2004
UCMEXUS-CONACYT
Collaborative Grant Application
Project Plan

Networked SEREBROs: Ad-hoc Networking for Collaborative Search and Rescue Biomimetic Robots

Introduction

In recent years robots have demonstrated their usefulness in supporting life-threatening humans tasks. Among these, Urban Search and Rescue (USAR) [Rescue, 2002] has been an area where robotics is starting to have an important impact [Orfinger, 2001][Murphy, 2004]. In particular, as a result of earthquakes or other collapsed building disasters, one of the most important tasks involves search and rescue of trapped survivors. The main challenges in rescue operations are posed by the unstable nature of the structures, the hard to reach spaces, the lack of oxygen, and the hazards resulting from fire, toxic gases, or other chemicals. In the past, specialized sensory equipment has been used in assisting rescuers, yet most of this technology is used from outside the disaster perimeter. In order to get closer to survivors, scientists are currently experimenting with mobile robots with varying shapes, sizes and capabilities [Osuka et al., 2002]. Until now, most search and rescue robots are remotely operated, resulting in a number of limitations:

(a) The number of robotic devices required to control a large-scale search and rescue operation is significant, requiring a large number of trained human controllers.

(b) Coordination between human controlled teleoperated robotic devices is hard, limiting the possibility of shared decision support systems.

(c) Poor environmental conditions, such as low visibility, make human maneuvering of robotic devices difficult.

(d) Teleoperation relies on continuous availability of robust communication channels and power sources, including the use of wirelines.

In overcoming these restrictions, search and rescue robots will become more autonomous with time, interacting only with human controllers for higher-level decisions making. In the past, a number of approaches for autonomous robot exploration and navigation in unknown maze-like urban structures have been proposed. Some approaches involved producing metric maps of buildings, while others, taking lessons from nature, proposed biomimetic robot approaches [Franz & Mallot, 2000]. In such a way, studies of rats and the brain hippocampus have inspired a number of robotic architectures for these tasks [Etienne, 1998; Mataric, 1991; Arleo & Gerstner, 2000; Burgess et al., 2000; Kuipers & Byun, 1991; Owen & Nehmzow, 1998; Touretzky & Redish, 1998]. It is interesting to note that some scientists have even proposed the use of “roborats” (part rat and part robot) in USAR [Talwar et al., 2002].

It is the goal of this project to provide an understanding and initial design for a distributed network of collaborative SEREBROs (Search and Rescue Biomimetic Robots) or “Networked SEREBROs” taking inspiration from cognitive maps based on the rat’s hippocampus in developing Urban Search and Rescue (USAR) robots. The particular approach to be taken in “Networked SEREBROs” is a hybrid one, where individual robot models are biologically inspired while collaboration among these robots will not necessarily take a biological approach. In other words, robots will share individually learned biologically inspired cognitive maps with the non-biologically ability to share these maps in reducing the overall time necessary to explore unknown areas. At this stage, robots will not rescue survivors; they will help produce topological maps of how to reach a survivor’s location. Eventually, these tasks can be extended in asserting survivor condition and existing hazards. These robots will be tested under RoboCupRescue arenas [RoboCupRescue, 2004] (ITAM already competes in other RoboCup [Robocup, 2004] categories with its Eagle Knights soccer team). In order to enable such a collaborative robotic approach, it is also necessary to incorporate adequate ad-hoc network support. As part of this research, we plan to develop efficient ad hoc network protocols that address the specific needs of collaborating robots operating in rescue scenarios. In designing these protocols, some of the main design goals include power-awareness and support for different sensing devices, including cameras.

