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Performance evaluation of sensor node deployment strategy for maintaining wireless sensor network communication connectivity

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Abstract– We propose a wireless sensor networks construction method with maintaining the communication connectivity by utilizing a mobile rescue robot. Recent studies concerning with a reducing of disaster damage are focused on gathering disaster area information in underground spaces. Since the underground space has some risks of secondary disasters, a lot of rescue workers were injured or killed in the past. Because of this background, gathering information by utilizing the rescue robot is discussed in wide area. However, the fixed-point observation that is important to reduce the disaster damage and to construct a communication infrastructure for tele-operation of the rescue robot has not been discussed deeply. Thus we have been discussed about the gathering information method by utilizing wireless sensor networks that is constructed by the rescue robot. In this paper, we evaluated the proposed method in field operation test, which is confirmed the availability of performance.

1. Introduction

Gathering information in disaster areas is very important for assessing the situation, avoiding secondary disasters, and managing disaster reduction [1]. In general, bird's-eye image information gathered by unmanned air vehicles (UAVs) and artificial satellites is useful for understanding post-disaster situation. However, in an underground space in the city part where such UAVs etc. cannot gather information, it is difficult to ascertain the extent of the damage, which is important for avoiding secondary disasters [2]. Also, rescue teams cannot organize a suitable rescue plan for underground spaces because sufficient information is not gathered. Under such a situation, the rescue team must go into the underground spaces directly to gather disaster information, and the information should be shared within the teams by communication between above ground and underground space for efficient and cooperative rescue works. However, when the communication infrastructure is broken due to damage, rescue teams cannot cooperate closely because of communication disconnection. Therefore, the rescue team has to work in the underground space with being unable to know the situation correctly, and they face the added risk of secondary disasters. For example, in the underground disasters in Korea in 2003, a lot of rescue workers were sacrificed because of smoke damage. The rescue teams could not expect the smoke damage because they could not gather enough information about post-disaster situation in underground space, thus many lives were lost. This is a typical case of underground disaster damage due to secondary disasters that has triggered because the rescue teams entered underground areas without adequate information. From discussions based on past-accidents analysis, researchers have recently focused on a disaster information gathering method using a wireless sensor network (WSN) and a rescue robot in closed areas. The WSN consists of spatially distributed sensor nodes (SNs) to cooperatively monitor physical or environmental conditions such as temperature, sound, vibration, pressure, motion, etc. Then, the WSN is enabled to provide the wireless communication function in place without existing infrastructure. The WSN in closed area is constructed by rescue robot. Therefore, an information gathering method by constructing the communication infrastructure to disaster area by using the WSN has been discussed. One of them, a SN deployment strategy by utilizing the rescue robot is very important to the performance evaluation of adaptability in closed space. Many SN deployment strategies have been discussed in the WSN research field. In these strategies, deployment methods have been proposed based on evaluation scales that consider factors such as packet routing, energy efficiency, power saving, and coverage area.

Several SN deployment methods using mobile SNs and mobile robots to construct the WSN have been developed. Parker et al. proposed the WSN construction method using an autonomous helicopter for environmental monitoring and urban search and rescue [3]. Umeki et al. proposed an ad-hoc network system, Sky Mesh, using a flying balloon for targeted disaster rescue support [4]. Also, deployment methods have been developed based on virtual interaction between the SNs based on several physical models, such as the potential field model and the fluid flow model [5].

A great deal of effort has been made on SN deployment strategy. However, what seems to be lacking is the strategy that is considered the specification of underground space and maintaining of the WSN communication connectivity by utilizing rescue robot. Then, communication connectivity of the WSN in underground space is important to maintain the information gathering system, it is necessary to prevent the secondly disaster. Therefore we have been discussing a SN deployment strategy that is considered these important matters (Fig. 1) [6][7]. In this paper, we proposed the novel deployment strategy and evaluated the proposed method in field operation test.

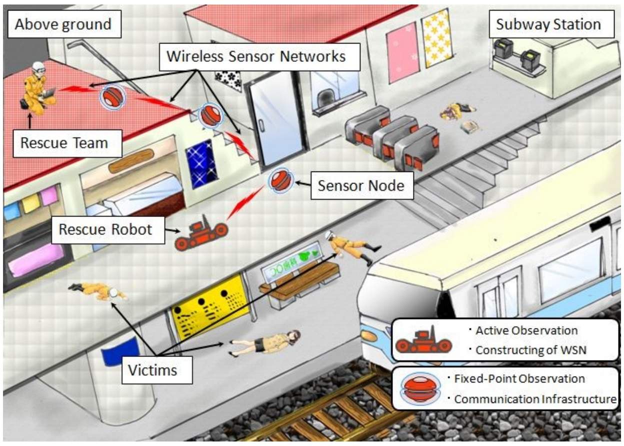


Fig. 1 Gathering disaster area information by utilizing wireless sensor networks and rescue robot

