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Easy Striders

New humanoids with efficient gaits change the robotics landscape

Naila Moreira

Before it moves, the robot doesn't look like much. A rickety bundle of metal plates and rods standing on two thin legs, it resembles a science fair project more than it does a major advance in technology. Only two small motors, some simple wiring at its hip, and two batteries weigh it down. Then, with a slight push off one heel, the robot steps forward and ambles along with a remarkably human gait.

This graceful stride differs radically from the stiff, unnatural motion of traditional two-legged robots. Not only that, says its co-creator Andy Ruina of Cornell University, but the walker uses a small fraction of the energy required by other two-legged machines, and it runs on a control system no more complex than that of a coffee machine. In fact, Ruina says, this slender, 1-meter-tall robot, simple as it looks, introduces a new class of robotics based on the theory known as passive dynamics.

STEPPING UP. This energy-efficient robot from Cornell University has inspired new prosthetic designs.
Ruina/Cornell Univ.

The principles of passive-dynamic walking emerged in the late 1980s, pioneered by roboticist Tad McGeer, now with the InSitu Group in Bingen, Wash. While at Simon Fraser University in Burnaby, British Columbia, McGeer showed that a humanlike frame can walk itself down a slope without requiring muscles or motors. Unlike traditional robots, which guzzle energy by using motors to control every motion, McGeer's early passive-dynamic robots relied only on gravity and the natural swinging of their limbs to move forward.

"It's taken 10 to 15 years for McGeer's impact to really sink in," says prosthetics researcher Art Kuo of the University of Michigan in Ann Arbor. "It was such a novel thing."

Now, he says a "movement" has begun. Although McGeer's entirely passive robot could walk only downhill, a new generation of related, mostly passive, machines uses small motors to navigate flat ground. Some roboticists still see these robots as toys that can't handle complex tasks. Others see them as a step toward more-sophisticated machines.

An increasing number of researchers say that the energy-efficient walkers are providing insight into human locomotion. Such devices may inspire new prosthetic-limb designs and eventually move robotics closer to science fiction's popular vision of ambulatory humanoids.

Walking on air

McGeer learned how to build robots by thinking about how planes fly. Trained as an aerospace engineer, he moved into robotics because he felt he'd missed taking part in the major advances that had transformed flight technology in the 1950s and 1960s. "For me, walking machines were an unexpected diversion," he says.

McGeer became interested in robot locomotion after some of his colleagues at Simon Fraser University had developed a concept for a crawling robot "with all sorts of muscles," he says. "It struck me as all rather complicated."

Because of his aerospace background, McGeer then thought of how the Wright brothers pioneered flight. They had explored how an airborne plane might maintain stability and control by experimenting with a series of unpowered gliders, which eventually stayed aloft while traveling over 1,000 feet of ground. McGeer realized that such an approach, focused on equilibrium and mechanics, might work equally well for bipedal robots.

McGeer also knew of a concept called ballistic walking, developed by Harvard roboticist Thomas McMahon in 1980. Inspired by a simple walking toy called a Wilson Walkee, a penguin-shaped, unpowered gadget that could toddle down a slope on two legs, McMahon and his student Simon Mochan calculated that a walker could take a single step using no energy after an initial activation. In their model, a leg behaves like a pendulum that swings passively until the body leans forward and the foot strikes the ground.

In a series of seminal papers, McGeer extended McMahon's concept. He calculated that a walker could not only take one step without energy beyond the initial nudge but could also execute the entire walking cycle powered only by gravity. The downhill-walking cycle, he found, was passive and repeatable—even, remarkably, if the walker bent its knees.

"I could write down these formulas that said you could build a machine that looks like this and it will walk by itself," he says. "Intuition said that seems pretty farfetched."

Intuition proved wrong. McGeer succeeded in building a passive walker that could march downhill while bending and straightening its knees. However, the simple robot cheated slightly by relying on four, rather than two, legs to maintain side-to-side stability.

When McGeer left academia for industry, another outsider to robotics picked up where he'd left off. Ruina had started his career as a geophysicist but became interested in mechanical engineering when someone in his lab insisted on studying bicycle mechanics. Ruina took a sabbatical to learn more about biomechanics, encountered McGeer's work, and was hooked.