Research Objectives and Methodology

The specific objectives of this joint U.S.-Mexico research project are twofold: (1) to provide an understanding and experimentation arena by which multiple biomimetic robots can collaborate in search and rescue exploration and navigation tasks; (2) to design an ad-hoc communication environment to support robot collaboration in a transparent, adaptive, and power-aware manner. In order to achieve these goals, the following issues will be addressed in this project:

- *Collaborative Search and Rescue Robots*: There are restrictions to what single robots can independently accomplish in Search and Rescue Robotics (USAR) exploration and navigation tasks. In particular, non-cooperating robots have the risk of missing search areas while overlapping in other ones. On the other hand, collaborating robots should be able to improve overall search performance. Yet, there are many alternatives in the kind of collaboration and interaction that could take place between these robots considering the unstructured and unpredictable nature of disaster-type scenes. While there are a number of efforts in using rat-inspired robots, most deal with single robot experiments. Very little has been done in terms of collaborative biomimetic robot search and rescue. Thus, we propose to take existing rat-inspired robot models and extend them to groups of collaborative robots in such a way that hippocampus based cognitive maps can be shared in reducing the time it takes to explore large unknown scenes.
- *Ad-hoc Networking and Adaptive Communication*: Collaborative robots pose an important challenge in terms of communication. Since we cannot assume that each robot will always be in communication range to another particular robot or to a base station, we will employ the ad-hoc networking communication model for robot and base station interaction. In other words, every robot may be a traffic source, destination, or forwarder. Yet, some particular considerations are necessary when dealing with mobile robots. For example, depending on the type of sensors used, the resulting data streams (e.g., video, scalar data, etc.) may be of different nature, may be destined to different types of nodes (e.g., another robot, a data collection node, etc.), and may require different quality-of-service (QoS) from the network. Additionally, communication policies will need to adapt in response to the dynamics of the underlying network topology (e.g., links going up and down due to mobility or physical channel impairments).

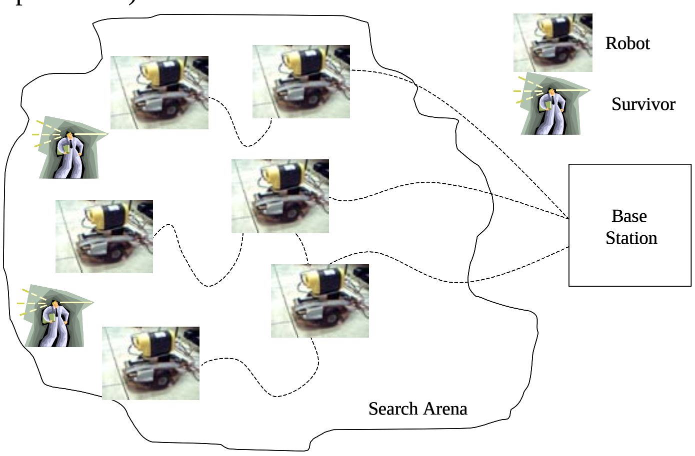

Figure 1. Sample search arena with search robots, communication robot relays and base station.

An illustrative search and rescue scene is shown in Figure 1. Robots need to identify and locate human survivors by exploring the disaster area. In relaying this information back to base, robots can be used as communication relays [Nguyen, 2003] following an ad-hoc network model. Application level collaboration could be done directly between robots or indirectly through base station.

The Networked SEREBROs project is described in the following sections: (1) biomimetic robots, (2) robot navigation, (3) collaborative robot exploration, and (4) ad-hoc networking for mobile robots.

Biomimetic Robots

Living organisms have been a source of inspiration for robot applications in many different areas for many years. These biologically inspired robots, known as *biomimetic* robots, have been useful as a platform to test knowledge about specific biological models [Webb, 2001]. These models have served as basis for a number of robotic applications including *ecological* robotics [McFarland & Bosser 1993]. For example, a number of biomimetic robotics systems have been developed taking inspiration from animals such as frogs and toads [Arbib, 1987], praying mantis [Cervantes-Perez et al., 1993b], cockroaches [Beer, 1990], and hoverflies [Cliff, 1992]. In order to model and field such biomimetic robots it is necessary to address the underlying complexity of neural based robotics systems, usually distinguishing among two different levels of modeling, behavior (*schemas* [Arbib, 1992]) and structure (*neural networks* [Arbib, 1989]).

