SENEKA - Sensor Network with Mobile Robots for Disaster Management

Helge-Björn Kuntze, Christian W. Frey, Igor Tchouchenkov, Barbara Staehle, Erich Rome, Kai Pfeiffer, Andreas Wenzel, Jürgen Wöllenstein

Abstract— **Developed societies have a high level of preparedness for natural or man-made disasters. But such incidents cannot be completely prevented, and when an incident like an earthquake or an accident in a chemical or nuclear plant hits a populated area, rescue teams need to be employed. In such situations it is a necessity for rescue teams to get a quick overview of the situation in order to identify possible locations of victims that need to be rescued and dangerous locations that need to be secured. Rescue forces must operate quickly in order to save lives, and they often need to operate in dangerous environments. Hence, robot-supported systems are increasingly used to support and accelerate search operations. The objective of the SENEKA concept is to network the various robots and sensor systems used by first responders in order to make the search for victims and survivors more quick and efficient. SENEKA targets the integration of the robot-sensor network into the operation procedures of the rescue teams. The aim of this paper is to inform on the goals and first research results of the ongoing joint research project SENEKA.**

Keywords - disaster management, team work of sensor based robots and firemen, situation responsive networking and mission control, more comprehensive reconnaissance, faster detection of victims and hazard sources

I. INTRODUCTION

The earth is shaking, buildings are collapsing, power and utility lines as well as roads are destroyed. A disaster can have many causes but usually the outcome is the same: chaos, panic among citizens, and well-trained first responders faced with the challenge of quickly adapting to a new and complex situation. People lying buried under buildings turned to rubble hope for an immediate rescue but often it takes hours or even days to work through an entire area. To make matters worse, the work of rescue personnel is often extremely dangerous, but must not be slowed down, as for saving lives, every minute counts.

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Moreover, after such a natural or man-made disaster, the urban environment in the vicinity of the destruction is dramatically changed. Hence, on-site teams have difficulties in identifying routes accessing the area, access potential locations of victims or securing severed parts of the infrastructure. Prior knowledge of the area and existing maps are no longer sufficient for detecting paths, entrances and infrastructure assets. This makes the immediate assessment of the area mandatory for a comprehensive and fast mission planning and prioritization of the necessary exploration actions.

According to the quality criteria of the International Search and Rescue Advisory Group (INSARAG) of the United Nations the probability of survival of buried victims in cases of earthquakes drops significantly after 72 hours [1]. Thus, the reconnaissance and detection of victims and sources of danger have the highest priority of all search and rescue (SAR) operations. As for saving lives, speed is indispensable, state-of-the-art SAR methods dominated by human forces, and dogs are insufficient. Essential advances to accelerate the exploration of the hazard area and detection of victims and dangerous hazard sources can only be expected by the introduction of new robot and sensor-based SAR technologies.

While remotely or directly controlled special ground robots (UGV) are increasingly successfully introduced for supporting rescue operations in hazardous areas (the growth rate of robots for fire and bomb fighting applications from 2009 to 2013 is predicted to be 61%) the contribution of robots to reconnaissance and detection of victims and hazard sources in large disaster areas is rather low [2]. Especially recent experience of the tsunami and nuclear disaster in Fukushima (Japan) 2011 impressively revealed that just by employing event driven dynamic networking of various heterogeneous sensors and robots the time for reconnaissance and detection of victims and hazard sources could be considerably reduced [3], [4].

In order to increase the efficiency of this networking, five German Fraunhofer Institutes have teamed up and started the SENEKA project in January 2012. The goal of this project is to combine the institutes' individual strengths and develop a system that can effectively network a heterogeneous set of robots and sensors. The project team includes the Fraunhofer Institutes of Optronics, System Technologies and Image Exploitation (IOSB), for Manufacturing Engineering and Automation (IPA), for Intelligent Analysis and Information Systems (IAIS), for Integrated Circuits (IIS) and for Physical Measurement Techniques (IPM). Also involved in the project by advising the researchers as potential end users, are the German federal disaster relief organization (THW) and the fire departments of the cities Berlin and Mannheim.

II. STATE OF THE ART

After the destruction of the World Trade Center on September 11, 2001, the benefit of sensors and mobile robots for SAR operations was proven the first time. Individually remotely controlled UGVs have been successfully deployed for searching victims and sources of hazard [5]. Under the impression of this disaster, considerable effort has been dedicated to research projects on various tasks of robot- and sensor-based disaster management. Examples of such successful projects include [6] and [7]. Real-world applications with sensor-based UGVs are devoted particularly to fire fighting, bomb mitigation, as well as to the detection of victims buried under debris. Some of the used UGV worked autonomously, most were manually operated [2].

