MIRO: A DISTRIBUTED EMBEDDED ARCHITECTURE FOR VISUALLY-GUIDED NEUROETHOLOGICAL AUTONOMOUS ROBOTS

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Abstract

An alternative to traditional simulation of biological behavior is to investigate problems in neuroethology, the study of neural basis for behavior, by developing embedded physical robot models. While a number of neuroethological robot models have been developed, these tend to be quite expensive in terms of computational needs. Two different approaches have been taken to neurotheological robot design: (1) having fully local computation in the robotic system, and, (2) distributing processing between robot and a remote computer system. While the first approach simplifies the overall robotic architecture it involves usually specialized and expensive hardware. The second approach considers smaller and less expensive components, where robots are used as remote sensorimotor devices. In this paper we present the MIRO (Mobile Internet Robots) architecture distributing processing between the robot and the NSL/ASL (Neural Simulation Language / Abstract Schema Language) neural simulation system. The distributed architecture enables a single computational system for both simulated and real-time robot experiments with the ability to monitor robot performance directly from the Internet. We discuss some of the issues having arisen in using the MIRO architecture while experimenting with a toad's prey acquisition and predator avoidance neuroethological model. We conclude with future work in neuroethological modeling and the MIRO architecture.

Key Words

Robot, neuroethology, schema, neural, embedded, and distributed

1. Introduction

An important question in the behavioral and brain sciences community is "how should biological behavior be modeled". Webb [23] discusses a methodology using neurothological models as basis for biological behavior modeling by building physical robots. Neuroethological robotics is different from the more traditional behavior-based robotics [5] in that neural models are incorporated as basis for behavior. The reason for doing robot experimentation as opposed to simulation-only is that models tend to be oversimplified during simulation while embodiment provides a much richer and realistic interaction environment. In addition to this, neuroethology provides a rich inspiration for new robotics architectures, as in search and rescue robotics [19].

One important concern with neuroethological robotic experimentation involves how to achieve real-time performance considering the expensive nature of neuroscientific processing [30]. One approach to overcoming this challenge is to have "super-robots" in analogy to supercomputers, something that usually requires specialized, usually bulky, and expensive hardware. It should be noted that while there are neural based micro-controllers, these are produced as a result of previous stages of model design and experimentation. During model development and robot testing it is necessary to be able to modify the model architecture, something purely electronic devices do not allow.

A second approach is to incorporate smaller and less expensive robotic hardware reducing overall physical size and power requirements. This approach involves embedding the robot into an inexpensive network of computers where time-consuming tasks, e.g. neural and image processing, can be remotely computed [17]. The robot is used as a sensorimotor device sending input to the remote computer while receiving back motor commands in a wireless fashion. Depending on the robotic hardware configuration there may be additional local robot processing, such as image pre-processing or simpler local robot tasks. In practice, this distributed robot approach supports both autonomous as well as teleoperated robotic architectures in a varied applications [18][20].

In this paper we discuss our current work with the MIRO embedded distributing robotics architecture supporting remote image and neural processing using the NSL/ASL neural simulation system via wireless communication. We describe experiments with MIRO-based neuroethological robotic models followed by conclusions from this work.

2. Biologically inspired Robots

The study of biological inspired robotics comprises a cycle of biological experimentation, computational modeling and robotics experimentation as depicted in Figure 1. This cycle serves as framework for the study of the underlying neural mechanisms responsible for animal behavior.

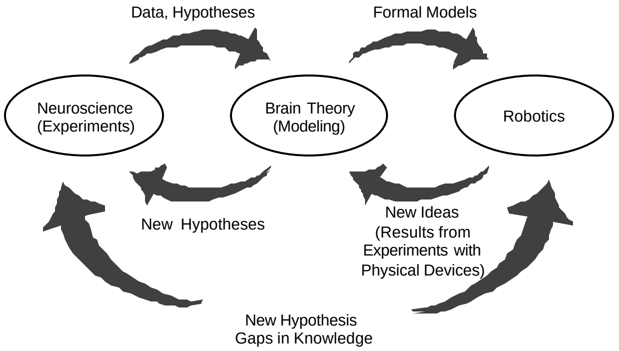

Figure 1. Framework for the study of living organisms through cycles of biological experimentation, computational modeling, and robotics experimentation.

