STAND UP ROBOTICS

By Shereen Lee
Photos by Wendy D Photography

A Vancouver exoskeleton startup is reimagining assisted walking to support people with paraplegia so they can experience upright motion.

Hossein Dehghani, Chief Technology Officer of Human in Motion, experiments with the XoMotion R.

Every day, an estimated 1,000 people around the world suffer a spinal cord injury, often leaving people with paralysis below the waist. In 2015, Vancouver-based fashion designer Chloe Angus became one of those people, after doctors found a benign tumor in her spinal cord they couldn't remove.

"Doctors told me I would never walk again," Angus said. But she refused to believe a wheelchair was the best option, especially when the secondary health implications of a sedentary lifestyle began to set in: bone density loss, circulation issues, and muscle atrophy.

When her doctors offered her a fentanyl patch program for the pain she experienced from sitting for extended periods, she realized the world needed a better solution for addressing issues like the paralysis she experienced. So, Angus began a search for a solution to help her regain mobility.

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>
> *Chloe Angus*
> *Director of Lived Experience, Human in Motion*

Next door in Burnaby, engineers working at Simon Fraser University (SFU) had just embarked on a similar journey. Two years prior, mechatronics professor Dr. Siamak Arzanpour, P.Eng., had been following the crowd at a San Francisco conference when he witnessed a person with paraplegia taking their first steps in an exoskeleton. “I was excited, similar to everyone else,” said Arzanpour.

He quickly realized the technology had a long way to go. Early-stage exoskeletons could only walk forward and required human assistance for balance.

“The user had to balance his or her own weight and the weight of the robot,” said Arzanpour. “To use an exoskeleton like that, they have to be in very good health.” An exoskeleton that would fully support the human in it, rather than requiring outside intervention for maintaining equilibrium, would be far more accessible. It would also be much more challenging to create.

Arzanpour and his SFU department collaborator, Dr. Edward Park, were drawn to the challenge of creating a self-balancing exoskeleton with a full range of motion. They immediately began prototyping and soon met Angus – an end-user and collaborator who would go on to influence the team’s design process deeply.

“I met the team and saw that their vision was exactly what I was looking for,” said Angus. The group formed Human in Motion Robotics in 2016 and began to pursue world-class exoskeleton development in earnest.

Eight years and hundreds of iterations later, Human in Motion released its first product, ExoMotion R, and became the first self-balancing exoskeleton to receive Health Canada approval. Commercial units are now being sold for clinical rehabilitation. And Angus, a core member of the Human in Motion team, has walked over a quarter of a million steps across five countries during the development process.

Patenting a hybrid robotic configuration

Today, Human in Motion’s self-balancing exoskeleton is a joystick-controlled wearable robot, providing mobility assistance to those with disabilities. A “dance mode” version of the robot also predicts intended lower-body movement using an inertial measurement unit that captures upper-body speed and torque, allowing the user to walk – or dance – hands-free. ExoMotion R is designed for rehabilitative use and has already been installed in physiotherapy clinics across Canada.

“When I get in [the exoskeleton], it can run through a whole physiotherapy session, or I can put it on to walk and entertain,” said Angus. “It could also be simply assisting and supporting me while I speak with people at eye level.”

This adaptability allows clinicians to adjust the amount of support patients receive from the exoskeleton as they progress in their treatment programs. The team is

Behzad Peykari has been with Human in Motion since his days as a graduate student at Simon Fraser University and now serves as VP of Engineering and Chief Innovation Officer.

developing other versions that will be suitable for at-home or personal use, while navigating global regulatory approval for its existing product.

To reach its current stage in development, Human in Motion had to first design a product that addressed the issues in early prototypes. Traditional robotic limbs use serial architecture – motors and gearheads, combined into what roboticists call actuators, stacked on top of each other to generate movement. In a serial configuration, each motor carries the weight of the components that follow. This method mirrors the biology of human limbs but means that actuators close to the base of each limb need to be powerful – and bulky. Imitating the range of motion seen in a human leg requires up to seven actuators: three for the hip joint's 3D motion; one for the knee's swiveling motion; and three to model the ankle.

