IEEE DISTRIBUTED SYSTEMS ONLINE 1541-4922 © 2005 Published by the IEEE Computer Society
Vol. 6, No. 12; December 2005

News: Small Robots Team Up to Tackle Large Tasks

David Geer

Swarm robotics, a subset of multiagent systems research, focuses on very large teams of small robots working together toward a common goal. The robots could eventually be engineered to nanoscale size—invisible to the human eye—and number in the hundreds, thousands, or tens of thousands per group. David Payton, a research scientist at HRL Laboratories (http://www.hrl.com), expects these robot groups to become more effective as their numbers increase.

"Generally, other methods of multiagent teaming have a much tighter command hierarchy and tend not to easily scale to large numbers of units because of this," says Payton. Swarm robots, however, are generally autonomous, cooperating and coordinating among themselves. They have the potential to quickly enable applications that so far have been the stuff of only science fiction.

Swarm communication, cooperation

Payton works with *pheromone robots*, which he and his colleagues modeled after the chemical insects use to communicate. Ants, for example, leave a pheromone trail that attracts other ants. When one ant discovers a food source, it backtracks along its own trail, doubling the strength of the chemical marker and attracting other ants that further strengthen it until the food source runs out.

Payton's robots use a *virtual pheromone*. Instead of spreading a chemical landmark, pheromone robots use communication to "spread information and create gradients [like slopes, or distance vectoring] in the information space," Payton says. By using these virtual pheromones, the robots can send and receive directional communications to each other and so sense clear pathways and the number of network hops between them.

Each robot has arrays of directional transmitters and receivers. It can send infrared signals in certain directions and detect where signals are coming from. The communications themselves are simple message packets.

Infrared requires line of sight to send and receive. According to Payton, this ensures that two robots successfully communicating with each other have an open space between them. In spatial activities like those of distributed swarms, you must know where a signal is coming from and how far away the sending robot is. Payton's pheromone robots tag arriving messages with their signal intensity, which degrades over distance. Because pheromone robots constitute a network, they can tell each other how many network hops they are away from each other.

Pheromone swarm applications

Search and rescue missions are one military, public, and private-sector application area for pheromone swarms. When dispersed into a damaged building, the robots would spread out and find injured victims by detecting sound, perhaps breathing. "When a robot is near enough to [make a detection]," says Payton, "it could send out a signal and create a gradient throughout the robot network." A human rescuer could then follow the gradient mapping to the injured party.

Pheromone robots could detect an enemy target in a building as well. A soldier could enter a building, according to Payton, open his or her jar of nanosized robots, and dump them out so that they disperse inside the building. If one of them detects human movement or sound by means of a sensor, it can transmit a signal through all the nanobots until it gets back to the soldier. According to Payton, the soldier would see highlighted nanobots in an augmented-reality helmet display that would point the way to the source.

Formation control is another application area. Several nanobots could join to form columns or an array. "You might want to use them as a distributed antenna, for example," says Payton.

Building security is another application. For this, you need robots with different kinds of sensors, and many with none at all, to make up the communications infrastructure. "Let's say you're trying to detect intruders," says Payton. A motion-sensing robot isn't sufficient for detecting intrusion. "What you really want is to know that you have motion and sound together in the same place," he says.

By setting up a pheromone gradient, you can attract acoustic-sensing robots to the motion-sensing robot that detected the motion. Then you can tell whether you have sound and motion in the same place. "The motion-sensing robot sends out a signal that propagates through the network of robots and establishes this network hop-count gradient," says Payton. "The acoustic-sensing robots detect that gradient and are attracted to its source."

However, the system requires a decision-making mechanism that automatically sends one acoustic-sensing robot and not all of them; otherwise you've weakened your security elsewhere in the building. "Every acoustic-sensing robot that wants to go where the motion-sensing guy is transmits another pheromone," says Payton. Based on the gradient, the pheromone encodes the information about how close the acoustic-sensing robot is to the motion sensor. While transmitting the signal indicating their proximity to the motion sensor, acoustic-sensing robots also listen to hear if any robot is closer than they are.

"If there are two guys and one says, 'I'm four hops away,' and the other guy says, 'I'm five hops away,' when that five-hop guy receives the signal from the four-hop guy, he shuts up and says I'm just going to wait," explains Payton. "Meanwhile that four-hop guy says, 'I don't hear anybody else that's closer than me so I'm going.'" This happens automatically and instantaneously.