Ruina and his students soon began developing passive-dynamic walkers that could navigate a slope on two legs instead of four (SN: 3/21/98, p. 190). In 2001, undergraduates Martijn Wisse and Steve Collins put together "some sticks and hinges," Ruina says, to build a more advanced version that he still describes as "the nicest, best passive-dynamic walker that's out there." The walker ambled downhill with a comfortable, humanlike stride.

PASSIVE PROMENADE. Swinging its limbs in response to gravity's pull, this walker built at Cornell University strides down a slope without using a single motor.
H. Morgan

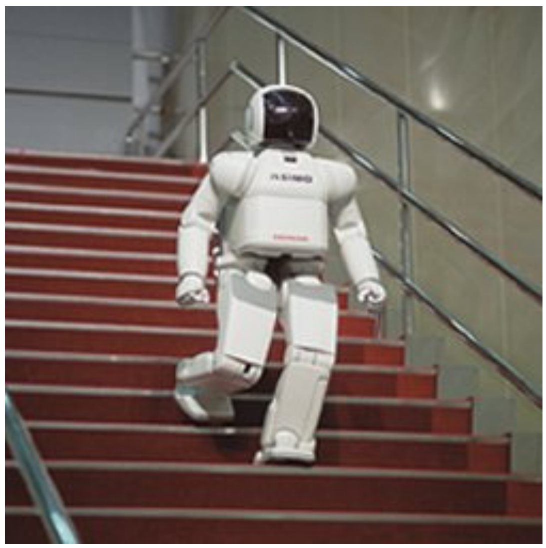
"People were sort of confused because lots of people have made robots and no one has made one walk so nicely," Ruina says.

Still, the robot could only walk down a slope. So, Ruina and several colleagues at the Massachusetts Institute of Technology and Delft University in the Netherlands decided to prove that robots developed from passive-dynamic principles could, with the strategic addition of some motors, walk on flat ground. The researchers, who worked semi-independently, jointly announced the creation of three new semipassive walkers in the Feb. 18 *Science*.

A hippie thing

The new robots rely on carefully designed mechanical tricks to walk while using extremely little energy. For instance, in the Cornell model, which was built first and is more energy efficient than the MIT and Delft robots, a single motor at the hip winds up a spring at the ankle of the robot's planted leg. When the robot's other leg strikes the ground ahead, an electrical signal back to the motor releases the spring, which pushes upward the ankle of the planted leg to start the next step. This mimics a person, who steps by pushing up from the ball of the foot, Ruina says.

Compare this with the movement of Honda's Asimo robot, perhaps the most capable bipedal robot ever created. A computer-controlled motor sits at each of Asimo's 26 joints, directing the full trajectory of joint motion. This complete control enables the robot to walk, shake hands, climb stairs, kick a ball, and even run.



ALL UNDER CONTROL. Honda's robot Asimo can climb or descend stairs, kick a ball, and shake hands, but requires an energy-intensive motor for each of 26 joints.
Honda Motor Co.

But Asimo pays a price for its virtuosity. The motors make the robot stiff and unwieldy. When the motors are turned off, each joint freezes in place, so even joints that don't need power in a given motion must be activated. Asimo must also lug around its full collection of heavy motors, gears, and electronics. The robot's large battery needs recharging every 45 minutes.

Neither Asimo nor Sony's similar robot, Qrio, is currently on the market, though a simpler biped called Nuvo, developed by ZMP in Tokyo, can be purchased for $6,000.

In contrast to the motor-intensive robots, the new walkers based on passive-dynamic theory achieve an energy efficiency similar to that of a human being. Mathematically, a person's or a robot's energetic cost of transport equals the energy expended to move the walker's body weight a certain distance.

When walking, both an average person and the Cornell robot have a cost of transport of about 0.05, a unitless quantity based on work performed over a distance. The Delft robot, nicknamed Denise, uses pneumatic devices at the hip to power its walking and has a higher cost of 0.08. The person and these robots all achieve 10 to 20 times the energy efficiency of Asimo, however. Collins has estimated Asimo's cost of transport during walking at 1.6.

The MIT robot, designed to learn during passive-dynamic transport, has a large computer and as high a cost of transport as Asimo does.