At the behavioral level, neuroethological data from living animals is gathered to generate single and multi-animal systems to study the relationship between a living organism and its environment, giving emphasis to aspects such as cooperation and competition between them. Examples of behavioral models include the praying mantis *Chantlitlaxia* ("search for a proper habitat") [Cervantes-Perez et al., 1993a] and the frog and toad (*rana computatrix*) prey acquisition and predator avoidance models [Cobas & Arbib, 1992]. We describe behavior in terms of perceptual and motor *schemas* decomposed and refined in a recursive fashion, where schema hierarchies represent a distributed model for action-perception control [Weitzenfeld, 2000]. Behaviors, and their corresponding schemas, are processed via the Abstract Schema Language ASL [Weitzenfeld, 1993].

At the structural level, neuroanatomical and neuronphysiological data are used to generate perceptual and motor neural network models corresponding to schemas developed at the behavioral level. These models try to explain the underlying mechanisms for sensorimotor integration. Examples of neural network models are tectum and pretectum-thalamus responsible for discrimination among preys and predators [Cervantes-Perez et al., 1985], the prey acquisition and predator avoidance neural models [Cervantes-Perez et al., 1993b] and the toad prey acquisition with detour behavior model involving adaptation and learning [Corbacho & Arbib, 1995]. Neural networks are processed via the Neural Simulation Language NSL [Weitzenfeld et al., 2002].

Due to intensive processing requirements, most biomimetic robot systems are designed and implemented at only one of the above two levels of granularity. For example, in [Arkin et al. 2000], we describe a praying mantis prey-predator model simulated and experimented in a fielded robotic system modeled exclusively at the behavior level. On the other hand, models that actually involve neural networks are usually limited in scope as in [Corbacho & Weitzenfeld, 2002]. Due to high processing costs, the larger models are usually simplified in terms of their inherent neural complexity [Weitzenfeld et al., 2001]. Yet, it is important to be able to experiment with the more complex biomimetic systems involving both behavior and neural structure.

Robot Navigation

In order for robots to be able to explore unknown areas it is necessary for them to be able to navigate requiring some form of mapping capabilities [Thrun, 1997]. Mapping involves both knowing the robot own position as well as its relation to destination and a course to follow. Many mapping approaches have been considered in the past with different levels of success. While some of these are non-biological, such as those based on metric maps, some other have taken inspiration from biology from animals such as bees, ants, rats, birds and fish [Trullier et al., 1997]. These particular animals have well developed navigational systems that only need to know how to reach their destination without knowledge of their exact location. In general, two non-metric navigation approaches have been considered, *local navigation* and *global navigation*, also known as *way-finding* [Franz & Mallot, 2000].

In *local navigation* the objective is to find the location without the need for object representations along the path. Some of the local navigation strategies are:

- **Direction-following and path integration** where the robot must be able to align its course by estimating direction and distance to goal. For example, *idiothetic* (internal) odometry and active proximity sensors can be used for simple wall and corridor following behaviors. On the other hand, for example, *allothetic* (external) pheromones, light compasses and optic flow can be used in reactive trail following as in ants [Sharpe & Webb, 1998], bees [Coombs & Roberts, 1993; Srinivasan et al., 1991; Santos-Victor et al., 1995; Weber et al., 1997], desert ants [Lambrinos et al., 1997] and flying insects [Chahl & Srinivasan, 1996].
- **Aiming** where the goal is associated with some salient cue, as opposed to direction following, and can be approached from various directions. This approach can be easily implemented in mobile robots with beacons [Braitenberg, 1984]. Biomimetic examples include following sound sources such as in crickets [Webb, 1995], and following objects with strong visual contrasts such as in flies [Huber & Bulthoff, 1998].
- **Guidance** where the goal can be reached by considering a spatial relationship of objects along the way without having salient goal cues or even external object representation. Instead, special features or landmarks are stored into *cognitive maps* [O'Keefe & Nadel, 1978]. Biomimetic examples include landmark learning and guidance such as in insects [Collett, 1992], and matching visual snapshots [Cartwright & Collett, 1983; Rofer, 1995; Franz et al., 1998b; Moller et al., 1998].