While UGVs are mainly used for reconnaissance and detection tasks in close range, flying robots (UAVs) are particularly suitable to perform fast reconnaissance and detection of hazards (such as smoke, fire, etc.) in the case of disasters covering large areas. For this scenario, more and more partly autonomous, networking capable UAVs are used [2]. Recent joint research projects like AirShield [8], Avigle [9] and AWARE [23] developed methods for a smart swarm formation of UAVs for sensor-based monitoring of environmental disasters (e.g. forest fire monitoring).

The wide-range reconnaissance by UAVs allows a limited resolution and the more accurate close-range monitoring by UGVs over a large environment is very time consuming. It is hence an obvious approach to combine both wide and close range monitoring approaches and thereby opening up the possibility of a more efficient, more comprehensive reconnaissance and faster search and detection of victims and hazard sources. The prerequisite for this is a dynamic networking of UGVs and UAVs, in order to enable the interaction of local and wide-area sensors. For this need, however, no practical holistic solution exists.

The recent experience with the use of robots in the tsunami catastrophe in Japan 2011 has shown that the deployment of individual specially equipped robots is not suitable for fast wide range reconnaissance [3], [4]. Only the wireless networking and communication of heterogeneous robots, sensors and rescue workers will allow to achieve synergies and thereby a work-sharing SAR management. This will in turn allow to accelerate SAR operations and finally to save more human victims. SENEKA [24] and other joint R&D projects [10], [11] are contributing to closing this still existing gap.

III. OBJECTIVES OF SENEKA

The SENEKA project will create a system concept and associated hardware and software components enabling a situation-specific disaster management:

- Dynamic wireless networking of different heterogeneous robots (UGVs, UAVs), sensors and human rescue teams,
- Optimal collision-free route planning and control of the robots in order to explore and reckon the hazardous environment as well as,
- Goal-oriented sensor responsive search and detection of buried victims and sources of hazard.

A parallelization of tasks as well as the exploitation of synergy effects is achieved by situation-dependent swarm coordination, in particular by the combination of local and wide area information with specific short and wide range sensors and sensor vehicles (UGVs, UAVs). This more targeted, comprehensive and ultimately faster reconnaissance will accelerate the detection of victims and risk sources.

In order to achieve the ambitious project goals, the SENEKA hard- and software components required for the reconnaissance and detection will be developed, implemented and demonstrated within 7 different work packages that we will shortly describe in the following.

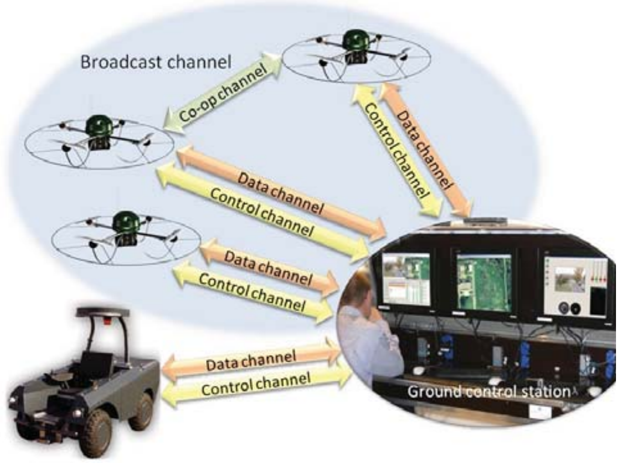

Figure 1. Decentralized communication between the ground control station, heterogeneous robots (UAVs, UGVs) and sensors

IV. DECENTRALIZED CONTROL STATION

For the combined coordination and monitoring of dynamic networkable heterogeneous robot sensor networks, no appropriate control systems are commercially available. Therefore, the SENEKA project will create a decentralized multi-software-agent based cognitive system architecture. The concept is characterized by interoperable standardized interfaces to the heterogeneous system components and the human operators. Additionally, intuitive concepts and user interfaces for the scheduling and coordinated control of heterogeneous robot and sensor networks are used.

The decentralized control station developed in SENEKA is based on a generic ground control station formerly developed by Fraunhofer IOSB within the project AMFIS [12], [13]. It is an adaptable and scalable prototype system for managing sensor data acquisition with stationary sensors, mobile ad hoc networks, and mobile sensor platforms (Fig. 1). The main tasks of the ground control station are to work as an ergonomic user interface and a data integration hub for multiple sensors possibly mounted on UAVs, UGVs, and a superimposed control center. Depending on the actual scenario, the ground control station is able to connect to a wide range of sensors and can be equipped with electric-optical, or infrared cameras with movement dispatch riders, acoustic, chemical, or radiation sensors.

