Rescue Robots at the Collapse of the Municipal Archive of Cologne City: a Field Report

Thorsten Linder
Fraunhofer IAIS
Schloss Birlinghoven
Sankt Augustin, NRW, Germany
thorsten.linder@iais.fraunhofer.de

Viatcheslav Tretyakov
Fraunhofer IAIS
Schloss Birlinghoven
Sankt Augustin, NRW, Germany
Viatcheslav.Tretyakov@iais.fraunhofer.de

Sebastian Blumenthal
Deparment of Computer Science II
Bonn-Rhein-Sieg University
Sankt Augustin, NRW, Germany
sebastian.blumenthal@inf.h-brs.de

Peter Molitor
Fraunhofer IAIS
Schloss Birlinghoven
Sankt Augustin, NRW, Germany
peter@molitor.biz

Dirk Holz
Dep. of Computer Science VI
University of Bonn
Bonn, NRW, Germany
dirk.holz@ieee.org

Robin Murphy
Deparment of Computer Science
and Engineering
Texas A&M University
Bryan, Texas, USA
murphy@cse.tamu.edu

Satoshi Tadokoro
Graduate School of Information Sciences
Tohoku University
Sendai, Miyagi, Japan
tadokoroat.@rm.is.tohoku.ac.jp

Hartmut Surmann
Fraunhofer IAIS
Schloss Birlinghoven
Sankt Augustin, NRW, Germany
hartmut.surmann@iais.fraunhofer.de

Abstract — This paper presents a field report and summarizes the problems of the appliance of rescue robots during the Collapse of the Historical Archive of the City of Cologne. Two robots where on the field, ready to be applied: A shoe-box size tracked mobile robot (*VGTV Xtreme*) and a caterpillar like system (*Active Scope Camera*). Due to the special type of collapse and design limitations of the robots, both robotic systems could not be applied. Either they could not reach/fit into voids or could not be controlled from a safe distance. The problems faced have been analyzed and are described in this paper.

***Keywords*: Search and Rescue Robots, Urban Search And Rescue, Teleoperation, Field report**

I. Introduction

On March 3rd 2009, the historical archive of the city of Cologne (Germany) and two adjacent residential buildings collapsed into a building excavation of the local subway. Initially, it was unclear how many victims where affected, so the fire department of Cologne initiated a major alarm. Amongst others, an international robotic rescue team composed of Dr. Robin R. Murphy (Texas A&M University), Dr. Satoshi Tadokoro (Tohoku University), Clint Arnett (Project Coordinator for Urban Search and Rescue in TEEX) and members of the Fraunhofer Institute for Intelligent Analysis and Information Systems (IAIS) offered their support to the local response teams.

This paper presents a description of the collapse, its characteristics and the problems that were faced by the rescue team. It provides a brief overview on lessons learned and discusses the reasons why rescue robots could not be applied in this scenario. The remainder of this paper is organized as follows: Section II describes the scenario after the collapse, Section III illustrates which and how the rescue robot systems where intended to be applied, Section IV shows lessons learned during the mission and Section V concludes the paper.

II. Scenario Description

The historical archive of the city of Cologne was built in the year 1971. It was one of the most important archives in Europe and contained many historical documents and artifacts. The oldest certificate dates back to the year 922. Amongst other priceless documents in the municipal archive were stored papers and unpublished works by Heinrich Böll as well as articles and letters written by Karl Marx and Napoleon Bonaparte.

The building was built with a supporting skeleton frame of ferro concrete. The gaps between pillars and carriers were filled with bricks supporting the air conditioning. The surrounding properties were also built mainly of bricks (see Fig. 1). Inside the six-storied archive were 30 km of narrow standing shelfs for storing documents and artifacts [2]. Because of the massive construction and the contained material, the total volume of the debris was very high.

