Tinkertoy Robot

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It was just a few days before Mike Coleman's thesis defense. Since 1992 he had been working to generate computer models of an uncontrolled, two-legged robot that would walk somewhat like a person, but fall over when it stood still. Frustrated with the computer modeling, which had come a long way but still fell short of his goal, Coleman walked over to the lab bench from his office—he needed to build something to hold up during his impending Ph.D. evaluation.

His building material of choice for the big day? Tinkertoys.

Coleman, working in the Human Power, Biomechanics and Robotics Laboratory in the department of Theoretical and Applied Mechanics at Cornell University, began to build something that resembled his most successful models yet. A red wooden rod or two, a few yellow spools, some glue and a hinge later, he placed his contraption on a gentle slope and let it go. And it walked. Not very well at first, but at least, as Coleman remembers, "it was very eager to walk."

So, after a bit more *tinkering*, and some suggestions from his advisor Andy Ruina, he tried again. And what he had spent years in front of a computer attempting to model suddenly came to life on the fifteen-foot long ramp in front of him. No, it wasn't quite alive, but it sure was walking.

Coleman's goal, which was picked up from the pioneer in this field of so-called Passive-Dynamic Walking, Tad McGeer, was to figure out what aspects of human locomotion can be explained by mechanics, rather than by complicated control systems in the brain. The Tinkertoy Robot is the first of a new breed. It will fall over in any direction (forward, backward, or sideways) when standing still, yet is curiously comfortable walking down ramps. Researchers in this field hope that this and future advances in passive-dynamic robotics will provide the basis for understanding human walking, building better prosthetic limbs, and advances in rehabilitation strategies.

The reason these robots, including the Tinkertoy Robot, must be unstable when they are still is because that is what makes their gait analogous to human walking. Take a person and stand him or her up straight. Now take away any use of that person's balance control system, and wham! They're on the floor nursing a headache. Humans are top-heavy. Without the complex neural circuitry that controls balance we'd all fall over, all the time. McGeer's most successful models have only been unstable in two directions (forward and backward), or 2D passive dynamic robots. Coleman's model adds the ability to fall sideways when it stands still, making it a unique 3D passive dynamic robot. The BTIC even. (Big Tinkertoy in the Canister).

Coleman's luck didn't run out when he built the first version of the robot. Needing to make sure that the robot satisfied all the rules of a 3D passive dynamic walker, he and Ruina needed to be certain that the spools that served as the robot's feet were perfectly rounded, so it couldn't come to rest and stay standing. At first, Coleman figured he'd just fill in the holes at the bottom of the spools to round them out. Ruina, who is the head of the lab, suggested adhering brass strips to the feet instead, which would take less time. It turned out to be a wise choice—attempts to fill in the holes have since been unsuccessful.

Another "accidental" feature of the robot was the spacing of its "hips", which are responsible for a necessary side-to-side motion that it exhibits to help it shimmy down the ramp. Coleman remembered as he made adjustments to the first incarnation of the robot, that the lower its center of gravity, the more stable the gait would become. Looking around the lab he found some steel nuts which he attached to spools that extended from the "feet" of the robot. The resulting structure was analogous to a tightrope walker using a long rod to achieve balance high in the air. And as long as the robot was moving, it wouldn't need a safety net.

The Tinkertoy Robot stands about 15 centimeters high from hip to foot and is over 30 centimeters wide. The ramp, sloped at 4.5 degrees in the Ruina Lab, is where the robot draws energy only from gravity to strut its stuff. Coleman assures that the robot can walk any distance, provided the ramp is long enough. "There's no reason that it should have walked," he said, noting how the computer models failed to predict its success, "*but* we believe it has a stable, steady gait."

This ability to walk without some form of control is based on the theory that gravity, surface contact and inertia provide the body with enough passive physical cues to sustain locomotion. By de-emphasizing the role of the brain and neuromuscular control mechanisms in human walking, McGeer maintains that the approach is similar to the advent of powered flight. Gliders needed to be perfected before engines and navigation systems were applied. This simplified approach to locomotion relies on the well-established rules of Newtonian mechanics rather than the complex and largely speculative feedback loops and pattern generators of the central nervous system.

While the terrain may be familiar to these engineers, Coleman says that they still haven't created a computer model that predicts the success of the Tinkertoy Robot. "We've beefed up the model," he said, "but we still have to explain why it works."

Once the computer models are completed and understood, biomechanics researchers will be a step closer to understanding walking from a fundamental mechanics point of view. Clinical applications from this type of research are still years down the line and clinical researchers aren't exactly sitting around in rehab centers with a set of Tinkertoys. But understanding things like how mass is distributed in the leg for an optimum stride may help to guide prosthetic limb research or rehabilitation efforts in the future.

It may also lead to better two-legged robots, as Coleman, now a lecturer at Cornell, and Ruina point out in a recent issue of Physical Review Letters.

Son of Tinkertoy Robot?

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