2. Deployment Strategy for Maintaining Communication Connectivity by Utilizing Rescue Robot

2.1 Prior Conditions

In this method, the WSN is constructed by utilizing rescue robot to deploy SNs. In the construction environment that is deployed SN, we assume the place that has entrance stairs and the first basement floor. First of all, the activity of gathering disaster area information in underground space needs this area's information. Then in Japan, the entrance stairs in under-ground is required to set up at intervals 30 [m] and passage way is built in line. Therefore in our proposed system gathers this area's information.

IEEE 802.11b is adopted for wireless communication between SNs including the rescue robot, which has been used as proven communication in many studies of the mobile robot and the WSN.

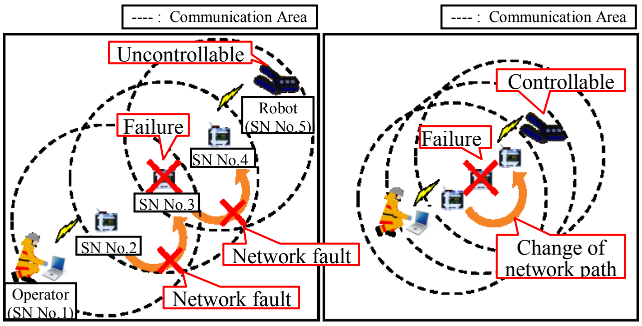
2.2 Requested Specifications

Teleoperation of the rescue robot by utilizing IEEE 802.11b need to keep the throughput that is over 1.0 [Mbps] in between the operator and the rescue robot (end-to-end communications). In the construction of the WSN by utilizing the rescue robot, the throughput between end-to-end communications has to maintain in the underground area. The construction length of the WSN is required 50 [m] by concerning the distance of first basement floor 30 [m] and entrance stairs 20 [m]. Moreover, this network consists of linearly aligned SNs to prevent the error of routing control and lowering of communication reliability occurring by random deployment of a lot of SNs. Then the number of SNs that can maintain over 1.0 [Mbps] is 4 nodes. Therefore the network consists of three SNs and the rescue robot regarded as the SN (Fig. 2).

2.3 SN Deployment Strategy

To keep the throughput, the electrical field density (RSSI) in the distance between two adjacent SNs (1 [Hop]) requires over -86 [dBm]. Throughput requires over 6.8 [Mbps] in this condition. To maintain the communication connectivity in the situation where the SN failure due to the battery problems and the radio propagation environment change occurs, the SNs have to be deployed in the place keeping RSSI to over -86 [dBm]. In the decision of deployment position, measuring the end-to-end throughput and the RSSI of 1 [Hop] is required.

Therefore, our proposed algorithm requires the repetitive measurement of communication quality and the movement of rescue robot. The SNs are deployed by the rescue robot in decided place. Moreover, our deployment method is designed to extend the end-to-end distance concerning the terminatory distance that can maintain the communication quality. Figure 3 shows the workflow of this deployment strategy. In the workflow, N is parameter of previously deployed SN ID, M is the number of un-deployment SN. The workflow is outlined below.



(a)A problem of Existing Method (b)Proposed Method

Fig. 2 Wireless sensor node deployment method

(1). Rescue robot deploys the first SN in the point of 0 [m], the deployed SN is numbered the ID "*N*" (initial value = 1). The secondary SN is numbered the ID "*M*" (initial value = 2).

(2). After the moving of the rescue robot, the operator observes the RSSI between SNs "*N*" and "*M*".

(3). If the RSSI is higher than -86 [dBm], the operator measures the throughput between the end-to-end communications. Moreover if the throughput is over 1.0 [Mbps], the rescue robot keeps task to construct the WSN. If the deployed SN ID is "*N*= 1" in the situation that the RSSI is lower than -86 [dBm] or the throughput is not enough 1 [Mbps], the rescue robot goes back a distance of "*D*" [m] that is the half distance of the total movement distance.

(4). After the movement, the rescue robot deploys the SN of ID "*M*". The rescue robot moves to the point of "*D*" [m] after the deployment.