In front of the archive is a construction site for new subway tracks (see Fig. 2). In particular, a rail-switch station was planned to be built below street level next to the archive building. The construction site reaches down 28 m and has three

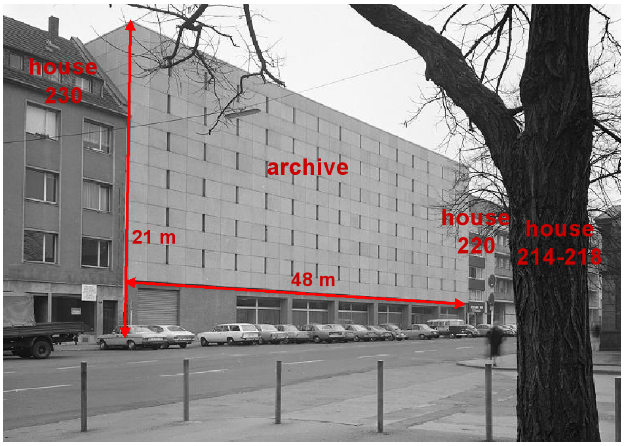

Fig. 1. The archive and the adjacent residential buildings no. 214-218, 220 and 230 in Severinstrasse/Cologne, Germany. The two victims lived in house 230 [1].

Fig. 2. The rail-switch station and the subway tracks are located below the horizontal concrete paving slabs in front. This picture has been taken four weeks before the collapse [1].

basement levels. From the very beginning of the construction work, there were problems with massive intrusion of ground water [3]. Several water pumps were used to keep the construction site clear. Most likely pumping down the water caused a hydraulic base failure followed by a massive underground landslide. The archive tilted into the resulting gap and the building slided into the excavation of the subway. Finally, it completely collapsed (see Fig. 3 & 4). The adjacent residential buildings where directly affected by this collapse. As a result, mixed rubble with bricks, bent steel beams, bookshelves and the inventory of the archive were mostly below street level (see Fig. 5 & 6). Furthermore, since the water pumps that kept the construction site free from ground water had been damaged in the collapse, it was unclear whether or not the refluent water threaten other nearby buildings. It is a blessing in disguise that only two people died in this catastrophe. Most residents and other nearby people evacuated themselves before and by the first indications of the collapse.

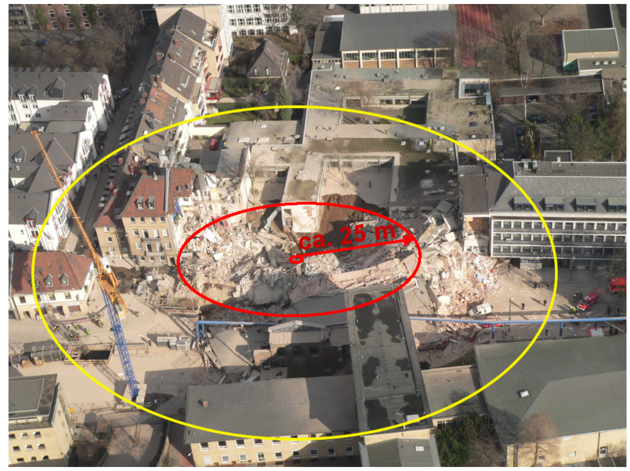

Fig. 3. Aerial view of the scenery on arrival of the first rescue units. The red circled area shows the "hot zone" with a pit diameter of about 25m [1]. The yellow circled area shows the restricted access area only for rescue personnel.

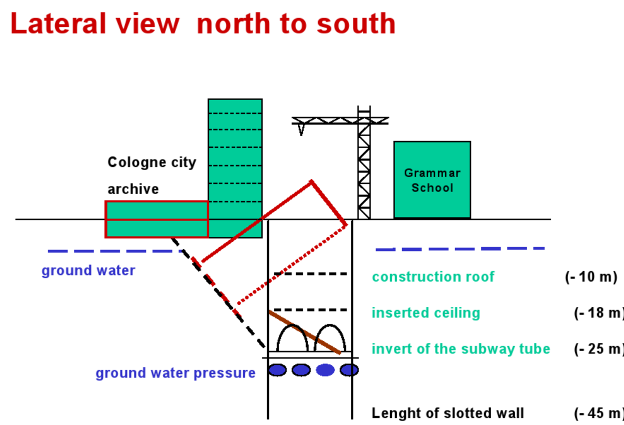

Fig. 4. Schematic overview of the assumed course of events. As shown the common groundwater level is about 9m below street level. The slotted walls are reaching down to -45m [1].

