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Analysis and Design of Human-Robot Swarm Interaction in Firefighting

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***Abstract*— In a variety of emergency settings robot assistance has been identified as highly valuable, providing remote, and thus safe, access and operation. There are many different forms of human-robot interactions, allowing a team of humans and robots to take advantage of skills of each team member. A relatively new area of research considers interactions between human and a team of robots performing as a swarm.**

This work is concerned with the interactive use of autonomous robots in fire emergency settings. In particular, we consider a swarm of robots that are capable of supporting and enhancing fire fighting operations co-operatively and we investigate how firefighters in the field work with such a swarm.

This paper outlines some of the key characteristics of this emergency setting. It discusses possible forms of interactions with swarm robotics being examined in the GUARDIANS project. The paper addresses the use of assistive swarm robotics to support firefighters with navigation and search operations. It reports on existing firefighters operations and how human-swarm interactions are to be used during such operations. The design approaches for human-swarm interaction are described and the preliminary work in the area are outlined. The paper ends by linking current expertise with common features of emergency related interaction design.

I. INTRODUCTION

GUARDIANS (Group of Unmaned Assistant Robots Deployed In Aggressive Navigation by Scent) is an European project developing and applying the concept of autonomous robots in urban search and rescue operations. Specifically the project is focused upon assisting humans involved in search-and-rescue emergencies and also employing robot mounted sensors to provide a heightened level of feedback in such settings. In addition, by employing a group of robots the potential to co-operatively compute environmental maps will be employed to further assist in search and rescue operations. The specific search and rescue activity focused upon is that of fire-fighting in a large warehouse. Project partner SyFire[1] was able to provide expert advice regarding the nature of such emergency situations.

The Swarm robotics is built upon the pioneering work by Reynolds [12], who simulated a flock of birds in flight. Sahin [13] describes the swarm robotics as a *(i)* a large number, of *(ii)* homogeneous, *(iii)* autonomous, *(iv)* relatively incapable or inefficient robots with *(v)* local sensing and communication capabilities. The GUARDIANS robot swarms consist of a number of robots with differing communication and sensing capabilities. The swarm is intended to support the real-life tasks of navigation and search operations in a smoke filled industrial warehouse.

The interest here is that although the robots in a swarm are primarily autonomous, they are designed and configurated to address an overarching requirement of assisting humans in search and rescue. Two types of robot operation to support the human firefighters are distinguished:

- First employing the robot swarm as a means of gaining essential information about an incident prior to engaging with it.
- Second employing the swarm as an aid to firefighters once they engage with the fire incidient.

This paper focuses on the second of these, where human firefighters are engaged with the incident and the main task for the robot swarm is to provide support in navigation and safeguard the humans.

From the point of view of human interaction there are two types of users to be considered:

- Users working in the context of a control/communication centre, remotely overseeing and managing operations in real-time. These base station users are able to monitor and control the overall activities of both the swarm of robots and humans on the field, and to provide decision making support to the operations commanders.
- Users working directly in the environment, engaged in specific exploration and rescue tasks in the field. The fire fighters are fully equipped with fire fighting apparatus and clothing, and are performing specific search and rescue tasks.

Recent research have highlighted some of the challenges of Human Robot Interaction for search and rescue environments. Driewer et al. [4] conducted a user requirement analysis using questionnaires and personal interviews with search and rescue professions such as military, plant fire brigades and fire fighters. Other research also highlighted requirements by studying interaction among human teams in bomb squad and fire fighters [1] and SWAT teams in training [6].

The aim of this paper is to present our grounding in designing the human-robot swarm interface for supporting firefighting operation. This is supported by initial domain research to ensure that the robots and related infrastructures properly comply with and support existing human practice

[1]South Yorkshire Fire and Rescue Service

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and rules. The safety of the human firefighters is the highest priority in such operations.