In *global navigation* the objective is to reach the goal where in addition to local navigation, objects or places along the way need to be recognized and represented. Some of the global navigation strategies are:

- **Recognition-triggered response** where local navigation methods connect different locations in forming routes. Biomimetic examples include association of visual landmarks [Dedeoglu & Sukhatme 2000] with way of passing such as in ants and bees. For example, neural associative memories have been used with unconnected landmark routes leading to single goal as in [Barto & Sutton, 1981]. This approach has been tested in a number of robots [Nelson, 1991; Gaussier & Zrehen, 1995]. On the other hand, connected landmark routes leading to a goal have been tested using rat navigation models (hippocampus "place cells" representing bearings and distances) [Recce & Harris, 1996; Burgess et al., 1997a].
- **Topological navigation** where routes can be integrated in reaching different goals from varying starting locations. Spatial maps are goal-independent and represented by a graph. Requires planning and route integration, where routes may pass same place although having different sensory configurations. One particular aspect in topological navigation is that novel routes over unvisited terrain cannot be generated. The main challenge in topological navigation is that robot needs to detect overlap of multiple routes, resulting in a number of perceptual aliasing problems [Owen & Nehmzow, 1998; Kortenkamp & Weymouth, 1994]. Biological examples of topological learning include bottom-up route integration [Lieblich & Arbib, 1982], from honeybees [Dyer, 1991] to humans [Gillner & Mallot, 1998]. In particular, the rat hippocampus place-cell navigation model has been extensively studied [Bachelder & Waxman, 1995]. Rat-inspired robot examples [Mataric, 1991] include learning of topological representations from global maps [Thrun, 1997]. Other related work includes human cognitive mapping theory [Chown et al., 1995] and "view-graph" approaches [Mallot et al., 1995; Franz et al., 1998a].

Collaborative Robot Exploration

There are many application areas and strategies for collaborative robotics [Arkin and Balch, 1998]. In this project we will concentrate on topological landmark navigation based on rat-inspired navigation models integrating both behavior and neural levels [Guazzelli et al., 1998]. We propose to develop "Networked SEREBROs" by integrating cognitive maps learned individually by different robots. This work builds upon research on landmark learning relating to hippocampus modeling in rats both at the behavior and neural levels. Since most of the existing work in rat inspired navigation has been done either at the behavior or neural levels separately, we will design as part of this project an initially architecture integrating across both. At the behavior level most of the existing work has concentrated in autonomous navigation once landmarks have already been learned. On the other hand, most of the neural level work has concentrated in the physiological aspects of the hippocampus, usually limiting the complexity of the actual navigation scenarios.

It is important to highlight that there are many strategies for collaborative robot exploration. If we consider that time is probably the most critical factor in human rescue, it is important to achieve this independently from robot cost or number of robots involved. When dealing with topological navigation, there are a number of strategies that can be used including different types of topological map integration and different communication schemes including direct communication between robots and/or base station. Additionally, different numbers of robots and order of navigation can be involved, for example groups of multiples robots sent one group after the other where each group starts its exploration from cognitive maps already produced by previous robots. Obviously the difficulty of the problem is directly proportional to the size and complexity of the search arena.

Ad-hoc Networks for Mobile Robots

Advances in wireless communications have extended the scope of wired internetworking to interconnect mobile computing devices and have enables a whole new set of applications such as collaborative robotics. However, interconnecting collaborative autonomous robots raise several challenges. Since we cannot assume that each robot will always be in communication range to a base station, an ad-hoc networking communication model will be employed. More specifically, the ad hoc network protocols to be developed in this project need to: (1) adapt to changing network and environmental conditions (transient failures, disconnection, or reduced connectivity) due to power consumption, available spectrum and mobility; (2) integrate *power aware* mechanisms yet reach the right balance between energy efficiency and system performance, and (3) provide required QoS depending on the type of traffic being transmitted. We will also investigate a heterogeneous architecture that allows robots to communicate with other sensors (e.g., temperature, motion, etc.) deployed on the field.

As part of this project, we will identify the specific communication requirements posed by robots collaborating in rescue-type scenarios. These requirements will drive the design of the ad hoc network protocols that we will develop. For example, the types of interactions and resulting traffic flow will dictate our choices for (1) medium-access control (MAC) protocols, (2) routing paradigms, and (3) transport-level services. Furthermore, since robots use cameras as primary sensors, video transmission becomes a critical issue in the design of the overall network architecture. This implies that the network must provide different QoS to handle different classes of traffic. For example, video transmission requires low delay and low delay variation delivery. However, robot's mobility may create situations where QoS for video transmission cannot be provided, due to unavailable bandwidth, frequent route changes, etc. Thus, the communication infrastructure should be able to adapt data transmission to the current conditions of the underling network. For example, if all of a sudden, bandwidth becomes scarce, more aggressive data compression algorithms can be used.

