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Event monitoring in emergency scenarios using energy efficient wireless sensor nodes for the disaster information management ☆

Metin Erd [a,*], Frank Schaeffer [b], Milos Kostic [a,1], Leonhard M. Reindl [a]

[a] Laboratory for Electrical Instrumentation, Albert-Ludwigs University of Freiburg, Institute for Microsystems Engineering, D-79110 Freiburg, Germany
[b] Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institute, D-79104 Freiburg, Germany

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ABSTRACT

Information gathering in tunnels, buildings, bridges, etc. during disasters is of vital importance in speeding up rescue efforts and for protecting the fire fighters. The collected data can be used by the emergency services in the planning of rescue operations and allocation of human resources at a local level. In this article we present design and implementation of a wireless sensor network, which consists of energy-efficient wireless sensor nodes with an integrated ultrasonic sensor, which establish a collision free data transmission in an emergency scenario. The developed network was tested in a field experiment in an explosion within a building to confirm its functionality and reliability. The wireless sensor network was able to pass critical data to the emergency units to initiate the rescue procedures during this disaster scenario.

1. Introduction

Long-term monitoring of critical infrastructure such as bridges, tunnels, dams, and skyscrapers is focused on detecting damages caused by static and cyclic loads during regular operation. The assessment of structural behavior and resulting lifetime predictions of these structures are also outlined in the planned work and still an active topic of research.

Deployment of a wireless sensor network for monitoring the condition of the infrastructure in the event of a disaster is an approach since a decade.

Previously used approaches for this purpose mostly employ wired communication systems, or use wireless sensor nodes where time-critical events are not considered in conjunction with wireless systems, e.g., environment [1,2]; buildings [3,4]; pipelines [5]; mine tunnels [6–8]; train- and road tunnel [9,10].

Using wireless sensor nodes in case of disasters in scenarios where there is no need for time critical aspects were discussed by George et al. [11]; Morreale et al. [12]; Liu et al. [13]. Several publications were also reported in emergency situations in tunnels, mines and pipelines. Their major focus is on the explosions effects on the infrastructure by van den Berg and Weerheijm [14]; Gui and Chien [15]; Ramulu et al. [16]; Shin et al. [17]; Peng et al. [18]; Wu et al. [19]; Pang et al. [20].

Few publications also reported on the data management of a disaster scenario by Jean-Christophe [21]; Mengolini and Debarberis [22]; Nouri et al. [23]; Zhou et al. [24]; Yang [25]; Meissner and Eck [26]; Geisler et al. [27]; Engelbrecht et al. [28]; Alexander et al. [29]; Arai [30]; Müller [31,32] Hristidis et al. but the time-critical aspects in disastrous situations is still not reported.

Extensive research in the area of wireless sensor networks has been frequently reported which includes research in energy-efficient wireless protocols [33,34]; in topology [35,36]; in routing [37–39]; in algorithms [40,41]; in synchronization [42,43]; in wake-up [44]; in maximizing the lifetime [45] and in position status determination [46,47]. However, the use of wireless sensor networks for the scenarios which includes the time-critical events has not been reported.

In the presented work, we will focus on time-critical events monitoring using wireless sensor networks. For this purpose, a system of energy-efficient wireless sensor nodes has been developed to obtain information about the condition of the infrastructure in the event of a disaster. The wireless sensor nodes were placed in strategic positions to detect possible explosions occurring in the structure. The acquired information is transmitted wirelessly to a central unit, where emergency services were

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* Corresponding author.
E-mail address: metin.erd@imtek.uni-freiburg.de (M. Erd).
[1] Now at: Im Eschengut 10, CH-8200, Schaffhausen, Switzerland.

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activated. Data from wireless sensor nodes provides the fire fighters and the related staff precise information about the infrastructure damages and possibility to detect the building collapse situation through this approach, efficient planning can be made to save lives.

Organization of this paper is as follows: Section 2 discusses the system architecture and the evaluation of the information for an emergency scenario monitoring. Section 3 is focused on development of software and hardware components for energy efficient wireless sensor nodes. In Section 4 wireless sensor node construction, analysis, testing, and its calibrations are discussed. In Section 5 results and discussions based on a field tests on an emergency scenario are elaborated. Conclusions are also discussed in Section 6.

2. Monitoring of a disaster scenario

Basic components in monitoring of a disaster scenario are as following.

2.1. System architecture of the monitoring

Fig. 1(a) shows a system architecture for situation-monitoring during an emergency event, e.g., explosion, earthquake, fire etc. The data exchanges hierarchies at different levels of the system, e.g., acquisition, communication, processing, and visualization layer, over various interfaces are also depicted.