The work reported here is based upon the assumption that the swarm robots are capable of extracting required information from the environment, and, subsequently, localizing and navigating themselves in the environment, tracking the firefighters, as well as safeguarding them. The swarm used in Guardians' experimentations is composed of a number (about 20) of Khepera III robots[2] equipped with IR, ultrasonic sensors and chemical sensors, 3 ERRATIC robots[3] equipped as the Kheperas with laser rangefinders and cameras in addition, and 1 RESCUER robot[4] equipped with a number of sensors including, laser range finder, DGPS, inclinometer, gyroscope/magnetic, vision and olfactory. Moreover, all robots will be equipped with a multimodal wireless communication chip (inc. ZigBee, Bluetooth and WiFi). For more details about the robotic system, the swarming algorithm, and the communication network infrastructure see [11] for example.

Our proposed human-robot swarm interface will be shortly presented in Section V. In addition to this, the design approach has to take account of technical constraints. One significant constraint is that the typical operating environment of a fire incident is one in which robot performance and reliable communication cannot be guaranteed.

II. Firefighting context, setting and operations

A. Emergency Setting

The emergency setting environment for the project is a large single story industrial warehouse. Such warehouses usually consist of large open spaces with a variety of differing goods and materials stored throughout. Such warehouses can be as large as $(400 \times 200)m^2$, and are often divided into sections separated by fire resistant walls. However, during a fire incident, smoke and fumes may cover entire sections in the warehouse. As a consequence visibility becomes an issue for firemen. This is a common concern for fire fighters, their normal training includes working fully blind-folded. A significant risk in such incidents is that fire fighters can become easily lost. There have been notorious tragic examples where firefighters died after becoming lost in the fire smoke. In the warehouse fire of 1991 in Gillender Street London (UK), two firefighters died this way, and in the 1999 warehouse fire in Worcester (USA), six firefighters lost their lives in similar conditions.

Thus, the warehouse fire setting is one where poor visibility means the search and rescue is both time consuming and high risk. Moreover, a warehouse in fire may contain high quantities of toxic gases or inflammable materials. Adding to the complexity and risk of such an incident is that key information about the fire may be limited: ambient conditions, warehouse layout, the potential for flashovers (i.e. a simultaneous ignition of all the combustible material in the area) are often unknown and likely to change.

B. Firefighters Operations

To help the develop user requirements and effectively understand the conditions that firefighters are subjected to, the industrial and academic partners of GUARDIANS have attended one full day training at the SyFire training centre. Following this, to develop a more specific understanding of firefighter activity and priorities there is an on going series of meetings and trials with SyFire. Successful system design and development often benefits from direct user involvement from the early stages of design. For the GUARDIANS project a participatory design [3] approach to support user involvement is highly important, partly due to the fire fighters lack of familiarity with robot swarm capabilities. To support both requirement gathering and end user involvement GUARDIANS has involved South Yorkshire Fire and Rescue Service (SyFire) as a project partner.

This section reports on findings about firefighters operations and practice to date.

There is usually little information provided when the fire brigade is alerted to an incident. The first task of the arriving appliances is to assess the incident and the primary risks. The firefighters safety is considered as a high priority at all times.

Firefighters are initially grouped into teams and briefed with their specific tasks and roles. Where possible a map of the premises is used, however this will only show structures such as walls and doorways. Other details such as interior materials will not be known.

The span of control for any officer is arranged to be between three and five lines of communication, in order to avoid an overload (and consequently neglect of) information as shown in Figure 1. In large incident involving industrial warehouses, the incident commander (IC) deals with the overall supervision of the incident, where the Operations Commander (OpsComm) deals with the sector commanders and crews who are directly involved. In addition, an Entry Control Officer (ECO) for each entry point is appointed with the following duties: *(i)* to update the Entry Control Board with the information of the firefighters who have committed into the scene of incident or have left it; *(ii)* to check the breathing apparatus's 'Time of Whistle' for committed crews into the incident[5]; *(iii)* to liaison with other ECOs; *(v)* to liaison with the sector commander.