The components of the communication infrastructure that will be developed in this project include:

- **MAC protocols:** We will evaluate whether power-aware contention-based protocols (a la 802.11, e.g., S-MAC [Ye et al., 2004]) are adequate or adaptive scheduled-access MACs (e.g., TRAMA [Rajendran et al., 2003] should be employed. This design choice will depend on issues such as the types of QoS required, the types of communication paradigms involved (e.g., one-to-one, one-to-many, many-to-many), etc.
- **Interconnection protocols:** Depending on the types of exchanges that take place, we will determine whether to use an IP-based protocol stack or rely on a more flexible interconnection protocol such as FLIP [Solis & Obraczka, 2003]. Due to its flexible headers, FLIP allows application developers to choose the exact functionality they need and thus incur only minimal overhead. This can achieve considerable energy efficiency that is critical in the case of devices connected o limited power sources.
- **Routing mechanisms:** Since the interactions among robots may include not only one-to-one but also group communications, multicast as well unicast routing protocols will be explored. While several unicast [Broch et al., 1998] and multicast [Lee et al., 2000] protocols have been proposed for ad hoc networks, we will investigate whether existing mechanisms are well suited to the application at hand. In particular, we will explore how to adapt existing protocols to the QoS and energy efficiency needs of collaborative robotics.
- **Transport services:** Another important component of the proposed research is to identify what transport-level services are required. Some exchanges may require reliable delivery (e.g., if a robot is sensing out its new location information), but some, like video transmission, may be loss tolerant but delay (or delay variation) intolerant. We can build on the idea of flexible headers (a la FLIP) and use a flexible transport-level protocol that provides he exact transport-layer services required. Security in the context of collaborative robots in rescue operations is another transport-layer functionality we plan to explore.

Work Plan

The work to be performed is an extension to research currently carried out separately by Dr. Obraczka at UCSC and Dr. Weitzenfeld at ITAM. The collaboration goal is to provide linkage between these separate efforts. The current scope of this project involves: (1) the design of the search and rescue biomimetic robotic architecture and collaboration strategies, and (2) the design of the ad-hoc networking for collaborative mobile robots in the context of search and rescue robotics.

Collaborative Biomimetic Robot Architecture

The ITAM's Robotics Laboratory has been for a number of years in the design and development of both robotic hardware and software architectures for varying applications. At this time we own a number of robots, some built by us and others have been acquired. The robots build by our students are for local experimentation in research projects as well as those built for international RoboCup soccer competitions. In addition to these we own Lego and Sony's AIBO robots, used the latter until now for international RoboCup competitions. We plan to use the AIBO robots for this particular project due to their flexibility and ability to communicate in a wireless fashion (WiFi) while including extensive processing capabilities. As part of this project we will:

- Specify a basic rat hippocampus cognitive map model to be used for each individual robot.
- Specify a distributed cognitive map model architecture to be shared among robots.
- Specify different map integration strategies.
- Specify what kind of data communication should be transmitted between robots.
- Experiment with different navigation strategies, including variations in group exploration.

Ad-hoc Networking

The UCSC's Internetworking Research Group (i-NRG) has been engaged in research on developing ad hoc network protocols at different layers of the network protocol stack. As part of this project we will:

- Analyze and specify the communication needs posed by collaborating robots in rescue operations. These requirements relate to the type and amount of data to be transmitted (in particular, we will be dealing with vision as one of the main sensory information), the type of interactions taking place, etc.
- Design, evaluate and implement power-efficient medium-access control protocols that are well suited to the needs of collaborating robots in harsh environments.
- Define the interconnection protocol to be used based on the types of interactions that will take place and on power efficiency considerations.
- Develop adequate routing mechanisms.
- Develop adequate transport-layer functionality.