V. Wireless Communication

A necessary prerequisite for a dynamic robot-sensor networking is a good transmission performance over a reliable and robust wireless communication channel. This is however in contrast to the reality of a disaster scenario, where the channel conditions are highly varying and interference from a multitude of systems exist. The SENEKA system will cope with those challenges by providing an adaptive communication system with redundant transmission opportunities. The robustness and fault-tolerance of the wireless networking is achieved by combining the Fraunhofer IIS low-power low-data rate s-net® technology [14] (see Figure 2 for an exemplary sensor node) and commercially available IEEE 802.11 components in a multi-hop topology. The combination of geo-location systems with the locally working s-net® positioning approach will moreover provide a positioning system for all components of the SENEKA system.

Figure 2. Miniaturized s-net® sensor node S3TAG

VI. Multi-Sensoric Exploration and Detection

For the planning and implementation of a targeted search and detection of victims and hazard sources, providing accurate and up to date 2-D/3-D maps of the damaged disaster area is required. This can be very efficiently implemented with the help of a swarm of networked sensors carried by UAVs (wide area sensing) and/or UGVs (close-range sensing). As there are no suitable tools available on the market, the SENEKA concept develops novel exploration and detection strategies ensuring high accuracy of information as well as a short exploration period. SLAM (simultaneous localization and mapping) algorithms play a central role because they allow both an optimal estimation of the robot position as well as a simultaneous creation of the environmental map [15], [16]. More sophisticated multi-source SLAM algorithms used for robot swarms are able to combine roughly screened wide range maps and finely screened close range maps in a mosaic-like way to a global hybrid 2-D/3-D environmental map (s. Fig. 3 and 4).

For the detection of victims and sources of potential risk (e.g. collapsed building structures) image-based detection and localization approaches will be applied. By comparing the currently taken images with stored image data hazard sources and disaster-related structural damages can be detected and localized. Moreover, with image-based algorithms individual members of a robot team can also detect and locate each other.

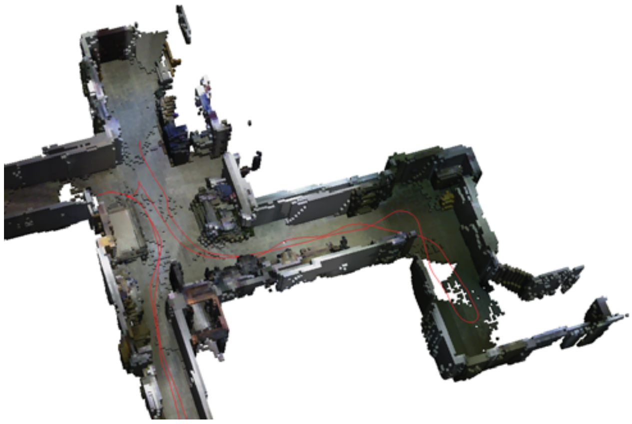

Figure 3. 3-D-mapping of ruins by LIDAR sensor carried by UGV

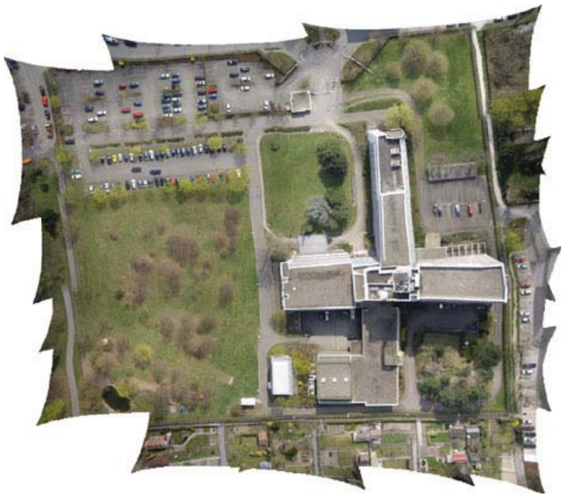

Figure 4. High resolution 2-D- map (Fraunhofer IOSB) created by mosaicking several 2-D maps taken from an UAV swarm

VII. Situation Responsive Mission Planning

To efficiently carry out the exploration and detection phase of disaster management, a proactive planning of the available resources, a situation driven reconfiguration of the robot sensor team, as well as efficient path planning of UAVs and UGVs is required. SENEKA will implement algorithms ensuring the optimum choice for networking and spatial distribution of sensors with regard to information content or the quality of measurements [17].

Moreover, new algorithms are developed to recognize hardware failures, malfunctioning, or potential collisions of the networked robots in time. SENEKA will adapt to these malfunctions by network reconfigurations that affect the functionality as little as possible, thereby providing a situation-dependent task shift between the networked robots and sensors (principle of "graceful degradation") [18], [19].