Firefighters are usually committed into the incident in teams of two. They are normally protectively clothed and wearing breathing apparatus. In the United Kingdom procedures are to deploy a guideline along a wall (see figure 2). The guideline is a special line which is used to indicate a route between the Entry Control Point and the scene of operations. Subsequent teams are able to follow the guideline. Once within a fire incident firefighters progress is slow due to unknown obstracles, such as debris, and very poor visbility.

[2]K-Team: http://www.k-team.com

[3]Videre Design: http://www.videredesign.com

[4]Robotnik: http://www.robotnik.es/automation/productos/agvs/robotnik-p01-e.html

[5]The cylinders contain roughly 20 minutes of air supply.

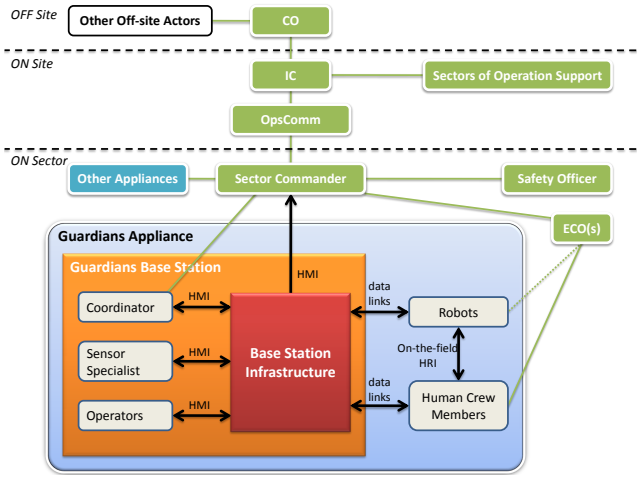

Fig. 1. Guardians appliance w.r.t. SyFyre fire brigade organization. CO stands for Communication Officer, IC stands for Incident Commander, OpsComm stands for Operations Commander and ECO stands for Exit Control Officer.

Fig. 2. Guardians partners experiencing "guideline" feeling with a leather glove (left). Guidelines have pairs of knot points all along the line, one in the pair having a single knot, and the other one having twice, to disambiguate direction following (right)

One of the firefighters, usually the squad leader, moves forward while feeling for obstacles/survivors and testing the integrity of the floor. The other firefighter holds on to the leader and maintain the communication with the squad leader (verbally) and ECO through the radio channel. On the way out, the squad team debrief the ECO who reports back to the sector commander. Further the sector commander feeds back the collected information to the operations commander.

III. Interfaces Design Challenges

There are several challenges faced in designing human-robot swarm interface: noisy and hazardous environment, high workload, communication issues (between human and robot swarm, between human at the base station and the robot swarm, and between human at the incident area and the base station), situational awareness and eventually testing and validation.

A. Environment and communications

In intervention-oriented missions, such as those of a rescue teams and armed SWAT-teams (Special Weapons and Tactics), a considerable amount of communication is devoted to clarifying positional information termed "re-calibration" such as confirming the position of specific agents [6]. The same can observed of firefighters working in an incident, reliable common locations and means of orienting are highly important.

The human firefighters cooperating with a swarm are subject to conditions such as poor visibility, noisy environment and a thick clothing gear, which restrict their senses, and thus their communication abilities. Therefore human robot swarm interfaces cannot fully rely on the (commonly used) audio and visual communication means.

Moreover, the wireless communication channels may be disturbed because of the presence of metalic structures inside the incident area. It is expected that the radio communication link will be lost intermittently due to this factor.

B. Stress and workload

Besides the disturbance from the environment, firefighters are further imposed a high level of stress from the inherent risks. In the scenario tackled by this project, the operation time is limited and the environment is hazardous. The need to work with, and interact with, robots may result in additional workload if the interactions and interfaces are not carefully designed. Thus 'alternative' interaction means are being investigated.