Timeline (1.5 year)

This project is an extension to existing research. Considering the ambitious research goals of the extended project, we will concentrate on part of the general objectives through this collaboration. In particular, we will design and implement the collaborative robot architecture and networking infrastructure while at the same time extend and adapt our existing robot navigation models under this framework.

ITAM

Dr. Weitzenfeld will supervise robot modeling and experimentation.

Semester 1: Prototype single robot architecture. Design collaborative robot navigation model.
Semester 2: Prototype collaborative robot architecture.
Semester 3: Prototype collaborative robot architecture under different strategies with linkage to ad-hoc network system.

UCSC

Dr. Obraczka will supervise the development of the ad-hoc network protocols.

Semester 1: Define ad-hoc networking requirements based on robot collaboration model.
Semester 2: Prototype ad-hoc communication architecture.
Semester 3: Experiment with different communication strategies. Analyze results.

Prior UCMEXUS-CONACYT Projects

Prior to this proposal, Alfredo Weitzenfeld participated as coPI in a 2001-2003 UC MEXUS-CONACYT collaborative grant for Internet2 Advanced Network Services in collaboration with Nalini Venkatasubramanian from UCI. The project, entitled "MIRO: Adaptive Middleware for a Mobile Internet Robot Laboratory", involved the following research objectives: (1) provide an understanding and means by which Internet2 can be efficiently integrated into a public wireless network of single and multiple autonomous mobile robots capable of handling real-time video; (2) provide an adaptive communication environment that will make it transparent to the application and robot what the actual network characteristics are and how to deal with the inherent restrictions; (3) provide a Internet2/wireless "grid" that can be effectively applied to biologically inspired autonomous mobile robots linked to distributed computational resources in the Web; and (4) provide with a distributed virtual laboratory enabling real time interaction with autonomous mobile robotic systems to users anywhere in the world.

Shown in Figure 1 is the MIRO architecture consisting of the application level comprising neural computation system and autonomous robots; and the middleware level consisting of the adaptive robot middleware architecture (ARM) managing communication between the robot and neural computational system. Note that the current project builds on top of the MIRO architecture. As opposed to the currently submitted research project involving an ad-hoc network of communicating robots, the MIRO architecture enables only direct communication between the robot and computational system residing in a computer linked to an Internet2 interface. Remote experiments were conducted both at ITAM and UCI involving a sample model of the frog's prey acquisition with detour behavior under different initial conditions, with a sample cycle of computation is shown in Figure 2.

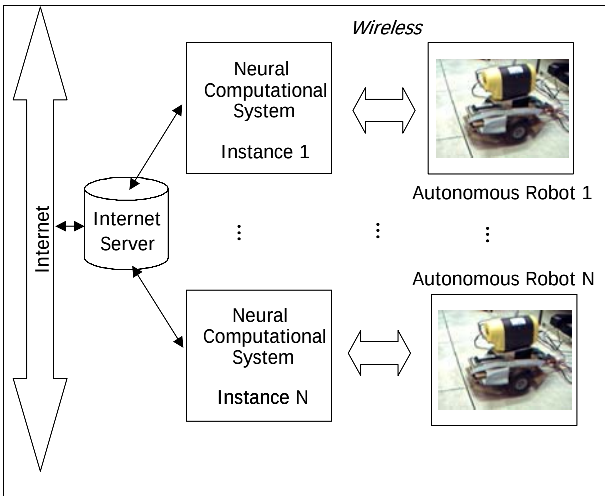

Figure 1. MIRO Architecture.

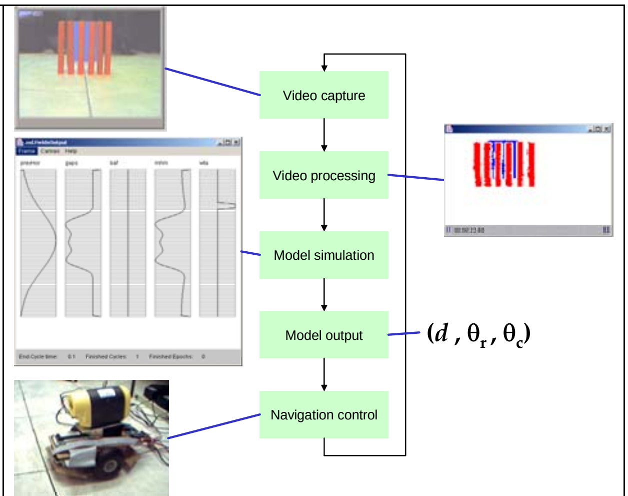

Figure 2. Exemplary robotic model processing cycle.