Examples of biologically inspired robot models include frogs and toads [1], praying mantis [11], cockroaches [9], and hoverflies [13] among others. To address the underlying complexity in building neuroethological robotic systems we usually distinguish between behavior and neural structure modeling [2].

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 *Chantlitaxia* ("search for a proper habitat") [10], the frog and toad (*rana computatrix*) prey acquisition and predator avoidance models [14], and the praying mantis prey-predator model [6] as a basis for *ecological* robotics [7]. Behaviors are described in terms of perceptual and motor *schemas* representing a distributed model for action-perception control [3]. Behaviors, and their corresponding schemas, are processed via the Abstract Simulation Language ASL [24].

At the structural level, neuroanatomical and neurophysiological 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, with particular emphasis in our group to visually guided systems [27]. Examples of neural network models are tectum and pretectum-thalamus responsible for discrimination among preys and predators [10], the prey acquisition and predator avoidance neural models [12] and the toad prey acquisition with detour behavior model involving adaptation and learning [15]. Neural networks are processed via the Neural Simulation Language NSL [26].

In Figure 2 we show a two-level schema diagram for a toad´s prey-predator visuomotor coordination model [16]. When available, behavior schemas are refined into neural schemas by finding direct mappings to brain regions [25].

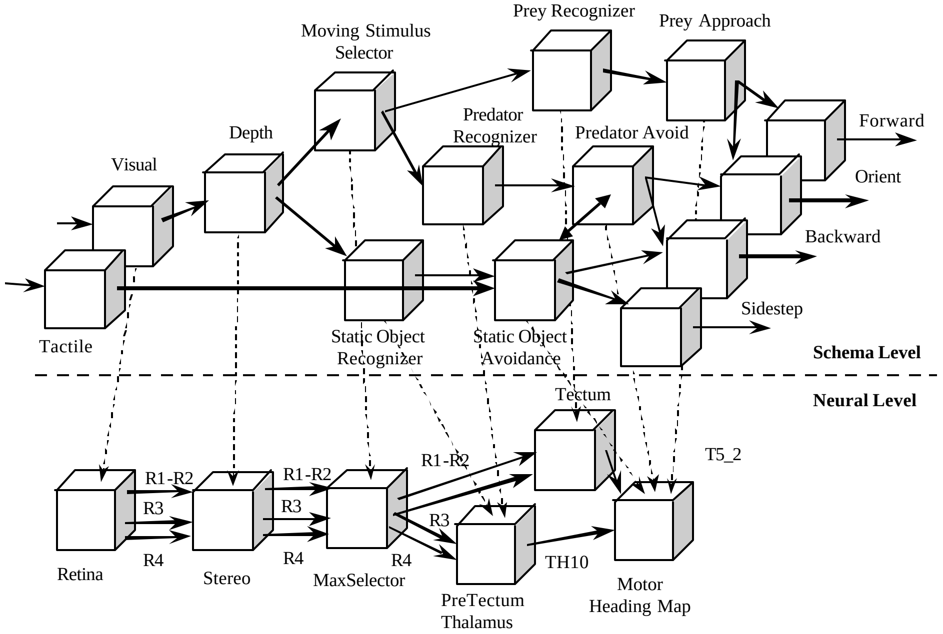

Figure 2. Toad’s prey-predator visuomotor coordination model architecture with schema and neural level modules. Arrows in the figure represent data transmitted between modules, for example R1-R4 correspond to retinal cell output, while T5_2 and TH10 are tectum and thalamus output, respectively.

3. Embedded Distributed Architecture

One of the main concerns with neuroethological robot experimentation is the expensive nature of neural processing. For example, a "typical" retina model may consist of more than 100,000 neurons and half a million interconnections and depending on the computer hardware may result in minutes of computer time [21]. While some specialized neural hardware exists for specific tasks such as vision, these are hard to adapt or cannot be adapted at all to new neuroethological architectures. The expensive nature of neural computation is further exacerbated by the fact that a comprehensive neuroethological model may include multiple neural modules involving multiple brain regions [4]. As such we have been designing a distributed computational model taking advantage of the parallel and distributed nature of neural network computation. Thus, the time it takes to process a neuroethological model depends on the model complexity, the schema distribution architecture and the available computer resources in the network [28].

