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Adventures in Swarm Robotics

By Sarah Lewin on September 11, 2012 10:34 AM |

A robot scuttles forward slowly, its motion driven by vibrations on three tiny legs. It executes one of the few simple programs housed in its microprocessor and circles randomly as it flashes an infrared light at the ground, searching. Every so often it flickers a colored LED. The robot's about the size of a quarter, so feeble that its forward progress can be stopped by a flat piece of paper, and so helpless that if it should fall it would be unable to get back up. All in all, the robot is rather unimpressive by itself. But then, Kilobots aren't meant to be considered on their own.

And this lonely Kilobot is searching for more of its kind. The robot's infrared detector picks up some light bounced off the ground by another bot, and it heads towards the source of the signal. Soon, identical robots surround it; as it spins it detects signals everywhere as other robots stream towards the group. The Kilobot's found the others: the 1,000-robot swarm. Now the real work can begin.

Radhika Nagpal's Self-Organizing Systems Research Group at Harvard is at the forefront of swarm robotics, and its thousand-robot army is almost complete. Swarms in nature--like those formed by colonies of ants, bees, or termites--fascinate scientists because, even though one individual in the swarm has only a small set of actions and works autonomously of all the others, somehow the actions all build up to produce very complex group behaviors.

Mike Rubenstein, a postdoc in the lab, describes an inspiration behind the pursuit of robot swarms: "Millions of termites will build mounds of dirt in Africa; towers that are meters tall. There's no leader, they're doing whatever they want to do, they're blind, they're a couple millimeters in size...yet somehow they're still capable of building these huge complicated structures to help them." Rubenstein and the others at the lab try to create collective behaviors from their own simple building blocks: in this case, tiny robots.

The Kilobots can move objects several times their weight, synchronize patterns of flashing lights, and map their immediate locations. Here are a few clips of smaller Kilobot swarms in action: pivoting, sensing one another, following the leader, and even foraging for "food."

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Writing programs for swarm behavior is a popular computer science pastime, but most large-scale swarms only exist virtually. A real-life swarm of this magnitude will allow researchers to see how swarm programs work in realtime. Since the project was revealed in 2011, the lab has almost reached their goal of 1,024 robots, and they've already discovered that there are unique hurdles to be overcome where giant swarms are concerned.

Having that many robots creates a tricky set of challenges, explains Rubenstein. "Everything you do on the robots has to be done on a collective level, as a whole, and not on the individual," he says. "You can't have a power switch that you push on each robot. You can't have a programming cable that you plug into each robot. You can't have a charging cable that you plug into each robot...."

To address this, the team had to think creatively. Each Kilobot has a conductive spring on top and conductive legs, and they're charged en masse by running a current through them via metal plates placed above and below them. The team programs the entire swarm at once by beaming a stream of infrared flashes in their direction; the robots pick up the infrared light with specialized sensors. It takes 35 seconds to send a program to the robots, whether the swarm's just a few or all 1,000. The same overhead system is used to wake the robots out of sleep--a state in which they turn all circuitry off, but revive for 10 milliseconds every 8 seconds to check for a wake-up call. The Kilobots can last a month without charging in this state.

The other obvious problem is construction--how do you *get* to 1,000 robots? A single Kilobot is inexpensive at just $14 worth of parts, and only takes five minutes to assemble. That's "only" $14,000 and over 83 hours of construction to create the swarm members. In addition, the lab has made the Kilobot design available to other labs, so someday labs everywhere can test out their programs on huge generalizable swarms.

The Self-Organizing Systems Research Group is also trying out more single-purpose swarm robots: TERMES, for instance, are construction robots that take inspiration from nature's termites. The palm-sized robots, which also operate in swarms, move foam blocks to construct any inputted structure.

The cool thing about TERMES is that you can set any number of them on the task and expect a completed product. "They're capable of building guaranteed structures," says Rubenstein. "You start them off and you're guaranteed the structure will be built after a certain amount of time." They will finish it eventually even if the structure is destroyed halfway through, or if robots are added or taken away from the team. Somehow, with only the ability to see just a short distance in front of them, they'll manage to put it together every time.

See what I mean in the video below:

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TERMES hard at work climbing, grabbing, and building structures virtually and in real life.

What could the future hold for robot swarms? Robots that attach to each other--"like Legos or Transformers," according to Rubenstein--could combine to form large, adaptable robots suited for a variety of tasks. The lab is already working on modular robots that can move collectively and work together, like supporting a table perfectly level as the surface beneath it moves. Robots like TERMES could build structures in hard-to-reach places, from caves to outer space.

Another application, someday, could be smart matter: Rubenstein envisions something like "a bucket with millions of sand-like particles, each a small robot that could attach to its neighbors." With this, you could reach in and pull out any tool, just by letting the robots know how to connect to form the object. It would be just like "an infinite toolbox in a small bucket of sand."

Smart matter may be far in the future--the "nano" level robots--but the lab's Kilobots and TERMES show that swarms of mini robots are becoming a tangible reality. There's power in numbers, and who knows what Kilobots and their descendants will learn to do next.

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