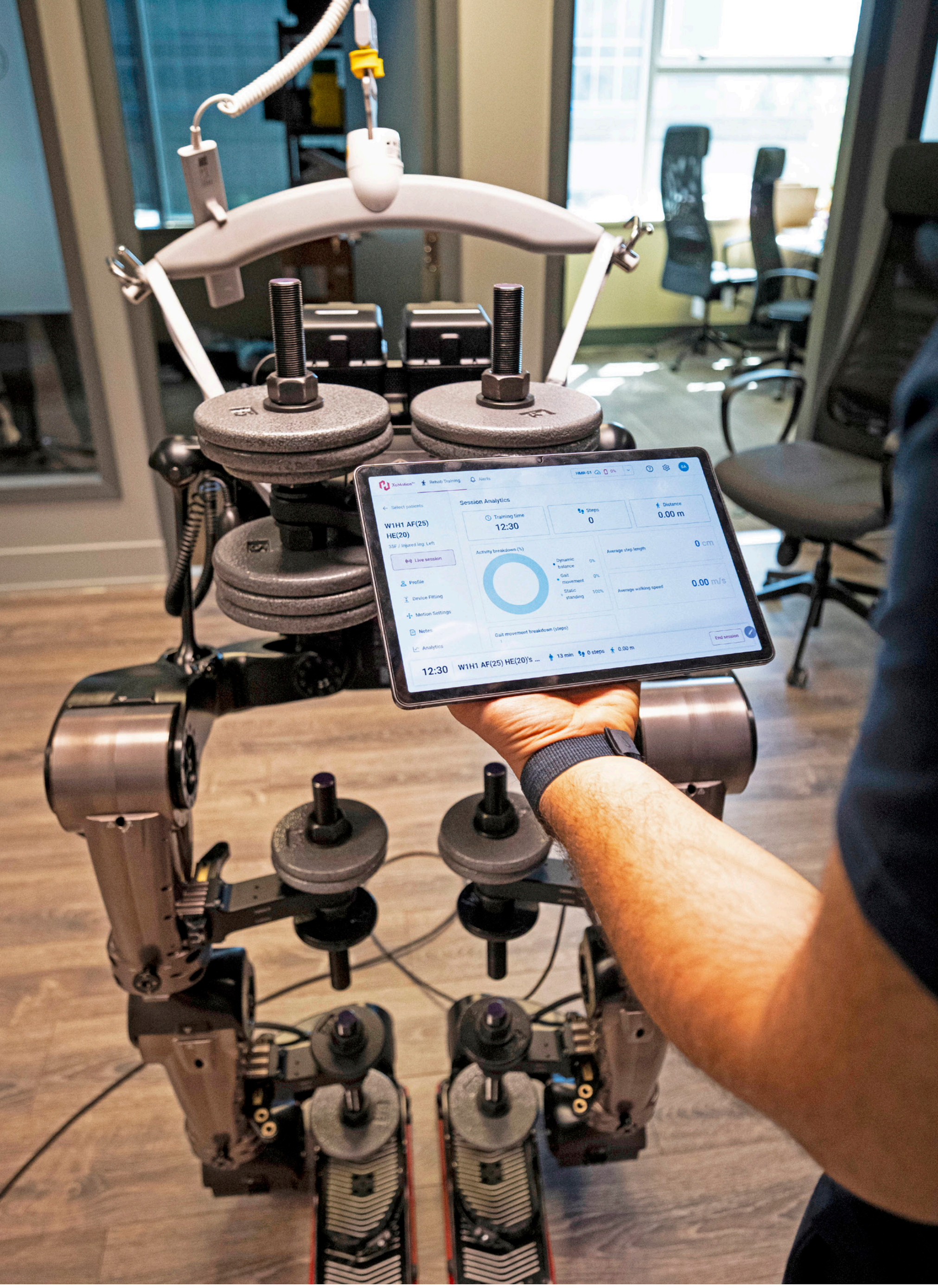
Early exoskeleton models on the market pursuing the serial approach made dramatic compromises to keep weight low, including limiting their devices' ranges of motion. The design solution to this issue came from the team's observations of fingers. Fingers, as opposed to joints, run in parallel; multiple actuators work together next to each other, rather than stacking sequentially. Parallel robots are typically designed for local applications, like dexterity.

