HOP method, not only to nodes near the obstacles, but also the whole topology. And we find that this method is suitable for the disaster mitigation scenarios. Future work will investigate in a more precise distance measurement to gain satisfactory accuracy as well as apply it in the real situations.

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