Paving the way for intelligent prosthetics

A new training tool to help amputees could usher in a new generation of prosthetics

By Richard Cairney

Necessity may be the mother of invention, but innovation is pure creativity. Given the opportunity to pursue his passions, Rory Dawson (Mechanical '08) has developed a tool with a robotic arm to help train amputees to use high-tech prosthetics that respond to muscle signals. Working in consultation with the Glenrose Rehabilitation Hospital, Dawson designed, built and tested the training tool as part of his master's degree. At the same time, he is assisting amputees who are in line to receive high-tech prosthetic arms.

"The work that Rory is doing is meeting a specific need," says Gary Faulkner (Mechanical '63, MSc '66), a former chair of the department of mechanical engineering who now serves as director of research and technology development at the Glenrose. "We don't have the capacity or ability to do these kinds of projects, especially when there is potential that you may not be successful, so we look for partnerships with groups in the university as one way to increase our capacity to design these kinds of things."

Dawson's robotic arm will benefit amputees who are waiting for advanced prosthetic arms that have a more 'intuitive' feel. When the user tightens a tricep or bicep muscle, the prosthetic arm flexes up or down just as an arm would ordinarily. Amputees are able to control multiple movements on their prosthetic arms through a surgical procedure in which doctors essentially re-wire severed nerve endings that control the wrist to a point on an amputee's chest, where sensors on the prosthetic arm can detect signals and carry them to the hand and wrist. Picture a series of extension cords and you've got the basic idea.

With his master's degree now completed, Dawson is working as a research associate with one of his supervisors, mechanical engineering professor Jason Carey, to put the final touches on the project and bring the research to amputees.

The project could expand in scope. Dawson and Carey are working with Patrick Pilarski, who earned his PhD in electrical and computer engineering in the Faculty of Engineering, to develop an advanced prosthetic arm that incorporates artificial intelligence. Pilarski, now doing post-doctoral research with the Alberta Ingenuity Centre for Machine Learning and the U of A Department of Computing Science, envisions a day when prosthetic limbs gather information about their environment and make predictions about what motions or functions they'll be required to perform next (see story, page 10).

Pilarski says it's possible to enhance a prosthetic with environmental sensors and computing power, giving it the ability to pool and make sense of data. Dawson's training tool is a great starting point, but that project is a long way off. At present, Dawson's project is nearly ready for patients to use.

The Glenrose project proved a perfect match for Dawson's interests in both robotics and mechanical engineering. Dawson credits extra-curricular projects for preparing him for his master's degree. Time spent working as a member of the Autonomous Robotic Vehicle Project helped him feed his fascination with robotics. "I was always interested in robotics, and being a part of the ARVP allowed me to supplement my mechanical engineering education with hands-on robotics work. I was able to take mechanical engineering and apply it to robotics.

"I never thought, starting in mechanical engineering, that I would be able to move into areas I was interested in, like biomedical engineering and robotics. Through summer research programs and student vehicle projects at the university, I was able to create my own educational program."

There was a time when Dawson felt less confident about his ability to take on a challenge like this. He says he often felt he was just keeping his head above water during his undergraduate years, until everything seemed to come together in his final year.

"During my fourth year, things started to click. I started getting more confident. My MecE 460 capstone design team went to the nationals," he says. "I went into my master's with this attitude that I could do anything. If you grind away at something long enough, you can make it work. And that's what I did."

Dawson built the arm and learned to write the computer software that it runs on.

Jason Franson

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— RORY DAWSON

He even changed his proposed project at the outset of his master's, from a prosthetic leg to an arm. Dawson approached Carey, a mechanical engineering professor with a special interest in biomedical engineering, about his interest in robotics and biomedicine. Carey, whose own master's and PhD research covered tissue mechanics of the shoulder and composite materials for catheters, knew how to combine the two.