(5). The rescue robot deploys the SN of ID "*M*++" in the point of "*D*" [m]. In this time, the parameters of "*N*" and "*M*" are changed to "*N*"=2 and "*M*"=4. And then, the rescue robot keeps deployment of the SN in the point maintaining the RSSI and the throughput. ("N"!=1 or "M"==5)

(6). Then the above deployment (5.), the rescue robot deploys the SN and updates it's parameters.(*N*=*N*++, *M*=*M*++)

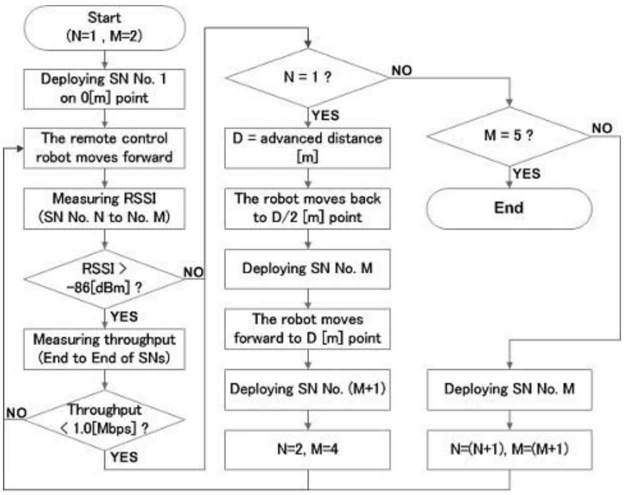


Fig. 3 Workflow of wireless sensor node deployment method

3. Communication Quality Evaluation of WSN Deployed by Using Proposed Model

3.1 Experimental condition

We verified the above-mentioned algorithm by actually constructing the WSN using the rescue robot. In this experiment, we evaluated the extended distance and the throughput between end-to-end communications in the situation of the SN failure in the WSN.

To construct the WSN, the SN device shown in Fig. 4 was developed. This SN mounts the CPU board, IEEE 802.11b/g wireless communication device, a digital camera, an A/D converter and a battery. It enables to construct the WSN by utilizing the Ad-Hoc application "AODV-uu". Table 1 shows the specification of this SN.

The crawler-type mobile robot,"S-90LWX" (TOPY INDUSTRIES, LIMITED), in Fig. 5 is adopted as the rescue robot in this experiment. The SN deployment mechanism was developed for the WSN construction and installed to the rescue robot, which can mount up to five SNs using five solenoid-operated locks. The crawler robot and the deployment mechanism can be operated remotely by the operator.

In this experiment, we measured the throughput and the RSSI three times every 1 [m] intervals, and calculated the average at each measuring point.

Generally, a wireless communication quality in physical layer level is measured using the spectrum analyzer in anechoic chamber. For the RSSI measurement in this experiment, however, we used "iwlist" command contained in the Linux wireless tools package because we aimed to evaluate the transport layer level communication. To measure the packet throughput, "utest" (NTTPC Communications Ltd.) was used. The experiment is performed in passageway with a length of 150 [m] or more in Tokyo Denki University, and the rescue robot constructed WSN in this passageway.

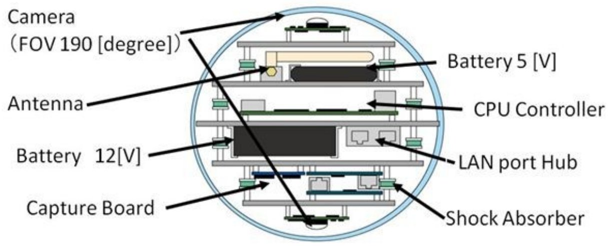


Fig. 4 Wireless sensor node

Table 1 Specification of wireless sensor node

Sensor Node	
CPU board	Armadillo-300 (ARM 200[MHz])
Web camera	Axis 207MW
Fish eye lens	Nissin 4CH190 (AOV 190[deg])
Weight	1.5 [kg]
Height×Width×Length	225 [mm] × 180 [mm] × 380 [mm]

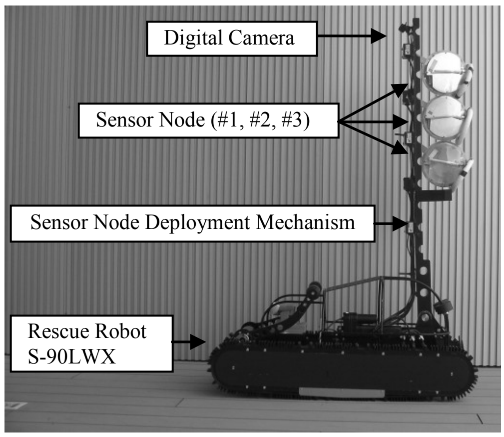


Fig. 5 Rescue robot mounting sensor node

3.2 Experimental Results

Figure 6 shows the results of the throughput between end-to-end communications and the RSSI between two SNs for a distance of 83 [m]. Arrowed lines on the bottom of graph indicate the deployment distance between two SNs of the RSSI. In the experiment, the RSSI was decreased to -87 [dBm] at 83 [m]. Therefore we confirmed the extended distance for the WSN construction with keeping the throughput of 1 [Mbps] is 82 [m] at this experimental situation.