If the intruder destroys the first acoustic robot, the next-closest robot—no longer hearing the signal—goes automatically. "Without any centralized decision making, the swarm automatically chooses who gets to go there, and it is also very robust in that if one robot is damaged or can't go, the next one goes," says Payton.

Nanobot sizes introduce opportunities for medical applications or others where swarm robots are seamlessly attached to humans. One such application includes injecting robots into people to perform tasks such as attacking cancer cells, says Payton.

Multiagent techniques

At the Georgia Institute of Technology, smaller teams of robots based on a computation model, rather than a pheromone model, could eventually progress to form larger teams (**see figure 1**). "Our whole paradigm is behavior based," says Ronald C. Arkin, director of Georgia Tech's mobile robot lab (http://www.cc.gatech.edu/ai/robot-lab/). Communication is largely accomplished by robots responding to other robots' behaviors.

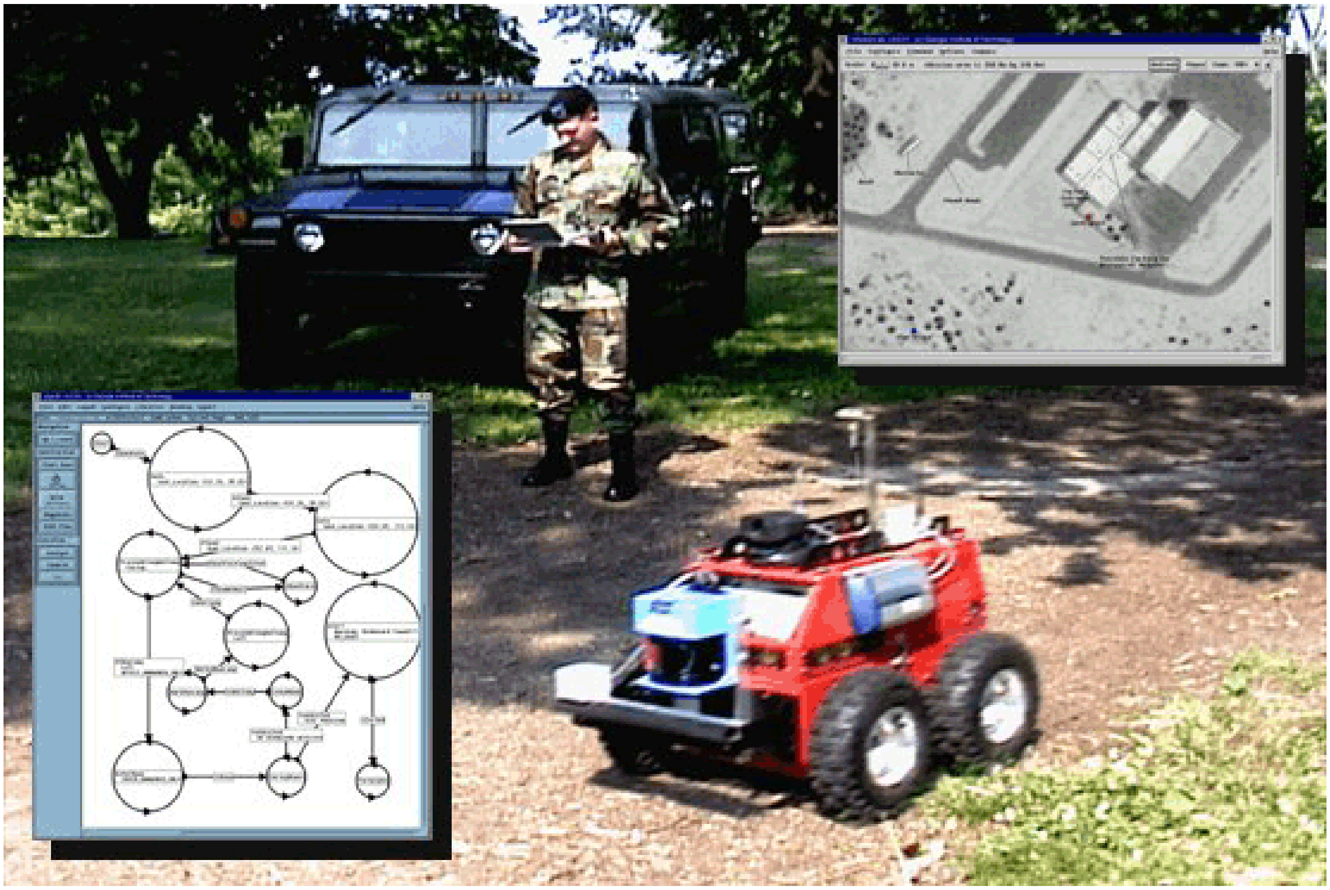

Figure 1. The soldier uses an iconic visual-programming environment (left inset) and an aerial view of the objective area (right inset), both available on his laptop screen, to task teams of robots, such as the one shown in the foreground. The GT Hummer in the background is the command-and-control vehicle. The system has coordinated teams of over 10 robots in field tests at Ft. Benning, Georgia.

