Chapter 56
A Hierarchically Structured Collective of Coordinating Mobile Robots Supervised by a Single Human

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ABSTRACT

Using a Single-Human Multiple-Robot System (SHMRS) to deploy rescue robots in Urban Search and Rescue (USAR) can induce high levels of cognitive workload and poor situation awareness. Yet, the provision of autonomous coordination between robots to alleviate cognitive workload and promote situation awareness must be made with careful management of limited robot computational and communication resources. Therefore, a technique for autonomous coordination using a hierarchically structured collective of robots has been devised to address these concerns. The technique calls for an Apex robot to perform most of the computation required for coordination, allowing Subordinate robots to be simpler computationally and to communicate with only the Apex robot instead of with many robots. This method has been integrated into a physical implementation of the SHMRS. As such, this chapter also presents practical components of the SHMRS including the robots used, the control station, and the graphical user interface.

INTRODUCTION

Mobile robots have been found to be useful for a number of applications such as combat (Yamauchi, 2004; Barnes, Everett, & Rudakevych, 2005), oceanography (Bellingham & Rajan, 2007), space exploration (Bellingham & Rajan, 2007; Halberstam, et al., 2006; Schreckenghost, Fong, & Milam, 2008), as well as search and rescue.

In particular, attention has been focused towards developing technologies for using mobile robots for Urban Search and Rescue (USAR) and research interest into USAR robotics is currently at a high level. This is not surprising given the

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potential benefits of applying robots to the domain of USAR. For instance, robots can be used to gather information pertaining to victims, potential hazards as well as the condition of the mission environment (Tadokoro, 2009; Casper, Micire, & Murphy, Issues in intelligent robots for search and rescue, 2000). In addition, robots can even be used to deliver water and medical supplies to victims (Casper, Micire, & Murphy, Issues in intelligent robots for search and rescue, 2000). If sufficiently compact in size, a robot can also be employed to explore spaces in building rubble that are too constricted or treacherous for human or dog rescuers to enter (Burke & Murphy, 2004; Yanco, Drury, & Scholtz, 2004). In practice, mobile robots have been deployed at Ground Zero in New York City after the September 2001 attacks to search for victims. More recently, similar robots have also been applied to survey the damage caused by the March 2011 earthquake in Japan. Therefore, given the potential advantages that may be derived from deploying robots for USAR, it has been selected as the envisioned application of the system of multiple mobile robots presented in this chapter.

However, the deployment of robots for USAR is not a straightforward affair. Despite the evolution of sensing and computing technology in the past half century, mobile robots are still unable to perform entirely devoid of guidance from humans for long durations. This is because the state-of-the-art robotic technology is yet to be able to robustly cope with the challenges of highly dynamic real-world scenarios (Wong, Seet, & Sim, 2011). This fact is especially true for demanding applications such as USAR. Therefore, to ensure that the deployed robots perform as desired, humans must supervise mobile robots and from time to time intervene in the robots' activities so that qualities currently unique to humans such as judgment, experience, flexibility, and adaptability may be used to augment robot capabilities (Haight & Kecojevic, 2005).

The availability of wireless communication means that humans can provide the required supervision for the deployed robots and yet be able to establish increased separation (compared to when communicating using tethers) between themselves and the possible hazards inherent in the robots' mission environments (Shiroma, Chiu, Sato, & Matsuno, 2005). Wireless communication has also facilitated improved robot mobility since deployed robots do not have to be encumbered with a communication tether.

Yet, despite the larger separation between humans and deployed robots made possible through the use of wireless communication, standoff distances are typically not infinite because the strength and integrity of wireless signals can deteriorate with increased separation. Therefore, humans must always be within communication range of the robots and some degree of human vulnerability to mission environment dangers will still exist. To minimize overall human exposure to such hazards, the number of humans allowed in or near the mission environment must be low (Murphy, Blitch, & Casper, 2002) but this should preferably not result in only a small number of robots being allowed to work on the mission. Rather, technology should be advanced to allow multiple robots to be supervised or controlled by as few humans as possible. Given that supervision from humans is indispensible for robots deployed in complex applications such as USAR, it would be ideal then if multiple robots could be supervised by only a single human. In this manner, the advantages of fielding multiple robots[1] such as added redundancy and reliability as well as parallelism can still be harnessed without significantly increasing the number of humans required to field them. The preference for such a system is reflected in the rules of the RoboCup Rescue Physical Agent League Competition, which issues penalties to teams with more than one human individual in the simulated disaster site. Hence, this study has been geared towards the design and development of a Single-Human Multiple-Robot System (SHMRS). In a SHMRS, the robots together form a robot collective while

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