Fig. 5. House 232 (left) and the ruins of house 230 (middle) where the two victims lived in and the ruins of the archive (right) [1].

Fig. 6. Mixture of debris. It is composed of ferro-concrete, concrete and bricks of walls, as well as interjacents shelfs and historical documents. As shown, there are hardly no voids, where possible victims could have survived [1].

III. Appliance of rescue robots for the Cologne collapse

A. Rescue robot systems

Two teleopereated rescue robot systems were intended to be applied at the Cologne disaster: A *VGTV Xtreme* and an *Active Scope Camera* (*ASC*). The *VGTV Xtreme* is a tracked robot, manufactured by Inuktun Services. It has the ability to change its shape by tilting the front axle up or down [4]. It has dimensions of $427 \times 277 \times 140\,\mathrm{mm}$ (L×W×H) in the lowered configuration and $216 \times 277 \times 343\,\mathrm{mm}$ (L×W×H) in the raised configuration. The weight is approximately $6\,\mathrm{kg}$. It is steered via a tether which can be up to $90\,\mathrm{m}$ long. The front is equipped with a tilt able color camera and lights [5].

The *Active Scope Camera* is a caterpillar like system. It enhances an industrial scope camera with the ability to move forward and change its direction. The movement force is generated with the help of vibrating inclined cilia. The maximum speed is $47\,\mathrm{mm/s}$ and the operating range is $8\,\mathrm{m}$. With its small diameter of less than $30\,\mathrm{mm}$, it is able to search for victims in rubble with small voids [6].

Both robot systems are depicted in Figure 7.

B. Application

Though it was clear that the both rescue robots were not able to manipulate and carry documents, we were asked about the possibility to search for the most important documents. Therefore, the rescue robots were planned to assist during the two following tasks:

- Rescuing victims
- Searching for historical documents

The two victims were supposed to be inside the house 230 during the collapse. Their locations have been estimated to be in the rubble beneath houses 230 and 232. The exact locations were unknown and there were no signs of live [7]. Before the start of the rescue mission, damaged surrounding buildings had to be torn down and the subway construction site was stabilized by pouring $1700\,\mathrm{m}^3$ of concrete.

Fig. 7. On the left side Dr. Robin R. Murphy with the *VGTV Xtreme* and on the right side Dr. Satoshi Tadokoro with the *Active Scope Camera* (*ASC*).

The actual rescue procedure can be briefly summarized as follows:

1) A layer of rubble is excavated.
2) Two rescue dogs examine the cleared area (see Figure 8).
3) If one of the dogs indicates a possible victim, a bio-radar is applied to be able to detect the heart beats of people. If it proves the dog's perception of a living person, one of the rescue-robots can be applied. The robot's task is to investigate the health status and how the survivor can be rescued best. With the acquired information, excavation can be performed more precisely while reducing the risk of further harming victims.
4) A "strange" behavior of one of the rescue dogs indicates a dead person. In this case, corpse sniffing dogs are sent into the respective area. If this supports the hypothesis of a dead person, the rubble is excavated at this very location. Once a dead person is found, the police take over.
5) If none of the rescue dogs shows a particular reaction, another layer of rubble is excavated and the process restarts with step 1).

Figure 9 depicts the rescue process and possible integration of the active scope camera system into it.

But as a consequence of the fact that no living victims have been found by the dogs in the investigated areas, neither bio-radar nor the robot were applied.

Fig. 8. A rescue dog is guided over the rubble to search for victims.