As Honda engineers see it, Asimo needs to spend more energy so that it can perform more-complex tasks. "Passive dynamics has very limited application," says spokesperson Stephen Keeney of American Honda in Torrance, Calif. "If you have to climb stairs, or if you have to sidestep, or if you have to carry a heavy load while you're walking, [passive-dynamics] research is still very young in that regard."

Wisse, now at Delft University, admits that passive-dynamic robots can't match Asimo's capabilities. But he says that Asimo consumes extra energy because, for example, the robot is controlled by algorithms that require it to walk flat-footed, without rolling up on its toes as a person might when walking.

Wisse also points to Honda's much larger expenditure on Asimo. The hardware of a single Asimo machine costs $1 million, Keeney says. The Cornell powered walker, in contrast, relies on a hardware budget of only $10,000.

"Asimo still wins mostly on all accounts," Wisse says. "We got here with very little funds and very little sophistication."

Roboticist Jessy Grizzle of the University of Michigan calls the new robots "very beautiful science" but points out that they tend to fall over easily. Grizzle's research, on a motor-controlled biped dubbed RABBIT, sacrifices energy efficiency for stability. RABBIT can be pushed forcefully without falling forward or backward, but it still requires a side boom so it doesn't topple sideways.

Wisse plans to continue research to make Denise less likely to topple over. He's also working on making the robot start, stop, and turn, since it currently needs a push to get moving, keeps going until it runs into something, and walks only in a straight line.

Meanwhile, Ruina says that he's still working on energy efficiency. "I'm a flower child, it's a hippie thing," he says. "During my formative years, I got the idea that the world was wasting energy."

Aside from moral high ground, energy efficiency has crucial practical importance, Ruina and others assert. "Once a robot is unplugged from the wall, once an animal is free to roam, either way, it's got to carry its energy supply with it," Kuo says. People typically engage in activity for half a day before stopping to power up with a meal. Robotics researchers hope to emulate this stamina.

Moreover, since people naturally minimize their energy usage, it makes sense that principles driving passive-dynamic motion could explain human walking, says Collins. The most immediate practical application of passive-dynamic robotics, he says, lies in understanding how people move.

Right this way

Strolling along might feel easy, but researchers have long struggled to understand walking. That's partly because human locomotion depends on so many joints, including the knee, ankle, and hip, says roboticist Jerry Pratt of the Institute for Human and Machine Cognition in Pensacola, Fla. Each joint behaves differently, and a roboticist must decide how to control the movement at each one.

"There's a lot of things that make walking hard, but instead of using that as a cop-out, most guys in passive-dynamic walkers try to look more at what makes it easy," says Pratt. Permitting the leg to swing like a pendulum, for example, simplifies the task.

Kuo says that passive-dynamic walking has challenged a commonly held notion of how people walk called the "six determinants of gait." This theory, developed in the 1950s, asserts that a person minimizes energy by using six ambulatory tactics to keep his or her center of gravity as level as possible. But Kuo says that both people walking normally and the new-style robotic walkers move their centers of gravity up and down.

More information on human walking, he says, will lead to new prosthetic devices for people who have lost lower limbs. He and Collins, now at the University of Michigan, are creating prostheses based on passive-dynamic fundamentals.

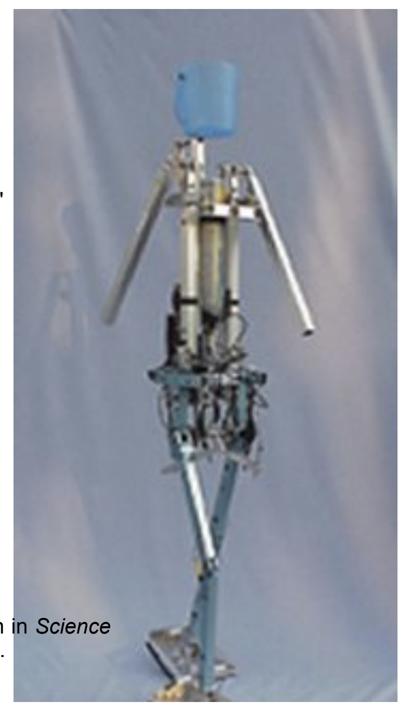
Hugh Herr, a prosthetics researcher at the Massachusetts Institute of Technology, isn't convinced that the new robots will prove useful in prosthesis design. He notes that prosthetics research used passive-dynamic principles even before McGeer formalized his theory. "Prosthetics has [already] really pushed the envelope on what can be done with purely passive systems," he says.