The system architecture is composed of local and mobile components. The local components are the devices that are installed on site which acquire data about critical events and send the data off to the mobile components. Mobile components consist of two exclusive layers "processing", "visualization" and one shared "communication" layer. The local components consist of exclusive "acquisition" layer and again one shared "communication" layer.

The collected sensor data is passed from the acquisition level to the processing level using a communication layer. The communication layer is a software interface, which is an implementation of "OLE for Process Control" (OPC) [48] and "Data Communication Protocol for Building Automation and Control Networks" (BACnet) [49].

The processing layer sorts the incoming data with respect to user-, pre-defined sorting rules and sends this information to the visualization layer for a visual output at the user terminals.

The communication between the local and mobile components is conducted using a standardized software interface, i.e., OPC, BACnet, which allow data exchange between different communication protocols. Due to the large number of sensors, several subsystem servers are required.

2.2. Evaluation of the disaster information

The evaluation of information is based on the work reported by Engelbrecht et al. [28] and Meissner et al. [50], as these systems have already been put to test and proven to work flawlessly.

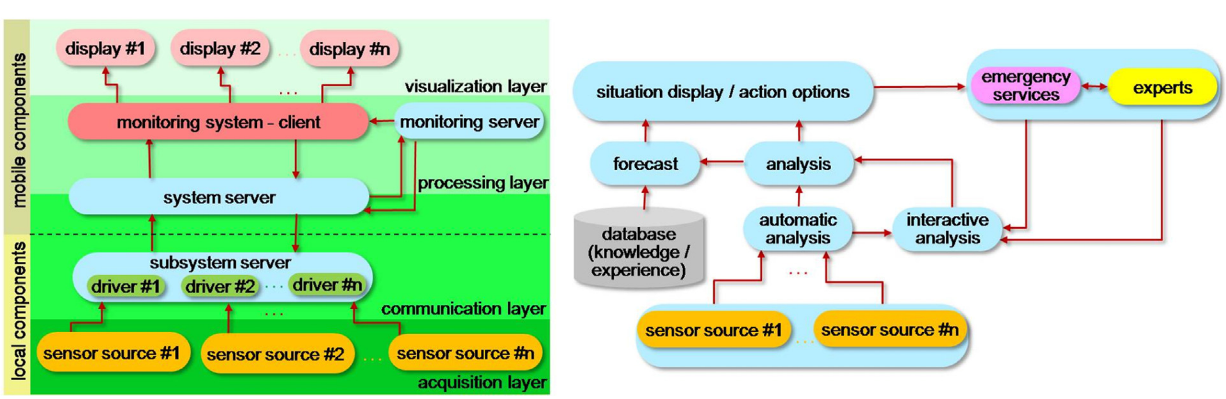
Data collected at the acquisition level by the wireless sensor nodes are evaluated through automatic and interactive analysis systems as shown in Fig. 1(b). Interactive analysis allows experts from the emergency services to provide case specific data evaluation. Both results from the automatic and interactive analysis systems are collected together and simultaneously displayed, e.g., with a portable laptop. At the same time, the analysis system compares the collected data to entries stored in a knowledge data base. Discovery of similar entries can help the experts to organize the rescue efforts to the previous incidents.

2.3. Implementation of a graphical user interface for the disaster monitoring

On the monitoring terminal station, we have implemented a graphical user interface (GUI) using "Laboratory Virtual Instrumentation Engineering Workbench" (LabVIEW) [51] for the visualization of the incoming data. After system configuration, a data communication between the terminal station and the sensor network is established. From the received wireless sensor node data, various important monitoring parameters can be extracted as follows:

- Wireless sensor node status, i.e., "emergency" or "alive".
- Wireless sensor node number.
- Transceiver temperature.
- Battery level of wireless sensor node.
- Emergency event information.

We designed two different implementations of our system for centralized catastrophe management and monitoring services as shown in Fig. 2. The first implementation as shown in Fig. 2(a) is dependent on the power limitations of the wireless sensor node and the router. In the second implementation as shown in Fig. 2 (b), the monitoring terminals and the wireless sensor nodes can be far a way from each other. The already existing cellular communication network General Packet Radio Service (GPRS) is used to communicate between the monitoring center and the wireless



(a) (b)

Fig. 1. (a) Shows the system architecture model. Here, data exchange within different levels of the system (acquisition, communication, processing, and visualization layer) over various interfaces is shown. (b) Shows the information flow from the sensors during an emergency event.