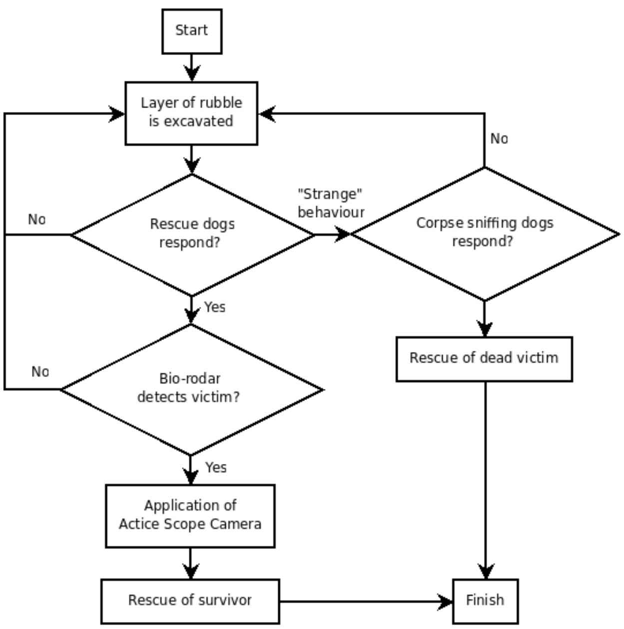

Fig. 9. The rescue process depicted as a flowchart diagram. The Active Scope Camera could have been utilized after locating a possible (living) victim.

C. *Reasons for not applying the robots*

As already mentioned, the archive had been built of ferro-concrete and bricks. The debris, resulting from its collapse, including kilometers of book shelfs, did not reveal larger voids. The space that needed to be searched was not been directly accessible. Furthermore, directly standing near the gaps, as well as moving over the debris, could have caused further avalanche-like collapses. None of the three collapsed building structures distinguished in [8], i.e. *pancake*, *lean-to* and *v-shape* collapses, adequately describes the collapse of Cologne's municipal archive.

In principal, smaller voids could have been inspected using the *Active Scope Camera*. However, due to the fact that directly standing near the point of interest was not possible and that the camera can not be operated remotely, the *Active Scope Camera* could not be applied (see Fig. 10-12). Furthermore, some voids in the upper layers of the debris could not be reached because the *ASC* was missing the capability of getting over larger barriers. Regarding the application of the *VGTV Xtreme*, the debris did not contain voids being large enough for the *VGTV Xtreme* to fit, as was the case in other scenarios: for instance the terrorist bombing attack in Oklahoma City [9], [10]. The combination of rain and brick dust resulted in an extreme slippery ground which made it difficult for man and machines to move around. Having carefully weighed the advantages and risks, the officers-in-charge and the operators agreed not to use the robots.

Fig. 10. Subsurface scenery. On the right-hand side the rail-switch is shown. The victims had been expected on the left side, behind the perforated slotted wall. The Active Scope Camera could have been employed in this situation, but the operating area was not safe [1].

IV. Lessons Learned

Notwithstanding all the problems which appeared, we can learn from this disaster, especially that each disaster site

Fig. 11. Bent H-carrier next to the operating area of the Active Scope Camera [1].

Fig. 12. Detail view of the scene in Fig. 10. What can be seen are so called widow-makers endangering the operators [1].

is unique and has its specific characteristics. Furthermore, lessons can be learned from:

- characteristics of the robots
- scenarios and their impacts on similar future collapses
- integration of rescue robots into rescue processes
- performance of rescue robot platforms

At first glance, the breakdown seamed to be an ordinary building collapse, but it was not. The architecture and the subway construction caused a huge amount of compressed rubble in the excavation. The few small voids, which showed up, were all located in unsafe areas and regions which did not allow to stay close. Only robots that could be teleoperated from a secure position and were able to get over barriers to reach potential voids would have fulfilled the requirements for a successful rescue operation. Regarding the size of voids in the debris, small-sized robots seem to be preferable due to better maneuverability and the ability to pass through smaller voids.

