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NO-FLY ZONE

Holonics in Manufacturing: Bringing Intelligence Closer to the Machine

Danna Voth

Manufacturing companies are under pressure to find ways to customize their products quickly, and a new approach to an old idea—holonics—might provide the answer. Arthur Koestler proposed the concept of the "holon" in his 1968 book *The Ghost in the Machine*. A holon is a self-organizing unit that can communicate with other holons and make decisions autonomously. A holon both comprises subordinate parts and constitutes part of a larger system. Some scientists refer to a holon as an agent, but most scientists think of holons as part of a system. Scientists interested in the holon's autonomous, cooperative, and self-configuring characteristics are researching ways to create distributed systems that can change manufacturing processes on the fly, manage systems robustly, and handle unpredictable processing requests and inputs.

Computing like ants

Research scientists at Rockwell Automation are exploring holonic systems as an alternative to centralized control systems. Instead of trying to project all possible combinations in a situation and then program a single control center to respond to any projected outcome, Rockwell scientists are exploring self-organizing intelligent agent systems that can make decisions and adapt to changing environments. As auton-omous entities that exchange information, collaborate, and organize system resources, the holons would be able to respond to a local situation and marshal resources to continue operations without a system breakdown. The holons' ability to respond locally while maintaining a global goal would make the system flexible, robust, and scalable. Kenwood Hall, vice president of architecture and systems technology at Rockwell Automation's Mayfield Heights, Ohio, lab, compares the holonic system to an ant colony: "If you look at an ant colony, you can't see anybody who's in charge, but they all seem to know what to do. And if you stomp on an ant colony, they recover pretty quickly and everything continues to kind of work."

The holonic system's key is redundancy and loose coupling, so that the system isn't necessarily optimized, but rather stabilized. Redundancy is built in so that holons can make choices, and it lets them shift resources when part of the system is disturbed. The loose coupling lets the holons maintain autonomy and keeps the system from becoming brittle and hierarchical, and therefore vulnerable to a single event. In response to environmental changes, a holon will communicate with nearby holons and make decisions about directing resources with the entire system's benefit in mind. "In a manufacturing system, you don't want things to be competitive," says Dorian Sabaz, chief technology officer of Intelligent Robotics Corporation in North Vancouver, British Columbia. "You want everything to work together peacefully and even have sacrifice involved."

Holons might communicate with each other through peer-to-peer devices, such as the Intelligent Wireless MicroRouter that Intelligent Robotics developed in collaboration with Simon Fraser University.

Responding to a local stimulus, holons negotiate with each other for the right to respond, much like in an auction. In most systems, holons are programmed to negotiate through algorithms that are usually based on some form of Contract Net Protocol, a method for assigning tasks by an arbiter in an auction. In some cases, holons employ bilateral contracts, including Dutch and English options, says William Gruver, CEO of Intelligent Robotics. Gruver also notes a third approach to negotiation known as ant negotiation, based on the way an ant puts down scent and the other ants follow it. "This is done now in a software environment where you have a local approach to negotiations and basically ignore what happens far away from the agent of interest. That scent becomes weaker as you go further out."

While the holons might seem sophisticated, they actually respond to their environment by following straightforward conventions. "Basically, you get complex behavior by having simple rules repeated many times," Hall notes. For example, Rockwell has been working on a prototype holonic system for the US Navy to control the chilled water system on its ships. The water cools important components such as radar and sonar systems, and multiple paths exist for the chilled water to reach the components. The system distributes holonic controls over many nodes, and holons are placed close to the equipment they direct. The holons must then determine that a break in the system exists and reroute the chilled water around the break. The valves individually decide whether to open or

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close on the basis of local information and messages they get from other valves and pipe connections. "Each valve only has four simple rules, but if you watch the system run, you would swear there was somebody behind there deciding all this," Hall says.

Benefits for industry

Rockwell has invested in an agent programming environment to make programming and debugging the agents easier, as well as in the Manufacturing Agent Simulation Tool for testing agents in different manufacturing scenarios. The University of Cambridge's Center for Distributed Automation and Control used MAST technology to test a holonic packing cell. The work cell has multiple robots that package coded items to assemble gift boxes. The test sends real-time information (as from stores) to the work cell, and it responds by changing the packaging schedule and assembling the new gift boxes on the fly.