In trying to achieve real-time performance while experimenting with neuroethological robotic systems, we have designed the MIRO (Mobile Internet Robotics) embedded distributed system as shown in Figure 3. The architecture consists of multiple robots, each one connected to its own instance of the remote computational system. Processing is distributed between the robot and the remote computational system with wireless communication between the two systems. Although it would be possible in principle to share robot "intelligence" among multiple robots, we keep a fully autonomous robot architecture in providing with truly neuroethological experimentation. Other application could easily take advantage of information sharing (see [8] for a discussion on distributed versus centralized robotic systems). Under our MIRO architecture: (i) time-consuming processing is done in the remote computational system, while (ii) sensory input and motor output are carried out in the sensorimotor robot system. The detailed MIRO architecture is shown in Figure 4. The remote computational system consists of the distributed schema system, image-processing unit, and video, tactile and motor servers.

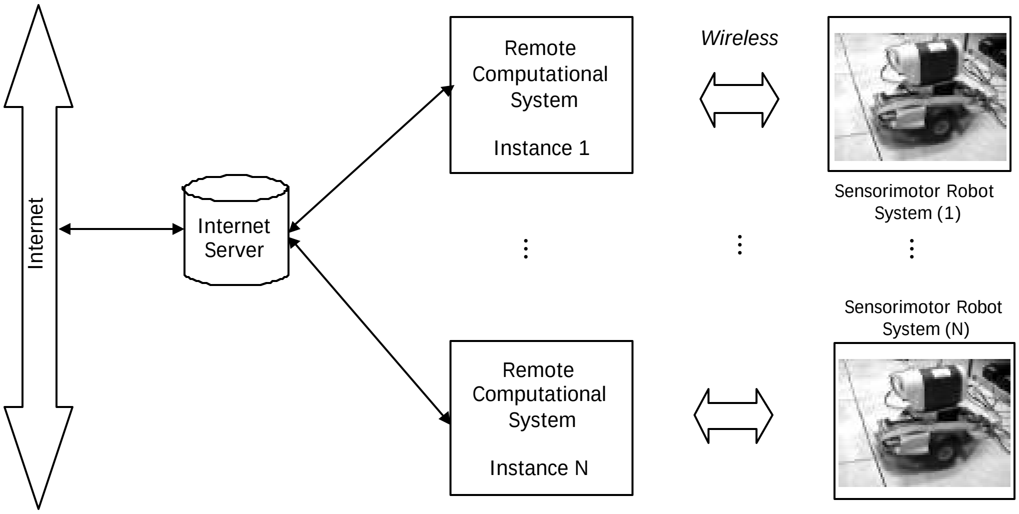

Figure 3. MIRO embedded robotic architecture consisting of multiple autonomous robots linked to their own instance of the remote computational system. All instances are connected to Internet for remote monitoring.

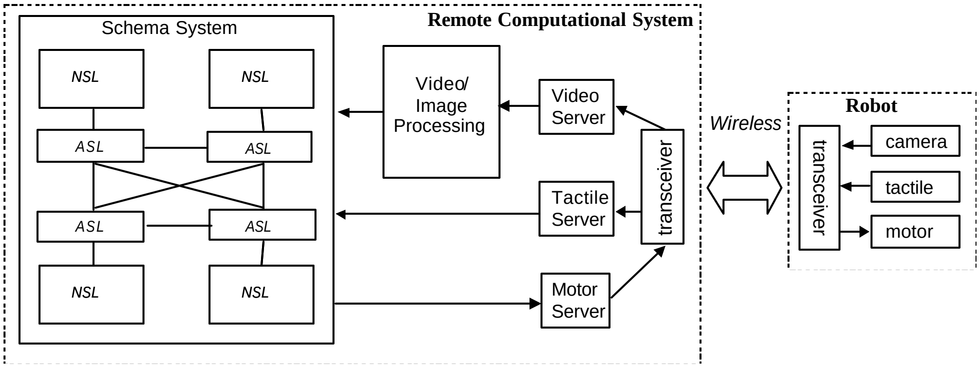

Figure 4. Detailed MIRO architecture consisting of the remote computational system and robot. The remote computation system includes the NSL/ASL schema system, the video/image processing unit and the sensorimotor (video, tactile and motor) servers. The robot incorporates the actual sensors and actuator. Two transceivers handle communication between robot and remote system.