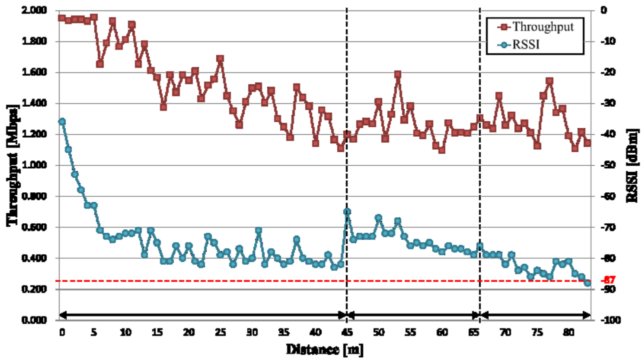


Fig. 6 Experimental result (RSSI, Throughput)

After constructing the WSN, we verified the throughput between end-to-end communications in the situation of a SN failure in the WSN. Table 2 shows the experimental results of the throughput after changing network path. The throughput was maintained more than 1.5 [Mbps] in all the distance.

Table 2 Throughput between End to End in the situation that has a fault sensor node in the WSN

Fault SN ID	End-to-End Throughput [Mbps]
No.2	1.594
No.3	1.730
No.4	1.845

4. Discussion

In this communication quality evaluation, we confirmed the WSN that has the maintenance capability of throughput between end-to-end communications by utilizing proposed method was constructed by the rescue robot. The extended distance of the WSN in end-to-end communications was 82 [m]. The movement distance of the rescue robot was 45 [m] that is the terminatory parameter of the RSSI without extending the WSN.

Then the maintenance capability of throughput in the situation of a SN failure was confirmed. The experimental result shows the throughput was more than 1.5 [Mbps] in all the distance. Therefore we confirmed the SNs of either side of a disabled SN were connected at the throughput more than 1.0 [Mbps].

5. Conclusion

This paper proposed the WSN deployment strategy that maintains throughput and performs a fault-tolerant communication connection. The proposed strategy maintained communication conditions such that the throughput between end-to-end communications in the WSN enables smooth tele-operation of the mobile rescue robot in a post-disaster underground space. Experimental results showed the effectiveness of the proposed strategy.

The rapid implementation of actions to reduce secondary disasters in disaster areas requires the stable referral of disaster information. Therefore, this strategy which prevents communication disconnection caused by SN failure is effective for WSN deployment in actual disaster scenarios. We will apply the proposed strategy to WSN deployment in practical underground space in the future.

Acknowledgments

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References

[1] Y. Kawata, “The great Hanshin-Awaji earthquake disaster: damage, social response, and recovery,” Journal of Natural Disaster Science, Vol. 17, No. 2, pp.1-12, 1995.

[2] H. Kawakata, Y. Kawata, H. Hayashi, T. Tanaka, K. C. Topping, K. Yamori, P. Yoshitomi, G. Urakawa and T. Kugai, “Building an integrated database management system of information on disaster hazard, risk, and recovery process” Annuals of Disas. Prev. Res. Inst., Kyoto Univ., No.47 C, 2004.

[3] Parker, E., L., Kannan, B., Xiaoquan, F., Yifan, T. (2003). Heterogeneous Mobile Sensor Net Deployment Using Robot Herding and Line of Sight Fromations, Proceedings of 2003 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2003), Volume 3. pp.2488-2493.

[4] Umeki, T., Okada, H., Mase, K. (2009). Evaluation of Wireless Channel Quality for an Ad Hoc Network in the Sky, SKYMESH, The Sixth International Symposium on Wireless Communication Systems 2009 (ISWCS’09). pp.585-589.

[5] Howard, A., Matric, J., M., and Sukhatme, S., G. (2002). Mobile Sensor Network Deployment using Potential Fields: A Distributed, Scalable Solution to the Area Coverage Problem, Distributed Autonomous Robotics Systems 5, Springer-Verlag. pp.299-308.

[6] K.Sawai,T.Suzuki, H.Kono, Y.Hada and K.Kawabata, “Development of a SN with impact-resistance capability for gathering disaster area information,” 2008 International Symposium on Nonlinear Theory and its Applications (NOLTA2008), pp.17-20 (A1L-C2), ISBN: 978-4-88552-234-5, Budapest, Hungary, September 7-10, 2008.

[7] H. Sato, K. Kawabata and T. Suzuki, “Information Gathering by wireless camera node with Passive Pendulum Mechanism,” International Conference on Control, Automation and Systems 2008 (ICCAS2008), pp.137-140, October 14-17, Seoul, Korea, 2008.