News

Self-Repair Techniques Point to Robots That Design Themselves

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Comments

The Dextre robot helping to repair the International Space Station in 2014.

Credit: NASA

Robots that can adapt like animals (Nature cover article)

When researchers at the Pierre and Marie Curie University (UPMC) in Paris, France, deliberately damaged two of the legs of their hexapod robot, the machine discovered for itself a novel hopping gait that not only overcame its injury, but proved to be faster than its original walking program. Injured another way, the robot found it could move around more easily on its back. The work was part of efforts to make robots that can work around damage and repair themselves when there is no human to help them.

David Johan Christensen, associate professor at the Technical University of Denmark, observes: "In the future, physical self-repair could become critical in applications where no humans are around to assist or repair the robots; for example, in space or underwater applications."

Robotic repairs are already being performed in space, where it is too expensive or dangerous for astronauts to perform the job. In 2014, the Canadian Dextre robot attached to the International Space Station replaced a faulty camera on the arm that normally carries it into position to perform repairs of other systems on the orbiting platform. Those repairs were performed under the guidance of human operators on the ground. Uses further afield that may be prone to communications failures, such as undersea cave exploration or the lengthy time delays encountered on deep space missions, make it important to give the robot the ability to repair itself or, if that is not possible, to work around damage.

Jean-Baptiste Mouret, associate researcher at UPMC, says, "You have two time scales in recovery. One is short-term, just like someone going to the hospital for treatment; that is what we are doing with our experiments. By adapting to damage, a robot could limp back to its base. But then something is needed to get it back to full speed. You could have a 'mother robot' that can supply other modules and reassemble the damaged robot in a new way, or maybe it could make new modules to improve the robot once it has gained experience of what is needed."

Alan Winfield, Hewlett-Packard professor of electronics at the University of the West of England, points to the idea of the "evo-factory" in which the mother robot takes account of the damage and, if unable to replace broken components, will come up with alternatives made on the spot using techniques such as three-dimensional (3D) printing.

"Even more exotically, you can certainly imagine a robot that has bits of 3D printing technology incorporated into it. You need not just work around a broken leg, but repair it using some exotic 3D printing organ that you could embed in the robot. People are thinking about this," Winfield says.

Among those people are researchers such as Kyrre Glette and colleagues at the University of Oslo. The superstructures of their robots are made from 3D-printed parts, although they are hand-assembled and combined with off-the-shelf motors so they can move independently. The team has developed algorithms to create the 3D-printed parts from a basic set of shapes and elements to deal with different environments. The aim is to use the experience developed from evolving robot parts to ultimately build a robot that can build additional limbs when needed.

Today, the research into robotic self-repair is in its earliest phase with few successes beyond basic proof-of-concept experiments, such as work on swarms of tiny robots that reconfigure their relationships to each other based on external pressure. "And people have made strange Heath Robinson (unnecessarily complex or implausible) robots with glue guns attached to them. The results can be a bit like toddlers gluing themselves to the floor," says Winfield.

The swarm approach could lead to modular approaches to robotic design in which the machines evolve novel shapes and behaviors when faced not just with injury, but with problems for which they were never designed. A modular robot that walks across the ruins of a building in the wake of an earthquake may find it needs to form itself into a snake-like shape to crawl into a gap in the structure to locate buried survivors.

Says Winfield, "I'm very attracted by the modular and cellular approach to robotics, but we still can't build reliable-enough and flexible-enough modules. You need cells that have a degree of autonomy and which are also capable of self-assembly."

One of the challenges in developing robots that are able to adapt to damage is the amount of time it takes to come up with a solution. After an injury, the robot has to work out what to do next with its remaining limbs and motors. Researchers have largely turned to evolutionary algorithms that progressively refine movements using random changes, discarding those that do not work and optimizing those that show promise. A big problem with traditional approaches to evolutionary design is the need for the algorithm inside the robot to start from scratch before coming up with a theoretically viable solution. "It would search for 20 minutes or so and then try something and then find it doesn't work," says Mouret.

The swarm approach could lead to modular approaches to robotic design, allowing the machines to evolve novel shapes or behaviors in response to injury or unanticipated obstacles.