C. Situational awareness

Another challenge in the design and development process is to provide situational awareness to firefighters in the incident area as well as users at the base station. In search and rescue missions, firefighters face hazardous environments and are expected to make decision within a short time window. As a consequence, it is imperative that acquired information and data allow firefighters and human operators at the base station to comprehend in real time the on-going situation, and accordingly to best perform decision making (Level three of situational awareness, according to Endsley: [5]).

D. Robots' and humans' roles assumptions

In designing interfaces, it is important to take into consideration the roles assigned to humans and robots. For humans, different roles have different expectations or models of the robots. If these differ from reality, this will lead to frustration, additional stress, and possibly serious or critical mistakes.

E. Testing and validation

As far as human-robot swarm interaction is concerned, testing and validation require the robot swarm to be actually operational. Although simulation may be helpful, operational robot swarms will be required to assess the adequacy and efficiency of the interfaces developed. Accordingly test and validation plans are being prepared, so that the interfaces can be actually tested and assessed within the upcoming setup of GUARDIANS' consortium's joint experiments.

IV. Human-Robot Swarm Interface Design & Development Process

Enabling users to envisage or make sense of design proposals is an essential element of good design practice. Users can only make informed choices when the proposals

being discussed are meaningful to them. Prototyping is one popular method of helping users (and designers) in this process, and this benefits from employing tools and methods which allow designers to rapidly prototype. In the case of this project it is important that the user interface concepts are physically prototyped so that they can be realistically assessed by firefighters.

Several techniques being considered to allow designers to rapidly prototype novel physical interfaces for human robot interactions that can be evaluated with the potential human swarm members. These include the use of Phidgets toolkit[6], Electronic Paper Prototyping [10] and mock-ups. Following sections report on some of the findings of our analysis.

A. Firefighters

Scholtz presents five roles that human may take during interaction with robots: *supervisor*, *operator*, *mechanic*, *peer*, and *bystander* [14]. Due to high workload during operation, project partner SyFire preferred maintaining a minimal approach to interaction. This has result in the interactions designed to be high level to ensure convenient interaction. To comply with this, we expect two roles the firefighters will have during operation: *team mates* or *bystander*. As team mates, firefighters work co-operatively with the robot swarm in achieving the goal, e.g. explore the incident area, search for victims, detecting potentially-hazardous materials, etc. As bystander, firefighters have no direct control over the robot swarm, hence the base station directly controls the swarm for some particular task.

B. Base Station Users

The GUARDIANS base station shall provide classical robot station features such as mission authoring tools, mission execution monitoring and control means, interface to robots and human crew members, and mission data recording. The originality of the approach is the ability to support multiple parallel client connections to a main base station server, featuring tailored (and tunable) M&C means according to user roles:

1) Base station coordinator: responsible for preparing and validating mission plans, coordinating the activities of operators, robots, human crew members and sensor data specialists, taking decisions in the scope of the GUARDIANS appliance activities and is an interface from and toward the commanding chain above the GUARDIANS appliance.
2) Operators: they remotely monitor and control robots and human crew members activities on the field, support the analysis of the operational situation and balance the autonomy level of robots (and crew members) according to the available information (situational awareness). They have the means and clearance to teleoperate robots, groups of robots and humans crew members.
3) Sensor data specialists: they observe and analyse sensor data and accordingly provide advices and reports to the appliance coordinator.
4) Stakeholder in the commanding chain: they remotely observe operations, requesting only from the GUARDIANS appliance the most meaningful information for decision making (reports, snapshots, etc.). They take general purpose decisions regarding the GUARDIANS appliance activities, that the base station coordinator shall apply accordingly.

[6]http://www.phidgets.com/

C. Robot Swarm

As described above, firefighters circumstances in an incident are far from the perfect. Smoke, noise and protective clothing impair their senses. Through consultation and interviews the following activities have been proposed as ways in a robot swarm may assist firefighters.