This project has been invaluable in bringing together complementary research work as part of an already extended collaboration between the involved participants and institutions. It has enabled the development of the preliminary adaptive robot middleware architecture to support distributed robotic systems. This support is crucial in providing with a transparent environment where robotic application can be developed without having to be concerned with many of the underlying wireless communication issues. We expect to integrate later on this work as part of the current proposal ad-hoc network architecture.

In terms of Internet2, this work should soon provide researchers and students located in different geographical regions with a virtual robotics laboratory where to conduct varied robot experiments in support of research as well as teaching. This is an important concern in Mexico considering the limited resources available to most public institutions. It should be noted that software developed as part of this project is been made available as shareware, as in the case of other software systems such as the NSL/ASL simulation system.

Alfredo Weitzenfeld has also received a UC MEXUS-CONACYT faculty fellowship grant to visit Nalini Venkatasubramanian research laboratory at UCI during the summer period July – September 2003. This work allowed further discussions and research interaction in "Distributed Embedded Robotics, Supporting Middleware Architectures and Applications".

The following are the main publications and talks resulting from this collaborative grant. It should be noted that there are pending publications and student thesis both at ITAM and UCI related to this project. The web site for this project is located at http://cannes.itam.mx/English/research/projects/miro/miro.html.

Work Significance and Benefits derived from the Collaboration

This collaboration is based on complementary research areas, at ITAM in robotics and at UCSC in networking. A previous UC MEXUS-CONACYT research grant with Dr. Venkatasubramanian at UCI has highlighted many of the benefits of this kind of collaboration and we expect that in the future we will be able to design a 3-way collaboration between ITAM, UCSC and UCI.

1. **Scholarship**. Many students graduating from Mexican institutions including ITAM have already continued with advanced degrees in UC institutions. One particular student, Sebastián Gutiérrez, a previous graduate of Dr. Weitzenfeld´s research laboratory at ITAM, is close to completing his PhD degree at UCI while being partially funded through a previous UC MEXUS-CONACYT research grant. Dr. Weitzenfeld is an external committee member of his doctoral thesis. This effort is being extended by new ITAM students have applied or interested in continuing their studies at UC institutions. In addition to this, new courses have been initiated at ITAM as a result of these collaborations, such as our new Robotics course building from our previous collaboration with UCI, where further collaboration between the different institutions is being considered. Additionally, UCSC is starting to build its robotics program, and this collaboration will be of considerable importance in helping jump-start this program.
2. **Science**. Collaborative robotics and biomimetic robotics are two areas of important scientific development involving themes such as sensor fusion, vision, control, learning, etc. Our current collaboration will extend scientific work by producing advances (and publications) in ad-hoc networking for collaborative robotics. It is worth noting that there exists extensive work on ad-hoc networking for sensor networks an area closely related to our current research.
3. **Technology**. The particular research theme relates to urban search and rescue (USAR) robotics, a development area that is already having an important impact in countries where earthquakes are common or in response to collapsed building disasters. We expect this work to have an ever increasing importance in society, not only in helping rescuers and survivors but also in areas such as homeland security or even entertainment, such as RoboCup competitions, where Dr. Weitzenfeld at ITAM is already very active as participant and organizer. (Dr. Weitzenfeld is an organizing member of the IEEE Latin American Robotics Council and Mexico robotics competitions.) We are planning to extend these competitions to search and rescue robotics.
4. **Importance**. We will like to emphasize the importance of this research area and collaboration. Both the search and rescue robotics area together with the related robotics competitions are getting a large attention in the world. In particular, in both the US and Mexico there has been an increased interest in these areas as experienced by the number of students, reporters and colleagues interested in our activities. We expect in the future new developments in the robotics industry helping cope not only with disasters but also with other environmental or social problems.

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