The Human in Motion team drew on both serial and parallel architecture, incorporating limbs in parallel to create a more compact, efficient design.

"Working together, they are very powerful and accurate," said Arzanpour.

Developing in-house manufacturing capabilities

After years of painstaking work, the team finally felt they had a design that could distinguish itself in the robotics space. But the group faced an issue: even after



Results from trials with the XoMotion R are reviewed.

designing the perfect system, no manufacturer could help them make the actuators that met Human in Motion's requirements for speed, torque, weight, and size.

"We searched for nearly six months," said Behzad Peykari, who joined Human in Motion as an SFU master's student in 2018 and now serves as the Vice-President of Engineering. "We spent a long time talking to different manufacturers."

The team's requirements were stringent. They needed motors powerful enough to move a human body, along with a setup small enough to wear, light enough for extended use, and fast enough to feel natural. At the end of its half-year search, the team was close to giving up on hopes of implementing a prototype.

"We almost got to a point of deciding to abandon the project," Arzanpour says.

Instead, Human in Motion decided to design its actuators from scratch and worked to customize solutions that would fit the team's specifications. Today, its actuators are still assembled by hand in its Vancouver laboratory.

"These actuator designs were perfected over the years," said Peykari. "It's become one of our points of core expertise." The hip mechanism, in particular, has three degrees of freedom and took years to develop using a critical interface.

"If you look at the first prototypes that we developed, the actuators' size and weight are very comparable to the actuators that we have in our product right now, but the speed and torque capacity that they have is four times more than what we started with," said Peykari.

Chloe Angus, Director of Lived Experience, is an end-user and collaborator who has influenced the team's design process.

Trials in exoskeleton development

Throughout the design process, prototypes began with localized goals and expanded to encompass more functionalities as the team's products became increasingly advanced. The first prototype, Alpha – a suit that Angus dubbed "Arnie" after Arnold Schwarzenegger for its massive profile – allowed the team to determine rough torque requirements, understand computational power requirements, and begin iterating on the control systems and battery sizing.

The next prototype, Beta I, began to address the issue of self-balancing. Human in Motion's prototypes were designed to fit 90 percent of the population, from five-foot tall, 90-pound users to six-foot-four, 220-pound users. This broad requirement means that exoskeleton engineers have even more considerations to keep in mind.

"Humanoid robots have the same dimensions. Since all the specifications are known, the robot can be precisely programmed, and you are not expecting any types of internal disturbances," said Arzanpour. "But in the exoskeleton, though the lower body is confined, I cannot predict how the upper body is moving: if the user wants to move suddenly, these disturbances might make the robot unstable and tip over."

As Arzanpour puts it, an exoskeleton-assisted person has two brains, not just one. "We need to consider the brain of the robot, but also the brain of the user," said Arzanpour. "The brain of the exoskeleton somehow needs to understand the motions of the user, and based on that, execute the commands. That is another layer of complexity."

As the team developed its actuating devices, Human in Motion simultaneously built out the suit that aligned the robotic exoskeleton with human joints, allowing for safe force transfer.

"One other important thing for us was to make sure that the centre of rotation of the robotic joint coincides with the centre of rotation for the biological joints," said Hossein Dehghani, who serves as Chief Technology Officer at Human in Motion. "Imagine that these exoskeletons will be used by people who may not have sensation in their lower body. If there is a mismatch in the centre of rotations, there is a chance of dislocation or fracture."

Custom-designed orthotics – padding, straps, and support pieces that create a comfortable interface between exoskeleton and human – distribute loads and ensure that users can use the exoskeleton for several hours at a time without discomfort.