1) Notifying the firefighters of possible hazards (e.g. obstacles, high temperature, chemicals);
2) Indicating unambiguously the direction to the scene of incident or backwards to the exit point;
3) Grouping - it is important for firefighters that the swarm stays within a relatively close range to them but also maintains its distance to the firefighters to allow them freedom of action.

V. THE PROPOSED INTERFACES FOR HUMAN ROBOT INTERACTION IN GUARDIANS

This section presents the potential interfaces for human robot interaction that are under consideration in consultation with the firefighters.

A. Direct Human-Swarm Interaction

1) Passive: The swarm has to adapt its actions to the firefighter's movement in form of a passive human to swarm interaction. GUARDIANS' robots are provided with sensors that are not affected by poor visibility and can be used to monitor firefighter's movements. If there is a need to help robot distinguish the firefighters from surrounding obstacles, firefighter's gear could be electronically marked with technologies such as radio-frequency identification (RFID) tags.

2) Tangible: When the swarm is committed into the field to accompany and safeguard the firefighters, it is assigned with a high-level task. Swarm algorithms are built based on the autonomous operations of the robots, however fire fighters may contribute to tactical instructions. Human control in swarm robotics allows for dynamic authoritative control of specific swarm activities based upon local circumstances and human expertise.

In order to enable firefighters to interact with the swarm, a tangible interface will be considered. This will have to take account of the limited ergonomic freedom of the firefighter when fully equipped with protective clothing. Work in this area may have to focus identifying the key tasks that tangible interaction should enable.

3) Movement-Based: Another potentially viable form of interaction is to enable firefighters movements to serve as instructional purposes for the robot swarm. In order to maintain the control and co-operation between humans and robots, a movement language could allow for richer communication supporting a large number of tasks. For instance, a form of interaction could be recognising simple gestures from the feedback provided by haptic devices on firefighter's hands and/or arms.

B. Direct Swarm-Human Interactions

1) Tactile: The safety of firefighters is a top priority, and the most noticeable form of interaction that can be used to notify firefighters of possible hazards is through sense of touch. A tactile interface consisting of eight tactors will be attached to the firefighters torso. The interface displays a "tactile picture" of possible hazards locations surrounding firefighters. Both parameters of the frequency and amplitude will be used to communicate the seriousness of hazards.

2) Visual: To lead the firefighters to a point of interest, the swarm has to forward navigational information to the firefighters. The swarm communicates unambiguous directions through a novel visual device (Figure 3) to be installed within the firefighters' helmet. The visual device display the directions in a simple form which requires minimum attention from firefighters in order to understand them. The direction conveyed to the firefighter is determined from collective feedback from the robot swarm and the environmental factors that determine their progress to a specific goal. Currently the predominant swarm direction is being examined as the basis for determining the direction indicated to the fire fighter.

To date, the second of these options has been trialed with SyFire. This has examining specific visual configurations and identifying the most effect means of communicating directions. The manner in which such information is acted upon in the high stress low visibility setting of a fire incident is of particular interest. Perliminary results seem to indicate that users of the device value clear ordinal indications of direction over continuous indicators.

C. Remote Interaction Via Base station

As a GUARDIANS appliance is deployed on the field, robots and human crew members interact to explore the environment, assess the situation, localize victims, performing their tasks in extremely harsh conditions. In such conditions a base station is critical to the safety of the crew members and the efficiency of human crew members and robots tasks execution. According to potential end users (and especially firemen), the base station shall primarily feature:

- Timely remote support to human crew members and robots: providing clear instructions at the right moment likely to be critical to effective communication. Even the simplest instructions may result in unexpected outcomes if the human fire crew is overloaded.
- Realtime overall situational awareness: a significant effort in the design of the base station is devoted to enabling simple, efficient situational awareness both for GUARDIANS system operators and at the different levels of the command chain (appliance coordinator, operations commander, etc.). This is of high importance as failures or accidents in critical systems are often due to *lack of situational awareness*[7].