"I literally grabbed Rory by the shoulder and we walked over to Fahimi's office [mechanical engineering professor Farbod Fahimi, who specializes in robotics and co-supervised Dawson's project] and we came up with a project," says Carey. "When we initially met with the Glenrose, it was to discuss a robotic leg—but that wasn't what they needed. Their priority was training amputees to use these arms; within a couple of weeks we had another proposal for them."

But it has always been clear that the project could also become a platform for new and improved control technologies for prosthetics. Enter Pilarski—a creative thinker with an imagination that runs amok and pushes boundaries. At the encouragement of his supervisor, reinforcement learning guru Rich Sutton, Pilarski attended the Glenrose's Spotlight on Research breakfast in 2009, where Dawson was presenting a poster about the training arm. The two hit it off.

It turns out that Pilarski's background isn't dissimilar to Carey's and Dawson's. He'd always been interested in robotics and, during high school, studied sports medicine. Pilarski's father is a metallurgical engineer and his mother is a renowned cancer researcher. For his PhD, Pilarski worked with electrical engineering professor Chris Backhouse, whose collaborations with Pilarski's mother led to the development

Patrick Pilarski, Jason Carey and Rory Dawson with Dawson's robotic arm. The device can be used to train amputees in the use of complex new prosthetics.

Jason Franson

of the so-called 'lab on a chip' technology that puts the diagnostic power of a clinical lab into the hands of front-line health care workers.

"I liked applying computational techniques to medical problems in novel ways, but what I really enjoyed about my PhD research was its artificial intelligence component—the aspect that brings a physical system to life," says Pilarski. "Now, pursuing AI with Rich Sutton brought me to a place where I realized, 'Wow—I can apply this work to my passion for prosthetics and robotics!' "

Specifically, Pilarski and Dawson hope their collaborative research will lead to the development of a prosthesis that can 'learn' through a form of artificial intelligence known as reinforcement learning. In its simplest sense, Pilarski compares reinforcement learning to training a dog: when the dog follows a command, it gets a treat; when it fails to follow a command, it doesn't. Pilarski and his colleagues in Sutton's lab have trained small robots

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to perform specific functions by simply pressing the plus or minus keys on a video game control pad. The same rules could apply to a 'smart' prosthetic. In fact, Pilarski and Dawson have evidence of this, based on work they have done using a computer simulation of the training device.

"Rory and I started working on applied reinforcement learning, and within three or four months we had enough data for a first demonstration of principles; within a year we had a research paper accepted to an international conference on rehabilitation robotics," says Pilarski. "Right now, Rory and I are reconstructing the proof of concept on the physical system so we can replicate what we did on the simulator, using the real robotic arm."

"It has always been at the back of our minds in this project that this could become a platform for a new and improved control technique," says Dawson. That project may well go ahead but, for the time being, his work will focus on helping patients in the immediate term.

"We want to interface this with a patient," says Carey. "The idea is that you are given this tool that you can use to train yourself for your special arm so that once you get that arm, you at least have an idea of how to use it."

A LEG UP

How creative thinking and persistence changed the lives of amputees around the world

By Isabelle Gallant

Kelly James, inventor of the C-Leg, in his workshop.

Jason Franson

Inspiration can come from the most unlikely sources. It was a humble farm tractor that helped Kelly James (Mechanical '81) design the world's most sought-after prosthetic leg. James is the inventor of the C-Leg, a microprocessor-controlled knee joint that adapts to a person's walk in real time.

In the early '90s, however, when James was working on the leg, the hydraulics were giving him trouble. He realized that when an amputee was about to take a step, there was so much pressure on a valve inside the leg that it wouldn't open, causing mobility problems. The challenge was vexing.

One day, James was watching tractors in a farmer's field. He realized that the hydraulics used in the tractors did remarkably heavy lifting under intense pressure. James studied the hydraulics in the machines and applied them to the prosthetic leg.

"That was really the moment where I said, 'OK. I can now, with a very small motor and a very small battery, control this guy, his whole body weight, on the edge of a stair and control his descent.' "

James first started working with prosthetics while earning his degree in mechanical engineering. He was interested in biomedicine and, in essence, created his own course option, doing research on electric hands in the Department of Physiology. After graduating in 1981, he was hired by the department to conduct research into prosthetic legs.