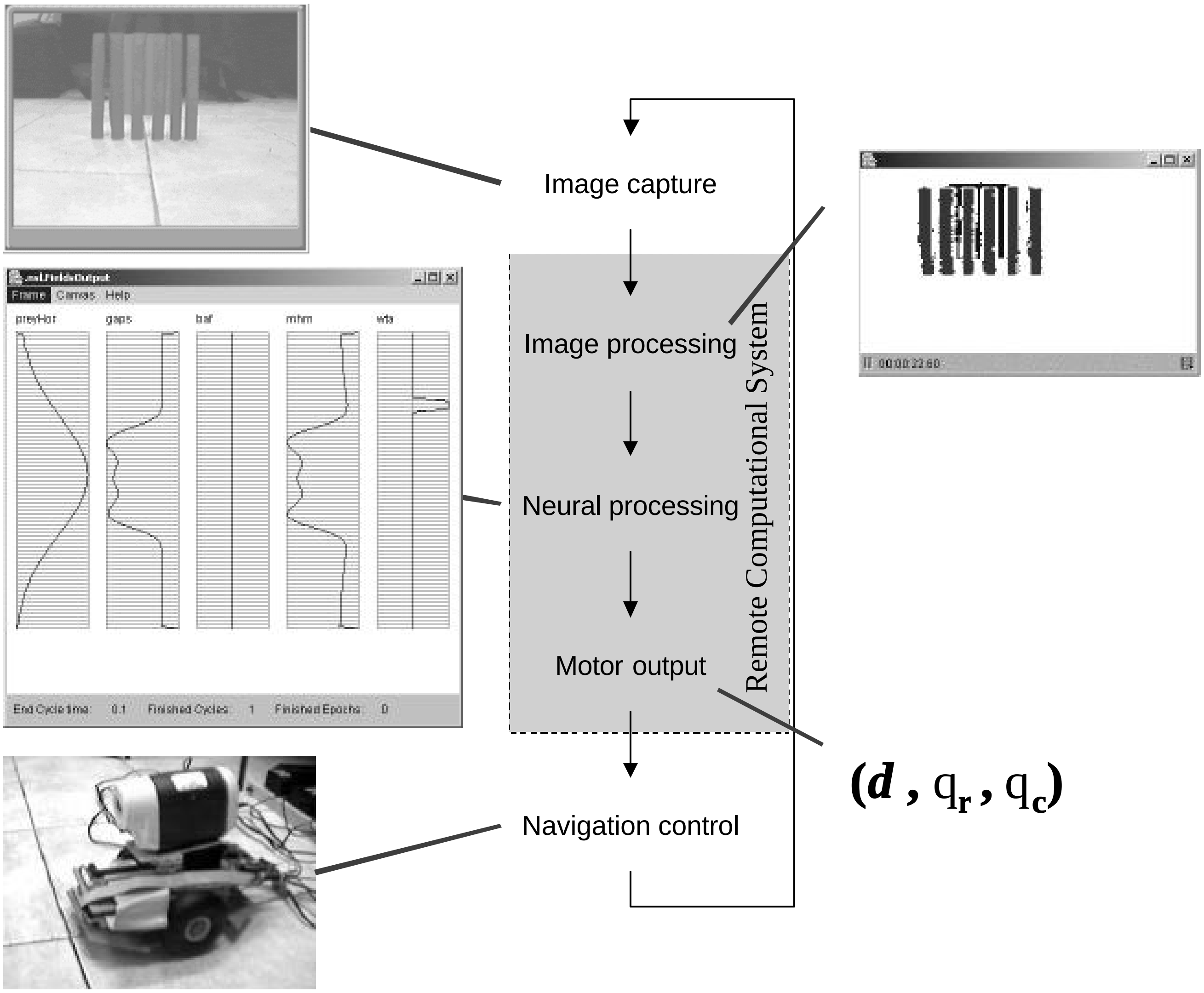

Figure 5. MIRO model computing cycle. An image is captured by the robot camera and sent to the remote computational system for image processing. Once the image is processed, mainly color filtering, visual blobs are sent to the neural processing unit where the neuroethological model is computed. At the end of each cycle, motor output is produced sent back to the robot for navigation control. These cycles continue indefinitely or until some task is achieved.