Sujeet Chand, Rockwell's vice president for advanced technology and chief technical officer, notes that companies have used MAST for testing agents for material-handling scenarios (such as those that companies shipping numerous packages experience when they must increase their capacity seasonally). "We know it's a nightmare to add additional conveyors and computers and routing stations. They have a very short time frame, and it's very expensive," Chand says. "We simulated this type of system in an agent-oriented environment. The beauty of that is the agents self-configure. You can go from 30 diverters and 40 conveyors to 100 diverters and 200 conveyors pretty quickly."

Chand adds that automotive manufacturers are also interested in holonic systems. "An automotive line is very sequential, and if the welding cell is down, then the entire line basically comes to a standstill," he says. Instead of having a welding cell, a welding resource with multiple welding cells would provide stability to the line. If one cell is down, intelligent agents would reroute the pieces to the functioning welding cells. "Create a redundancy, and in exchange you get fault-tolerant performance," Chand says.

With the ability to self-configure, holons can help move industrial automation into inexpensive and quick customization. Such flexible manufacturing would let drug companies produce customized dosage packages and let candy companies imprint pieces with customized names. Jim Barlow, CEO of Western Reserve Controls, sees holonics contributing to high-speed manufacturing. Giving the example of choosing between ordering numerous pieces of a product from overseas at an attractive price versus flexibly manufacturing fewer specific pieces domestically, Barlow explains that having the right mix on the shelf provides a competitive advantage. "You have the advantage that you don't need, or your customer doesn't need, to have huge inventory levels to support the supply chain from overseas."

Sabaz points out that holonics help make scaling up easier and cheaper. For example, he notes that when you come out with a great new product and everyone wants it, you often have to wait a year or more to build up and reengineer your production system. Holonic systems' modularity makes scaling to meet domain growth less problematic than with centralized systems. "A holonic environment enables people to add things on at will, and the system itself reconfigures all on its own," he says.

Chand says that simulations have shown that holonics aid in scaling up. He says Rockwell built a simulation in its lab for the Navy, which had about 50 agents. Then the Navy built Rockwell a prototype of a real system in Philadelphia. "We were able to scale from 50 agents in the laboratory to 70-plus agents for the real system in about two hours," he says.

Resistance

The manufacturing world hasn't unreservedly embraced holonics. "Holonic systems require a bit of a paradigm shift of the way manufacturing systems were being done for the last 100, 150 years," Gruver says. Most systems today have machines in one place and one smart computer somewhere else organizing everything. Holonic systems bring the intelligence closer to the machines and have the machines work out what needs to be done. "Companies have invested a lot of time and money in doing a centralized way of manufacturing they just don't want to let go," he explains. Sabaz points out holonics' incompatibility with hierarchical systems: "One of the concerns that people have about holonic systems is that they literally attack middle management, because they take away the decision-making."

Chand is aware of some reluctance toward holonics in manufacturing. "What we're looking for right now are high-leverage applications, small redundant cells where flexibil-

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ity and fault tolerance are absolutely critical, like the Navy application," he says. "In the water-routing example for the Navy, there is no operator involved—it is a completely autonomous system." Rockwell hopes to roll out an agent-embedded product in five years.

No-Fly Zone

Benjamin Alfonsi

Windmills use wind to create energy, just as hydrogen engines use water and solar-powered cars use the sun. Now scientists at the University of the West of England, Bristol, have gone a step further.

The interdisciplinary research team constituting the university's Intelligent Autonomous Systems Laboratory has created a robot that converts dead flies into energy to power itself. Moreover, the robot, called EcoBot II, uses artificial intelligence to do so.

Technology meets biology

By using flies for fuel, EcoBot II is the first invention of its kind to exclusively use unrefined fuel, representing an important step toward making robots fully autonomous. What is novel about the research is the ability of EcoBot II, a small scale robot, to integrate microbial fuel cells (MFCs) fed with raw, unrefined substrates while utilizing oxygen from the air. It is the first robot in the world to employ the oxygen gas diffusion cathode.

Such an undertaking requires the expertise of researchers from different fields. "This work is truly interdisciplinary since it is rare for microbiologists and roboticists to work together," says John Greenman, professor of oral microbiology at the university's School of Biomedical Sciences.

"In order to get a robot powered by organic substrates—that is, food—you need a special system to convert food energy into electrical energy," Greenman explains. "The system that does this is the microbial fuel cell. And to optimize MFC, you need to understand a bit about microbiology—hence the microbiologist."

Using AI

"The important thing here is that autonomous robots of this kind will need to be smart," says Chris Melhuish, director of the IAS Laboratory and professor of computing, engineering, and mathematical sciences at Bristol UWE.