Fig. 3. Early stage of visual LED-based interface prototyping for robot to human communication

The main modules of the base station are illustrated on Figure 4. The services manager provides users with adequate remote HRI means (display and other interaction means) according to their clearance level. It gets telemetry data (robot attitude, human crew members health monitoring, etc.), audio-visual data and processed sensor data from the mission data recorder that, in addition to recording and replaying mission data on request, is also a data centralizer and dispatcher for all the system entities.

The mission editor offers authoring tools to design mission templates that, once applied in the operational context through the MPSEM, give rise to mission tasks both for human crew members and robots in the field. The MPSEM allows different schemes of mission monitoring and control over the human crew and the robots, ranging from teleoperation (step by step action) to policy level control (high level request such as "explore and report any abnormal event"). Operators may interfere at any time with plan execution and can either use or disable the MPSEM autonomous execution monitoring.

Two types of remote human interaction configurations are considered from the base station:

1) Remote human - robot swarm interaction: The principle of a robot swarm is to rely on auto-organization and group behavior emergence to fulfill tasks, while benefiting from redundancy. The base station is useful to monitor the overall swarm activity, to send policy level requests, and to take the control if necessary over a single or few robots of the swarm, while others robots continue their activities. Visualization of the swarm activity in the base station is an essential issue: efficiently encompassing the overall robots activities in a single view is a major aim for the GUARDIANS' base station. Besides, individual (or small group) control means can be achieved with joysticks

[7]Historically this has sadly been the case in notorious tragedies such as the Tchernobyl disaster in 1987, or aerial disasters such as the Tenerife one in 1977

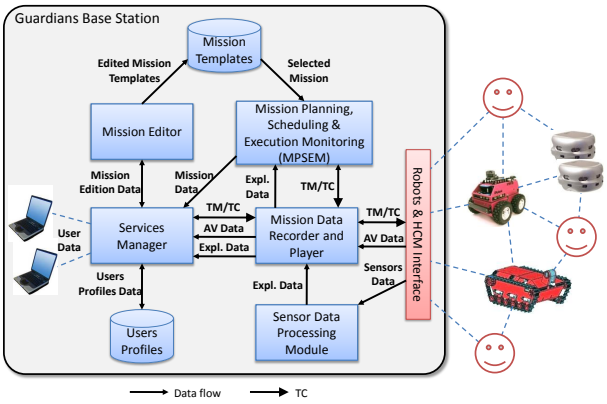

Fig. 4. GUARDIANS base station architecture and data flows. TM stands for telemetry, TC stands for telecommand, and AV stands for audio-visual.

and other interacting devices such as touchscreens. Efficient multi-scale agent control may typically find inspiration in real-time strategy video game (i.e. Warcraft like).

During normal operations, robots operate autonomously. However there are situations in which autonomy level adjustment [2], [7]–[9] is deemed necessary. Humans may take control over one or more robots to enforce a particular way of performing tasks, if they think it is appropriate in the current situation: typically if tasks are particularly complex, delicate, or require knowledge that the robots are not aware of. With adjustable autonomy, an entity needs not make all decisions autonomously, rather it can choose to reduce its own autonomy level and transfer decision making control to other users or agents. Thus the system is more flexible, since it can handle tasks that might not have been anticipated at the design process. Furthermore, the ability to shift the level of autonomy is an elegant way of balancing the load among all parties, whether it is human or robot.