But in walking, amputees with prostheses still use significantly more energy than unimpaired people do. Depending on the degree of limb loss, amputees expend 15 to 45 percent more effort walking than a person with both legs does, Herr says.

Kuo and Collins have developed a prosthetic foot that they say diminishes the effort of walking. With an ankle spring similar to that in the Cornell walker, their device cuts the amputee's energy expenditure by at least 10 percent, Kuo estimates from preliminary trials. His research team plans to unveil the device this month at the annual meeting of the International Society of Biomechanics.

Marching forward

Passive-dynamic robots have produced both enthusiasts and doubters. Many researchers suggest that the answer for bipedal robotics may lie between the opposing poles of control and passivity.



"Nature is in the middle between those extremes," says Herr. "There needs to be a marriage, and we need to steal from nature to achieve that marriage."

Roboticist Chris Atkeson of Carnegie Mellon University in Pittsburgh has begun several projects to develop the middle ground: partially passive bipedal walking. His robots will use motors to control most joints, but unlike those in typical robots, these machines' motors will disengage when limbs need to swing freely.

"Where am I putting my bet? I'm definitely putting my dollars and people's time on pushing the passive-dynamic approach," Atkeson says. "But I recognize we might need to deviate from it in order to make it work."

Even some Honda engineers agree that advances from passive dynamics can improve bipedal robots. Ambarish Goswami studied passive, or natural, dynamics before moving to the Honda Research Institute in Mountain View, Calif. He says that Asimo could benefit from some passive-dynamic principles.

"Having built Asimo and having seen that it walks well and can climb stairs, I think people will start looking at natural dynamics and seeing where we can turn the motors off," he says.

Besides their implications for prostheses and improved robotics, the walkers built by Ruina and his colleagues have another intriguing aspect. In their gaits, which are so strikingly similar to human walking, the robots emit an appealing charm.

"The motion that these robots have, it's very enticing. It's appealingly natural looking," says Grizzle.

"They really can walk quite well," concludes prosthetics researcher Dudley Childress of Northwestern University in Evanston, Ill. "I think it adds a bit of fun to the work."

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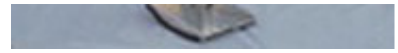

LADYLIKE LOCOMOTION. Denise, a robot built at Delft University, takes a graceful and energy-efficient step by relying on natural dynamics.
J. van Frankenhuyzen

References:

2005. Robot walks, balances like a human. University of Michigan news release. May 11. Photos and a video are available at http://www.umich.edu/~urecord/0405/Jan10_05/26.shtml, and http://www.umich.edu/news/?Releases/2005/May05/r051105.

2005. Bipedal bots star at AAAS media briefing. National Science Foundation press release. Feb. 17. Available online at http://nsf.gov/news/news_summ.jsp?cntn_id=102829&org=NSF.

2005: Robots that simulate life by walking with close-to-human efficiency described by researchers at Cornell, MIT and Delft. Cornell University news release. Feb. 17. Available at http://www.news.cornell.edu/releases/Feb05/AAAS.Ruina.bipedal.ws.html.

2005. Teams build robots that walk like humans. MIT news release. Feb. 17. Available at http://web.mit.edu/newsoffice/2005/robotoddler.html.

Collins, S., A. Ruina, R. Tedrake, and M. Wisse. 2005. Efficient bipedal robots based on passive-dynamic walkers. *Science* 307(Feb. 18):1082-1085. Abstract available at http://www.sciencemag.org/cgi/content/short/307/5712/1082.

McGeer, T. 1990. Passive walking with knees. IEEE International Conference on Robotics and Automation. Available online at http://ruina.tam.cornell.edu/research/topics/locomotion_and_robotics/ history/papers/mcgeer_1990_passive_walking_knees.pdf.

Further Readings:

Alexander, R.M. 2005. Walking made simple. *Science* 308(April 1):58. Summary available at http://www.sciencemag.org/cgi/content/summary/308/5718/58.

Peterson, I. 1998. A model walker. *Science News* 153(March 21)190.

To see movies of the three robots walking, go to http://www.sciencemag.org/cgi/content/full/307/5712/1082/DC1 (WARNING: Files are very large; Broadband connection recommended.)

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