4. Experiments

We have experimented with a number of neuroethological prey acquisition predator avoidance models using the MIRO robot architecture. For example, in Figure 5 we show a typical computation cycle taken from the toad´s prey acquisition with detour model involving a prey behind a barrier made of a number of fenceposts where the robot needs to detour around the barrier to be able to catch the prey [16]. Computation initiates with image capture from the robot camera sent to the remote computational system where image processing is performed in the form of color filtering, where different colors represent preys, predators and static objects. The remote computational system process the neuroethological model (neural processing) producing motor output sent back to the robot as navigation control (movement, camera and robot rotation). Note the large graph in the left of the figure showing five model outputs (visualized vertically): (1) the left column represents a gaussian corresponding to positive prey attraction, (2) the second column from the left represents the negative effect from the barrier, (3) the middle column has no activity since no tactile information has been received, (4) the second column from the right corresponds to the previous three columns added, and (5) the rightmost column represents the maximum activity in the previous column corresponding to direction of movement. From this last column the desired robot rotation can be obtained. These cycles continue indefinitely or until some specific task is completed.

This particular experiment was carried out using an OOPIC-based robot connected to a remote computer using two 914 MHz transceivers as wireless link. A wireless camera was added on top of the robot transmitting video in a wireless fashion directly to a remote video capture device in the remote computer using its own analog transmitter and receiver. The experiment was remotely monitored and visualized (both images and behavior graphs) via the MIRO Internet interface [31]. (It should be noted that there exists a different non-related MIRO (Middleware for Robots) system developed by a different research group concerned primarily with object-oriented distributed robot architectures [22].)

5. Conclusion

The work described in the paper discusses the challenges in experimenting with neurothological models embedded into robotic systems. One particular concern with these models is the expensive nature of neural processing. In order to reduce the size and cost of robots, we have developed an embedded distributed robotic architecture called MIRO where neural networks are remotely processed using the NSL/ASL neural simulation system. This architecture has proven quite beneficial in terms of processing efficiency, model development where a single version is developed for both simulated and robotic environment, as well as providing real-time robot monitoring and visualization capabilities.

The MIRO architecture has been used in a number of neuroethological experiments involving toad behaviors such as prey acquisition and predator avoidance with detouring. We are in the process of experimenting with additional models such as praying mantis *chantlitaxia* and urban search and rescue robot (USAR) applications where human rescuers need to be constantly in communication with the robot. Another application area where we are using the MIRO architecture is RoboCup´s small-size soccer league (our Eagle Knights team has participated in a number of competitions) where as opposed to the mobile camera in the neuroethological experiments, in this soccer league a fixed aerial camera is mounted on top of the playing field providing visual input to the remote computational system controlling and coordinating in a five robot team. Communication is wireless only between the remote computational system and robots but not with the camera.

Since real-time performance is crucial in many of these experiments, we are currently analyzing processing and communication performance under different experiment and network conditions. We are also testing different robot hardware configurations, including various cameras and transmission configurations, such as direct and indirect video transmissions to the remote system, and diverse communication devices such as transceivers, WiFi and Bluetooth. Additionally, we are investigating multi robot experiments and configurations where we allow data transmission between robots in addition to remote system. We are developing for this purpose an ad-hoc networking models, designing the mobile robot network as an extension to sensor networks. We are also experimenting with various robot hardware architectures, including those built by our group using DSPs (Digital Signal Processors) and PC/104 embedded computers, in addition to out-of-the-box robots such as the Sony AIBO (also used by our group in RoboCup’s 4-legged soccer competitions).

Finally, while most time-consuming tasks can take advantage of the distributed robotic architecture, there are a number of issues that have arisen from the distributed wireless network, such as complete or partial communication failures, and slow or unreliable transmission. We are addressing these problems at different levels, from low-level communication adaptation to, for example, limited bandwidth, to modified robot behaviors in response to complete signal failure. For example, as a response to a complete loss of signal the robot may simply wait without doing anything until communication is restored, it could end its mission, or perform other more limited tasks that may put it back in action such as backtracking or searching for a location where communication can be reestablished. To deal with these problems we have been developing an adaptive middleware architecture embedded into the robot and remote computational system managing QoS (Quality of Service) in relation to communication problems while also incorporating power awareness [29].

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