Another interesting possibility for enhancing the flexibility with respect to future rescue applications is a combination of capabilities of robots, like the *VGTV Xtreme* and the *Active Scope Camera*, in such a way that the *VGTV Xtreme* could transport the *ASC* to a location near a void where the *Active Scope Camera* could be released and further explore the void, like it is proposed in [11]. Such a combination could allow to remotely control the overall system from a safe region near the debris and make use of the advantages of both single systems. The carrier robot could supply the power to the *Active Scope Camera* and retransmit its data to the operator.

According to the schema in figure 9, if the dogs had indicated the presence of a victim, several robots being able to carry and place bio-radars could have been placed in the areas. This would have minimized the risk for human rescue workers.

Searching for victims is always the primary topic of interest during rescue operations. Nevertheless, in this special case, we were asked about the possibility to rescue the historical documents with the robots. Therefore, it would have been beneficial if the robots had been able to manipulate or recover these documents. A minimum requirement for the robots was at least to avoid further damage to valuable objects.

It is also important to mention that the type of building, like the municipal building in Cologne and its adjoining houses, is widely spread throughout Germany and are possible threats for future disasters. There are many abandoned mines in the densely populated Ruhrgebiet (Ruhr district, middle-west of Germany), of which some are not mapped due to the fact that they originate from the Roman Era. In the past, several of these abandoned mines collapsed causing landslides and damages to constructions above. The type of collapse and the resulting debris are, hence, likely to recur in the Ruhrgebiet. A bigger part of the debris resulting from collapses, like that of the municipal archive, which lies below surface level, might not be directly reachable and, in the worst case, can not be approached without causing further collapses or landslides. Similar events, especially in the aforementioned Ruhrgebiet, could happen again in the near future.

Sophisticated navigation and perception skills of a rescue robot could also be helpful for rescuers, e.g., in the case of a house fire with corridors field with smoke or contaminated areas. Also, areas like in this scenario which are unsafe for humans can be examined apriori. Here, a robot or a special measurement unit could be send in and gain important structural information about the setup of the scenery (e.g. number and position of doors in buildings, overthrown wardrobes, free paths or possible positions of victims and additionally temperature levels or harmful substances could be comprehended). In addition, to other geological sensing technologies like ramming core sounding, coring procedure, leveling instruments etc. such information could be used for a better scenery characterization. It could support the officer-in-charge in the decision making process. In addition the collected data-sets such as videos or 3D laser range scans could also be useful for simulating building collapses. Construction engineers and architects could also benefit from this information in such a way that similar catastrophes might be avoidable in the future.

Regarding the robots used on the field there were several technical issues. Both, the *VGTV Xtreme* and the *ASC*, are equipped with cameras mounted in front which allow the operator to get only a narrow overview of the surrounding. Though the *VGTV Xtreme* is able to change its shape to acquire a better overview from a different perspective [4], it still does not provide a wide situational awareness without performing multiple manipulations. Similar vision issue exists for the *ASC*. In addition, the teleoperator's interface of *ASC* does not explicitly display the position or orientation of the robot [6]. This drawback creates an additional cognitive load to the operator by making him to keep track of the robots position and orientation while exploring voids. Also could be mentioned that both robots are designed in that way that additional skills are required to make use of the teleoperator's interfaces. That means that it is hard for an untrained user to control the robots. The teleoperators are not designed to be used with gloves, which are worn in most cases by the rescue workers.

V. Conclusion & Future Work

Having understood from the feedback of the rescue workers and experts the need of a good situational awareness and intuitive user interfaces, the upcoming *NIFTi* project (*Natural human-robot cooperation in dynamic environment*) aims to take care of them by involving rescue workers into the research and development process from one side and by making use of their field experiences to setup realistic use cases and define requirements from the other side. In general, NIFTi focuses on improving human robot interaction in dynamic environments, as given in catastrophic scenarios. In addition, it tries to minimize the cognitive load of the rescue workers by adding autonomy into the robotic systems and by improving robustness and intuitiveness of user interfaces [12].