Using the basic evolutionary approach, a robot could be inactive for hours after an injury. A robot in a dangerous situation, such as negotiating a sudden landslide, will not be able to afford those long delays.

Mouret says, "The key thing is that searching these huge spaces of different types of motion from the beginning takes time, so we thought we should start with some previous knowledge. Then we realized that this approach makes sense because it's the way that most humans and animals work; they use their previous experience. That's what we thought we should do with our robots."

The solution developed by the UPMC team, together with Jeff Clune from the University of Wyoming at Laramie, was to arm the robot with basic knowledge of the types of movement it could adopt and use those as "seeds" to explore different types of locomotion after an arbitrary part was damaged. They built a six-dimensional map of different types of movement based on extensive simulations performed by a virtual robot, scoring them on expected speed.

"We store about 13,000 different gaits," says Mouret. "Each gait uses 36 parameters, with each one of those parameters needing about 4 bytes of data. That's very small compared to the amount of storage we have in a device such as a cellphone. I don't think we will be limited by space with this approach."

When injured, the robot picks from the map, favoring those types of motion that scored well from the simulations and which are still available to it. Often the robot finds that, with its injury, the high-scoring simulations do not perform well under real-world conditions, so the algorithm reduces the score of the approach it tried and those in its vicinity on the map before selecting another at random. Over time the map changes, and the robot focuses attention on techniques that show some level of success, using self-learning algorithms and trial and error to optimize its motion.

Simulation-based techniques are also being developed that will help robots deal better with obstacles and potentially avoid damage in situations where they push themselves too far. Sehoon Ha and Karen Liu of the Georgia Institute of Technology created an algorithm to help humanoid robots fall in ways that minimize damage by planning trajectories such as rolls that attempt to turn one sharp impact into a series of smaller, less-damaging contacts with the ground. However, in its current form, the algorithm is too slow to help a physical robot decide which falling strategy to use in real time. Planning can take up to 10 seconds.

As well as processing time, a key concern among robot designers is the effectiveness of algorithms tested primarily in the virtual world. Simulation-based techniques have their limits and need to be augmented by physical 'embodied' experimentation, says Christensen. "In my opinion, the models on which simulations are based can never truly capture the complexity of the interactions between the robot and its environment. Therefore simulations can be used as a starting point, to bootstrap and speed up the adaptation, but are too limited to fully replace embodied experimentation."

A form of embodied experimentation was demonstrated by the UPMC and Wyoming teams: an unusually slippery floor in the French lab, polished for a visit by politicians, provided the opportunity for the robot built by Mouret and colleagues to find it had a problem walking and needed to evolve a new set of movements that could cope with the unexpected surface. The experience of the robot flipping over on its back in another run of the experiment caused the team to look at a new design. The experience of adaptation can, as a result, inform future designs.

"It's inspired our next robot. We have a new robot that's a bit bigger and which has feet on both sides," Mouret says.

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To come up with more robust solutions, Winfield argues robotics needs to emulate biological evolution more closely. Today, evolutionary algorithms work by progressively altering a single robot design in simulation. Biological evolution works on populations of organisms in the real world. "We need populations of robots to think of ideas, then try them out."

Further Reading

Cully, A., Clune, J., Tarapore, D., and Mouret, J-B.
Robots That Can Adapt Like Animals, *Nature,* Vol. 521, p503 (2015)

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Glette, K., Johnsen, A.L., and Samuelsen, E.
Filling the Reality Gap: Using Obstacles to Promote Robust Gaits in Evolutionary Robotics, *Proceedings of the 2014 IEEE International Conference on Evolvable Systems (ICES),* pp181-186, (2014)

Ha, S., and Liu, C.K.
Multiple Contact Planning for Minimizing Damage of Humanoid Falls, *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS),* (2015)

Videos

UPMC adapting robot **https://www.youtube.com/watch?v=T-c17RKh3uE**

Humanoid Robot Fall Planning: **https://www.youtube.com/watch?v=gvKRlgc9pJI**

Author

Chris Edwards is a Surrey, U.K.-based writer who reports on electronics, IT, and synthetic biology.

Figures

(http://deliveryimages.acm.org/10.1145/2860000/2852231/figs/uf1.jpg) Figure. The Dextre robot helping to repair the International Space Station in 2014.

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