In Johns Hopkins University's Department of Mechanical Engineering (http://www.me.jhu.edu/), Greg Chirikjian, department chair, is working on self-replicating, self-repairing multiagent robots. The robots work in teams.

"In other words, team members look at other team members to figure out if they are working properly and, if not, how they can go in and fix them or take them apart," says Chirikjian.

The current working models are small mobile robots with two wheels, two motors, a small computer, and a small gripper. They go around, pick up the parts, and put them together. We operate in two modes, says Chirikjian. In remote-controlled mode, the human user does the sensing, not the robots. Autonomous mode depends on a structured environment with parts pre-positioned at locations the robots know; the robots can then sense landmarks.

Chirikjian expects to see more advanced working models that can replicate and repair more independently in about a year.

As the research progresses, the onboard computers will house the distributed communications technologies, which have not yet been selected. "What we are currently working on is the group behavior. We have not settled on a particular technology for the communication, whether it be optical infrared or radio, [for example]," says Chirikjian.

Multiagent robots applications

Arkin is applying his research to teams of robot vehicles for the Naval Air Systems Command (NAVAIR). "We're talking about unmanned air vehicles, unmanned ground vehicles, unmanned water surface vehicles, and unmanned undersea vehicles all working collaboratively together for a potential range of military scenarios," says Arkin. This application is intended for use in the tight seacoast environments.

Military applications for Chirikjian's self-replicating robots include reconnaissance where, if one robot is hit, the others scavenge for parts for reuse.

These replicators have applications in planetary exploration as well. "If you send a single robot out and it breaks down, you're stuck," says Chirikjian, "but if you have several robots that go out as a group and they have the ability to diagnose each other, the potential exists for much greater autonomy and robustness."

Obstacles to implementations

Payton's pheromone swarms can be scaled down quite a bit but at a proportional loss in intelligence. "You can't put your Pentium V in there," says Payton, but with the right software algorithm mechanisms and proper communications, you can get the swarm as a whole to do some very intelligent things.

The rows in formation-control applications don't yet exactly duplicate each other. As when crystals form, each robot formation is slightly different, "unless they have some kind of reference point they can use," says Payton.

According to Arkin, the biggest problems for multiagent robots are things like communications issues and power maintenance when robots are active in the field for extended periods. Communications is a big problem with robots for the military or the private sector. "There are electronic countermeasures, there's jamming," says Arkin, not to mention the quality-of-service issues that we're familiar with from cell phones.

The military's current overarching approach to battle—network-centric warfare—presents a hurdle for Arkin's work with NAVAIR . "Undersea vehicles can't communicate in the same way as unmanned air vehicles can. There are time constraints, different capabilities," he says.

Integrating robots with people also remains a large problem. Arkin sees robots becoming full-fledged partners with us. "So, how do we engineer systems that are restricted in terms of speed because of human [limitations]?" he asks. "How do we take the best of both human and machine intelligence and [fuse] them into fully integrated, complex societies of robots and people?"

Conclusion

Just as distributed computation and multiprocessing changed the paradigm for solving fundamental computation problems, so will the availability of cheap, distributed, low-cost robotic assets, says Arkin. You'll be able to use the technology to distribute sensors widely and draw information from vantage points around the globe. This opens the opportunity to take action at many points at once throughout the world. "You can't do that with only a single robot," says Arkin.

Related Links

- DS Online's Distributed Agents Community (http://dsonline.computer.org/agents)
- "Robot and Sensor Networks for First Responders" (http://doi.ieeecomputersociety.org/10.1109/MPRV.2004.17)
- "NASA's Swarm Missions: The Challenge of Building Autonomous Software" (http://doi.ieeecomputersociety.org/10.1109/MITP.2004.66)
- "Scalable Human-Robot Interactions in Active Sensor Networks" (http://doi.ieeecomputersociety.org/10.1109/MPRV.2003.1251170)

Cite this article: David Geer, "Small Robots Team Up to Tackle Large Tasks," *IEEE Distributed Systems Online*, vol. 6, no. 12, 2005.