Finalizing the field report, we can say that every catastrophic scenario is at some point unique. The authors to not intent to extract generic solutions, but wanted to point out on some narrow specific issues which were discovered during this recuse mission and which might be respected in future.

Acknowledgment

The authors would like to thank Guido Kahlen (City Director of Cologne) for his unbureaucratic support in inviting and transferring the the international rescue team, Stephan Neudorff (Chief of Fire Department Cologne) and Adrian Roehrle (Fire Department Cologne) for their cooperation on site and Thomas Christaller (Director of Fraunhofer IAIS) for bringing together all involved people and organizations. Special thanks to Robin Murphy, Satoshi Tadokoro and Clint Arnett (TEEX Urban Search & Rescue) for their fast response and willingness to help. Furthermore we are indebted to the fire department of Cologne, the German Red Cross (DRK), the German Federal Agency for Technical Relief (THW) and Simone Anderhub and Reiner Frings from the Fraunhofer Institute. This work was partly supported by the European Union grant EU FP7 NIFTi / ICT-247870.

References

[1] Direktor der Berufsfeuerwehr Köln (Chief of Fire Department Cologne), Dipl.-Ing Stephan Neuhoff, 2009.

[2] P. Hartl, M. Fiss, and J. Feyrer, "Sieben Wochen im Einsatz am Historischen Archiv der Stadt Köln - Eine Zwischenbilanz," *brandSchutz / Deutsche Feuerwehr-Zeitung*, vol. 5, pp. 388 – 391, May 2009.

[3] WDR online 2009, "Einsturz des Kölner Stadtarchivs," www.wdr.de, March 2009.

[4] J. L. Drury, H. A. Yanco, W. Howell, B. Minten, and J. Casper, "Changing shape: improving situation awareness for a polymorphic robot," in *HRI '06: Proceedings of the 1st ACM SIGCHI/SIGART conference on Human-robot interaction*. New York, NY, USA: ACM, 2006, pp. 72–79.

[5] M. Micire, "Evolution and field performance of a rescue robot," *Journal of Field Robotics*, vol. 25, no. 1-2, pp. 17–30, 2008.

[6] K. Hatazaki, M. Konyo, K. Isaki, S. Tadokoro, and F. Takemura, "Active scope camera for urban search and rescue," in *IEEE/RSJ International Conference on Intelligent Robots and Systems, 2007. IROS 2007*, 2007, pp. 2596–2602.

[7] S. Neuhoff and J. Feyrer, "Der Einsturz des Historischen Archivs der Stadt Köln, Eine erste Lagebeschreibung des Einsatzes," *brandSchutz / Deutsche Feuerwehr-Zeitung*, vol. 4, pp. 287 – 292, April 2009.

[8] R. R. Murphy, J. Casper, and M. Micire, "Potential tasks and research issues for mobile robots in robocup rescue," in *RoboCup 2000: Robot Soccer World Cup IV*. London, UK: Springer-Verlag, 2001, pp. 339–344.

[9] J. G. Blitch and R. Maurer, "KNOBSAR: A Knowledge Based System Prototype for Robot Assisted Urban Search and Rescue," *SIMULATION*, vol. 66, no. 6, pp. 375–391, 1996.

[10] R. Murphy, "Trial by fire [rescue robots]," *Robotics & Automation Magazine, IEEE*, vol. 11, no. 3, pp. 50–61, Sept. 2004.

[11] R. R. Murphy, "Marsupial and shape-shifting robots for urban search and rescue," *IEEE Intelligent Systems and Their Applications*, vol. 15, no. 2, pp. 14–19, Mar/Apr 2000.

[12] NIFTI - Natural human-robot cooperation in dynamic environment. [Online]. Available: http://www.nifti.eu