"The robot is a proof-of-concept machine. It has onboard a small processor which is mainly involved in reading data—temperature, in this case—from the sensor, processing it, and then sending the data back to a base station via an onboard radio transmitter—all powered by the MFCs, all powered by flies."

At the moment, the EcoBot II is performing photo-taxis. Because the experiment revolves around robots fueling themselves, a crucial aspect of the research will be the AI the robots require to eventually know how to balance the need for food with the need to conserve energy.

"They will be required to not only do the 'right' thing at the 'right' time, but will also have to make decisions about their behavior that will serve to manage their energy," Melhuish adds. "Does the robot ignore food and get on with its job? Does it stop doing its task and take on energy it doesn't need at the moment, but might need at a later time?"

A long term goal is to have the robot incorporate in its behavioral repertoire the ability to seek out and secure food and also remain inactive when there is insufficient energy to complete a task successfully. This will entail a paradigm shift in the way action and selection mechanisms have been designed in the field thus far.

Too smart?

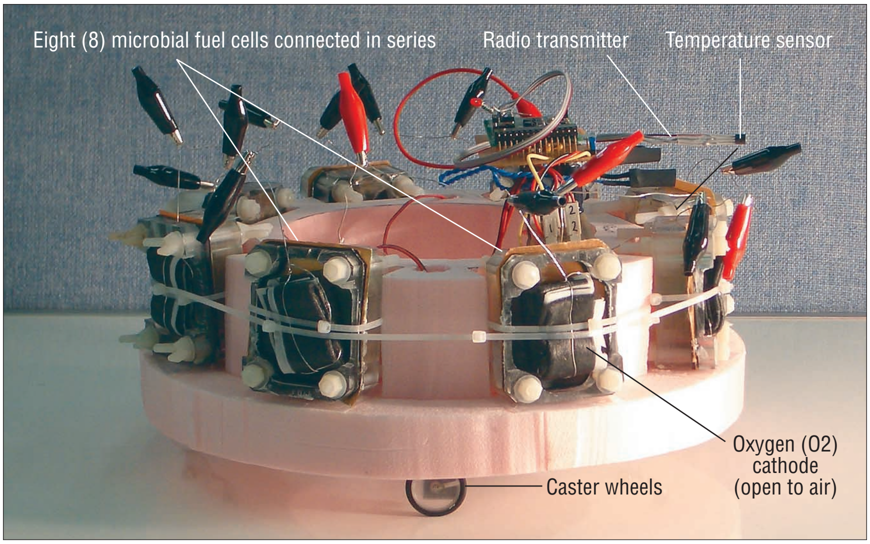
At present, EcoBot II must be manually fed dead flies. A future goal, however, is to make it more predatory by integrating a low energy consumption fly trap mechanism with the robot to feed the trapped flies into the MFCs. Of course, this begs the question, might not a robot that hunts down and catches flies be too smart for its own good? And does the danger exist that its prey might not be limited to flies?

"We are not in the business of producing killer robots," Greenman says. "We are peaceful scientists and would not want to have a hand in developing killing machines."

Still, Greenman concedes that the prospect of robots one day feeding off bigger creatures is "not impossible," quickly adding, "We are not interested in developing the 'mammalian predator' idea since it is too easily open to abuse and danger to humans."

According to Mel Siegel, associate

research professor and a director of Carnegie Mellon University's Robotics Institute, "There is right now a little war going on in our community on exactly this issue." Siegel remains pessimistic, or at least pragmatic, about how long it would take for technology to advance to the point where such AI-powered robots would pose a credible threat. But he believes that "the human species will survive that long only if it successfully develops shared political systems and ethical principles that are strong enough to reliably manage both the human component and the technological component of the risk."



The EcoBot II uses artificial intelligence to power itself.

Implications

Melhuish shrugs off such concerns. "I think these ideas are just daft, a credit to Hollywood," he says. "For what it's worth, I think robotics is in desperate need for newer, smarter materials. We still build machines which could be repaired by Victorian engineers!"

Melhuish might be hoping that EcoBot II will be just the invention to help bring robotics into the 21st century. In addition to technological advancements Melhuish and his team hope to make, there are also environmental ones—after all, it is called *Eco*Bot.

"This project has taught us that it is possible to build robots that use food as an alternate energy source to those currently used, and MFC can only improve with further research and development," concludes Greenman. "MFC might be scaled up to provide environmentally clean energy that does not rely on fossil fuels."

"In the future," he says, "MFC can be used to clean up organic pollution. It might even be possible to run more powerful applications—such as phones, computers, refrigerators, and remote sensors—in addition to robots." ■