2) Remote human - human crew members interaction: One of the specificities of the GUARDIANS system is the ability to take in charge both robots and human beings on the fields, both in terms of monitoring and control. The main benefit is the possibility to coordinate robots and humans activities on the fields together, in a comparable way. At first glance teleoperation of human beings is meaningless, but this should be understood in terms of successive fine grain actions requests, as operators are likely to have a better overall situational awareness than the firefighter in some situations: indeed firefighters sometimes face conditions where visibility is null and ambient noise makes it impossible to discuss with other crew members. In such a situation, the base station can send simple step by step elementary actions requests through the designed user interface, for instance to guide the firefighter toward the exit, or toward a victim that the robot swarm localized. Moreover it shall be mentioned that adjustable autonomy concepts introduced earlier *also* make sense for the remote human - human crew members interactions.

VI. CONCLUSIONS

The research on the human swarm interface has to tackle several very new problems. The combination of robot swarm and the base station in GUARDIANS is to help the human to navigate where the human senses are failing. Furthermore, this project aims to develop novel interactions technology to maintain control and coordination between the swarm and the humans.

Next steps consist of providing a full conceptual design to human - robot swarm interactions, and further the physical and operational prototype will be evaluated in full scale experiments with end users (i.e. firefighters).

VII. ACKNOWLEDGMENTS

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REFERENCES

[1] J. Adams. Human-robot interaction design: Understanding user needs and requirements. In *Human Factors and Ergonomics Society 49th Annual Meeting*, volume 4, 2005.
[2] J. A. Adams, P. Rani, and N. Sarkar. Mixed-initiative interaction and robotic systems. In *AAAI Workshop on Supervisory Control of Learning and Adaptative Systems*, 2004.
[3] CPSR. Participatory design, computer professionals for social responsibility, http://cpsr.org/issues/pd/, 2008.
[4] F. Driewer, H. Baier, and K. Schilling. Robot/human rescue teams: A user requirement analysis. *Advanced Robotics*, 19(8), 2005.
[5] M. R. Endsley. *Situation Awareness Analysis and Measurement*, chapter Theoretical Underpinnings of Situation Awareness: A Critical Review. Lawrence Erlbaum Associates, Mahwah, NJ, 2000.
[6] H. Jones and P. Hinds. Extreme work teams: using swat teams as a model for coordinating distributed robots. In *Proceedings of the 2002 ACM conference on Computer supported cooperative work: CSCW '02*, pages 372–381. New Orleans, Louisiana, USA, 2002, Nov. 2002.
[7] D. Kortenkamp, R. P. Bonasso, D. Ryan, and D. Schreckenghost. Traded control with autonomous robots as mixed initiative interaction. In *in proceedings of the AAAI Spring Symposium on Mixed Initiative Interaction*, 1997.
[8] D. Kortenkamp and D. Dorais. *Tutorial: designing Human Centered Autonomous Agents*, 2000.
[9] R. R. Murphy, J. L. Casper, M. J. Micire, and J. Hyams. Mixed-initiative control of multiple heterogeneous robots for urban search and rescue. In *in proceedings of the IEEE Transactions on Robotics and Automation*, 2000.
[10] A. M. Naghsh and M. B. Ozcan. Gabbeh - a tool for computer supported collaboration in electronic paper prototyping. In D. A and W. L., editors, *HCI 2004: Design for Life*, 2004.
[11] J. Penders, E. Cervera, U. Witkowski, L. Marques, J. Gancet, P. Bureau, V. Gazi, and R. Guzman. Guardians: a swarm of autonomous robots for emergencies. In *Workshop of Robotics in Challenging and Hazardous Environments in ICRA2007*, 2007.
[12] C. W. Reynolds. Flocks, herds and schools: A distributed behavioral model. In *SIGGRAPH '87: Proceedings of the 14th annual conference on Computer graphics and interactive techniques*, pages 25–34, New York, NY, USA, 1987. ACM Press.
[13] E. Sahin and W. M. Spears. Swarm robotics, a state of the art survey. 3342, 2005.
[14] J. Scholtz. Theory and evaluation of human-robot interaction. In *Proc. HICSS 36, 2003.*, 2003.