Finally, an optimized path planning and control of the UGVs and UAVs has to be implemented that minimizes the duration of the mission and avoids collisions with the dynamic environment (Fig. 5). To solve this planning and control problem, model predictive concepts as well as potential field methods are applied [17], [20], [21].

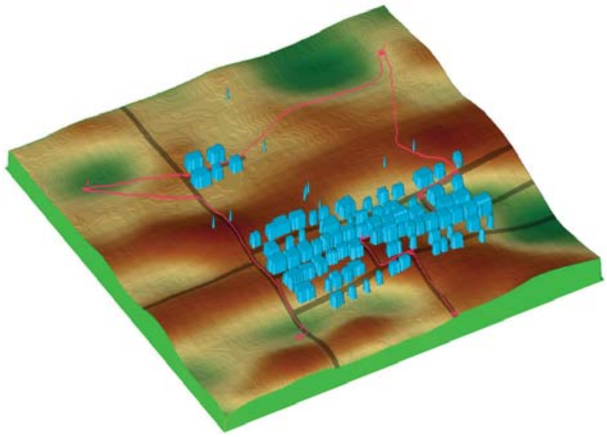

Figure 5. Collision free path planning of an UGV in a disaster area [21]

VIII. Autonomous Sensor Nodes

Autonomous miniaturized and energy-efficient sensors and multi-sensor probes are an important addition to the sensors that are permanently carried by UGVs and UAVs. All-terrain UGVs and low-flying UAVs but also firefighters can drop those specialized sensor nodes in ruins or small cavities that cannot be accessed otherwise. The SENEKA project, on the one hand, will consider autonomous miniaturized and energy-efficient sensors with multi sensor probes that can be exactly positioned. On the other hand, cheaper miniaturized sensors (e.g., gas array sensors, Fig. 6) are used, which can be randomly scattered by UGV- and UAV-based output units [22]. By using the Fraunhofer IIS s-net® technology, the deployed sensors wirelessly network with other sensors. Thereby, they contribute to gaining not only images, but also information from below the surface such as bio-information of victims. As such sensor and multi sensor probes are not commercially available, they, together with appropriate output components, are to be developed and realized in SENEKA.

IX. Demonstration and Evaluation

At the end of the SENEKA project, a realistic use case will be employed to proof the functionality and performance of the SENEKA concept. This public test and demonstration of the system will take place at the test site of the Federal Office of Civil Protection and Disaster Assistance (BBK) in Ahrweiler (see Fig. 7). The obtained results will be evaluated by experienced advising end users (e.g. civil protection and firefighters of the cities of Mannheim and Berlin (Germany) and the German THW). For the demonstration, various UAVs, UGVs, navigation and detection sensors (cameras, LIDAR, gas sensors, etc.), communication components and a mobile control station will be deployed.

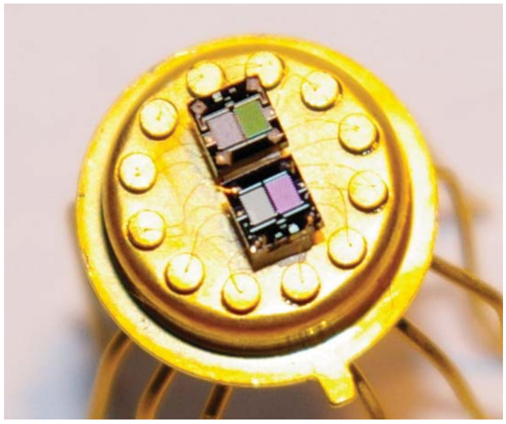

Figure 6. Gas sensor array in micro systems technology, diameter 7 mm, weight < 5 g [25]

Figure 7. Test site for SENEKA demonstrator in the Federal Academy for crisis management, emergency planning and civil protection (AKNZ) of the BBK in Ahrweiler (Germany)

X. Conclusion

The goal of the recently started SENEKA project is the development of a novel technological concept for supporting rescue teams in disaster response. In the case of unanticipated natural disasters or industrial accidents the SENEKA system will allow a situation-specific, dynamic, robust wireless networking of different heterogeneous sensors and robots (both UAVs and UGVs). This will allow handling reconnaissance, search and detection of victims and hazard sources significantly faster and more successfully.

SENEKA has an ambitious goal, but it may count on the expertise and support of the German THW and firefighters from the cities of Mannheim and Berlin (Germany) who provide their test centers and their expert advice. Another key enabler is the combination of the different core competencies and many years of research experience of the participating Fraunhofer Institutes IOSB, IAIS, IIS, IPM and IPA.

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