James studied animals to see how they moved, then hooked up prosthetics to instruments that recorded the knee angles and forces for amputees walking.

"I slowly honed in on the fact that with a computer program, I could follow the changes in the signals," says James. The computer in the C-Leg cycles once per step, tracking the person's movements and moving from one phase to the next in the gait cycle.

The C-Leg is battery-operated, with a small motor, the same kind used in remote-control airplanes. James started off by building four test units.

"All sorts of trouble occurred. The Edmonton winters, the signals would drift … I had to improve the electronic end of it. The air would get into the hydraulics. I wasn't really a manufacturer and a producer, I was an inventor. I didn't really want to get into building these things."

James eventually formed his own spinoff company, Biomech Engineering, bought the leg from the university and struck out on his own. He travelled around the world to conferences trying to sell his leg to a manufacturer. At trade shows, he walked from booth to booth with his prototype slung over his shoulder. But most manufacturers were reluctant. What James was selling was,

Jason Franson

James fine-tunes the workings on the C-Leg.

in retrospect, ahead of its time.

"They all said, 'I don't know, it's pretty complicated.' Remember, in 1992 people didn't know anything about computers."

James persevered, even when people in the prosthetics field told him the idea was crazy. But in 1992, German prosthetics manufacturer Otto Bock approached James at a trade show. In a closed-room meeting with the company's owner and top engineers, they made James a deal for the leg, on the spot.

"What really surprised me about the meeting was that they were so respectful of the leg. After I had talked to all the American companies and they had just slammed the door in my face, I spoke to the German company and they were so, 'Wow, this is really amazing, and how did you do it?'"

James sold the patent rights for the leg to Otto Bock, in return for a flat fee and a royalty agreement. He started flying to Germany three to five times a year to help the company perfect the leg. They produced the first C-Leg in 1995, a streamlined, silver-and-blue leg with reworked electronics that function in the cold and the heat. Today, about 2,000 C-Legs are sold every year.

But there were obstacles to overcome along the way. Otto Bock nearly decided not to manufacture and sell the leg after one doctor's experience. The doctor, an amputee, was impressed with the leg after wearing it around for a couple of hours. But when he took it off to put his old prosthesis back on, he fell down the stairs. The C-Leg was too good in the sense that it was dangerous for someone to readjust to a less-sophisticated prosthesis.

Otto Bock executives were upset, says James. "They were saying, 'This is a no-brainer, we're not going to build this knee … we can't put amputees at risk.'"

James managed to convince them otherwise. "Let's just change the number of phases the knee goes through during a step," he said. The idea of easily tweaking a few lines of code for the knee's microchip was an eye-opener for Otto Bock. Over time, the phases of the knee evolved, eventually eliminating any phase where the knee is locked and anything that made the knee too complicated for users to figure out.

The knee's simplicity is one of its main selling points. "You don't read a manual, you don't understand it, you don't think about it—you just walk," says James.

That's one reason Ben Proulx loves his C-Leg. The 20-year-old lives in Sherwood Park, Alberta. He lost his leg to cancer at age three and was first fitted with the C-Leg when he was 13.

Proulx played sports as a child and, until he got the C-Leg, his hydraulic knees broke every few months. Getting the new leg "was a big change for me," says Proulx.

He has back problems from walking with a limp for most of his childhood. "Right away the leg started diminishing that. It made running easier because of the resistance changes. It just made everything easier."

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— KELLY JAMES

Thousands of C-Leg users around the world are grateful to James for changing their lives. At trade shows, "people would come up and cry: 'Thank you for building this! It's saved my life.'"

James is now working on leg braces for people with spinal injuries and diseases, using the same microchip and valve combination as the C-Leg for easier movement. Despite having fallen into the field of prosthetics by accident, he has no plans to change his career path.

"I'm happy that so many amputees are walking properly now."

Isabelle Gallant is an Edmonton-based writer and broadcaster.