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An autonomous wireless sensor network deployment system using mobile robots for human existence detection in case of disasters

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ABSTRACT

This paper presents a novel approach of using autonomous mobile robots to deploy a Wireless Sensor Network (WSN) for human existence detection in case of disasters. During WSN deployment, mobile robots perform cooperative Simultaneous Localization and Mapping (SLAM) and communicate over the WSN. The proposed system has important advantages over a human-assisted system, including autonomous deployment, aggregated intelligence, and flexibility. However, the realization of these envisaged gains depends on communication and coordination capabilities of the system. In this study, the advantages of an autonomous WSN deployment system by mobile robots, design principles and implementation related issues have been explained. In addition, simulation studies have been performed to show the effectiveness of the proposed approach considering WSN coverage, coordination strategies, and SLAM perspectives. Overall, this paper addresses the advantages of using multiple robots for WSN deployment in terms of cooperative exploration and cooperative SLAM, the benefit of simultaneously deploying wireless sensor nodes during the exploration of an unknown deployment zone and the use of WSN-based communication as an alternative communication method during exploration.

1. Introduction

Nowadays, mobile robots are used to help people in performing specific tasks. Some tasks like exploration and rescue operations are inherently dangerous and robots can be used to perform these critical tasks. Specifically, exploration is such an application and is used in many applications including search and rescue operations, planetary exploration, and reconnaissance. Robotic exploration draws the attention of researchers all around the world. Different exploration strategies, such as frontier-based exploration [1], market-driven exploration [2], and role-based exploration [3] have been proposed. Mobile robot exploration mainly has two goals as follows [4,5].

1. Gathering information in the target region.
2. Ensuring that the target region is completely covered.

The main requirement of all exploration strategies is the coordination of multiple robots to improve efficiency. Specifically, mapping is of critical importance during multiple robot exploration. Mapping of an unknown environment by mobile robots and simultaneous localization is known as Simultaneous Localization and Mapping (SLAM) problem. SLAM is the process of building a map of an unknown environment from a sequence of noisy landmark measurements obtained from sensors [6,7]. Considering mapping, the cooperation of multiple robots allows mapping an unknown environment more quickly and robustly than a single robot case, especially in outdoor envi-

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ronments. This process is known as multi-robot SLAM or cooperative SLAM [8,9]. Recent research efforts prove that multi-robot systems finish map building tasks more quickly and robustly than single robot-based systems.

This paper presents a multi-robot-aided wireless sensor network (WSN) deployment system. In this system, a group of mobile robots are used to explore an unknown region and cooperatively perform SLAM. In addition to these, during exploration, sensor nodes are deployed to detect any human existence and provide communication between robots and a control center. WSN-based communication allows increasing communication range and covering a larger region. Sensor nodes to be used for this application have passive infrared sensors (PIR) as motion detectors to detect human existence. If an "object detected" signal is sent by the PIR sensor, the nearest mobile robot is directed to that area to take a photo in order to make sure that the detected object is a human and this photo is transmitted over the WSN to the control center for identification. If a human is detected, then an equipped rescue team, which is ready to hazardous environmental conditions, can be directed to the area to rescue him/her. Here, it is important to emphasize that the proposed approach is an after-deployment strategy. Different from pre-deployment strategies, the proposed system is deployed after a disaster occurs and brings cost advantages compared to the pre-deployment strategies. In this system, sensor nodes collect information about physical world conditions and transmit the collected data to an operator or to a central control system through single-hop or multi-hop communications. Also, the proposed approach is a dynamic system, in which sensor nodes can be collected and deployed again during a rescue operation. This system has a potential use for robotic exploration and SLAM applications in hazardous environments or situations like nuclear disaster zones, mined terrains, battlefields and chemical attacks, where environmental conditions can be dangerous. The main advantage of this system is that rescue operations can be performed effectively with a limited number of rescue crew, since rescue teams are going to be directed only to areas where human existence is detected. Also, in case of nuclear and chemical disasters, urgent things such as water and food can be delivered to the detected people by robots. Another possibility the system brings is that robots with complicated sensors can be sent to the areas where humans detected to perceive the environmental conditions before sending rescue crews.

In general, our approach is motivated by the nuclear disaster in Fukushima, Japan. The proposed system can help the authorities and security forces measure radiation levels in affected areas without compromising the life of the rescue personnel. For this purpose, battery powered sensor nodes can be used to measure radiation levels automatically and send the latest data on radiation levels in real time using wireless technologies to multiple robots to perform a desired action. Here, the proposed system brings several advantages, including rapid deployment, flexibility, and aggregated intelligence via parallel processing. However, it needs to be designed carefully considering battery life of wireless sensor nodes, detection range of PIR sensors, communication range and performance of wireless sensors, mobile robot exploration strategies and cooperative SLAM.

Overall, in this work, the advantages of an autonomous WSN deployment system by mobile robots, design principles and implementation related issues have been explained. In addition, simulation studies have been performed to show the effectiveness of our approach considering WSN coverage, coordination strategies and SLAM perspectives. The main contributions of this study over similar systems, such as in [30–33], are the use of multiple mobile robots to perform cooperative exploration, cooperative SLAM and WSN deployment simultaneously. The proposed system is a smart sensor deployment system, with which approximate sensor locations are known and in case of a detection rescue operations can be handled efficiently. In other words, the proposed system does not perform a random deployment, positions of sensor nodes are known during and after deployment. Thus, as soon as an alert is received, rescue teams can be directed to the area near the estimated position of the alerting node.

The remainder of the paper is organized as follows. Related works are explained in Section 2. In Section 3, WSN-based human existence detection system is explained in detail. Also, simulation results are given in this section. In Section 4, firstly, WSN-based communication is explained, and then, related simulation experiments are given. Section 5 gives information about future research directions. Finally, the paper is concluded in Section 6.

2. Related work

WSNs are composed of sensor nodes and widely used in many applications. Sensor nodes can be placed either randomly or deterministically based on the deployment scheme which depends mainly on the type of application, the environment, and the sensors [45]. In general, poor deployment of sensor nodes leads to bad network connectivity or redundancy of coverage. Random deployment often results in initial sensing holes inside the environment even in a very high density network. Therefore, deployment of a WSN using autonomous agents is a highly sophisticated work. Depending on the desired goal, this approach brings several difficulties which must be addressed. For instance, if a WSN deployment region is not known before, which means that no priori map exists, then robots need to explore the region and map it. If a priori map exists or an operator directs a deployment mission, then exploration and mapping processes can be ignored and it makes the deployment mission relatively much easier to be handled.

One of the early approaches for sensor network deployment using an autonomous agent is proposed in [27]. In this paper, Avatar, an autonomous helicopter designed for sensor network deployment and repair, is explained. Also, deployment and repair algorithms are proposed. The authors implemented the proposed algorithms using a sensor network with 50 nodes and Avatar in their experiments. They executed previously defined tasks on a grass field, marked as a 7×7 grid, in both manual mode and autonomous mode to be able to compare obtained results.