The third prototype, Beta II, focused more directly on algorithms and mechanical affordances for fall prevention and preventing robot deformation, resulting

Dehghani points to Human in Motion's first working prototype, Beta I.

in a streamlined and consistent prototype. Most recently, the team completed development of ExoMotion I and ExoMotion R, where the team made usability improvements, experimented with different control configurations, and made specific adjustments to allow for efficient rehabilitation.

Torque sensors, in particular, played a large part of their work on their rehabilitation-focused ExoMotion R. "Rehabilitation facilities work with patients on a range of conditions, from spinal cord injury, to stroke, traumatic brain injury, and MS," explained Arzanpour.

Torque sensors allow physiotherapists to measure the motor functions of the user and augment them.

"For example, for spinal cord injury most of the time you need 100 percent assistance, but for stroke patients, you don't want 100 percent assistance," said Arzanpour. "You want to push them to force themselves to exercise. With these precise measurements that we can now do with our torque sensors, the device can be used for more advanced rehabilitation."

Iterating with artificial intelligence

Improvements in artificial intelligence (AI) are also deeply changing how Human in Motion approaches its design process. "Right now, the algorithms that we have in our robots are model-based algorithms," explained Arzanpour. These models, typically based on empirical or mathematical formulas, require engineers to make simplifications and to limit the comprehensiveness of the design.

The team's pre-AI approach involved setting up a test rig of barbell plates on the exoskeleton to test the rig, a simplified approach that required trade-offs for precision and accuracy. As AI technology matured, the team began emphasizing machine learning as a way forward to improve the stabilization technology and design process.

Now, in collaboration with researchers from tech giant Nvidia and the renowned robotics company Boston Dynamics, Human in Motion is overhauling its hardware to adjust to AI simulation and training.

"The reason that [early] exoskeletons did not initially follow the path of self-stabilization was because you needed a million data points to train the robot and make sure that the robot is not falling," said Arzanpour. Now, with improved virtual environments, robots can be "trained' in simulated spaces with accuracy, generating stable motion for users of different heights and weights.

"Right now, what we're doing with AI is closing the gap between simulation and reality," said Arzanpour.

Experiments in AI have even led to integration with brain-computer interfaces (BCIs), which gather electrical inputs to interpret a user's movement intentions without needing a joystick.

"The interface might go from being a handheld controller to voice-controlled or controlled with a BCI," said Dehgani. "The processes we are using are future-looking, trying to refine our product, accommodating different scenarios."

Upcoming releases of Human in Motion's exoskeleton will focus on physical controls due to the experimental nature of the technologies and regulatory requirements for physical control fail-safes. "It is a medical device, and safety is of utmost importance," said Arzanpour.

As the technologies for different approaches become more widely accepted, the team plans on looking into different control mechanisms that allow for increased user autonomy.

Striding into the future

When the Human in Motion team began its work on exoskeletons, none of the members had truly anticipated the scale it would grow to, breaking national records and appearing on international stages. The concurrent development of AI has allowed the team to progress even farther than it had imagined possible in 2014.

"We brought this product to such a level of technical excellence, it's walking itself out of what we would traditionally call an exoskeleton and into a wearable humanoid," said Dehgani. "With the very fast pace of growth we're seeing in robotics, it is very hard to predict where the technology will go. For us, adaptability is important."

Even more surprising than the technological growth of the industry was the visceral experience of seeing lives change in front of them.

"We have had many moments that put us all in tears," recalls Arzanpour, "when we saw people walking for the first time after 20 years, hugging their family members after a long time."

These emotional moments have become part of the daily work of developing at Human in Motion, where extraordinary achievements have quietly become routine.

"It changes my day when I get to walk in the XoMotion," said Angus. By now, she's crossed platforms small and large. During a particularly memorable moment in early 2025, Angus walked across the stage at the Invictus Games closing ceremony in front of over 10,000 attendees as a flag-bearer.

Ten years after her lower-body paralysis, the question isn't whether she will walk again; it's where she'll go.

The team considers the in-house manufacturing capabilities and mechanical design to be some of the company's core strengths.