TECHNOLOGISTS' PRACTICE CASE STUDY | JANUARY 2011

RESISTANT MATERIALS TECHNOLOGY/DIGITAL TECHNOLOGIES | YEARS 9-13

REX THE ROBOTIC EXOSKELETON

Developed by a New Zealand-based technology company, Rex the Robotic Exoskeleton could change the lives of millions of disabled people world-wide. Rex is a pair of robotic legs made of strong, lightweight materials that is worn outside the body and enables those with non-functioning legs to stand up and walk with their arms free, move sideways, turn around and go up and down steps. This case study profiles the company that developed this ground-breaking device and examines in detail its development from concept through to the manufacture of the first eleven working prototypes and the plans to launch a commercially available version on the international market.

FOCUS POINTS INCLUDE:

Characteristics of Technological Outcomes

- Justify the fitness for purpose of technological outcomes in terms of their physical and functional nature and the socio-technological environment s they are used within.

Technological Modelling

- Explain the role of technological modelling in the exploration and identification of possible risks.

Technological systems

- Explain the variety of roles played by subsystems in complex technological systems

ADDITIONAL SUPPORT MATERIAL

- **Company website:** www.rexbionics.com
- **YouTube videos:** www.youtube.com/user/rexbionics#p/u/5/bnX3eSM1Klo
- **3News video:** www.3news.co.nz/REX-could-help-disabled-people-walk-again/tabid/311/articleID/166012/Default.aspx

TEACHING ACTIVITIES

Discussion starters (Years 11-13)

- The developers' first priority was uilding a working prototype. Discuss the reasoning behind this and explain the steps involved in the development process.
- Discuss the complexity of evaluating the fitness for purpose of an innovative medical product like the exoskeleton.
- Explain the following terminology in relation to the development of the exoskeleton:
  - precision-orchestrated actuators
  - integration of sensors and feedback loops

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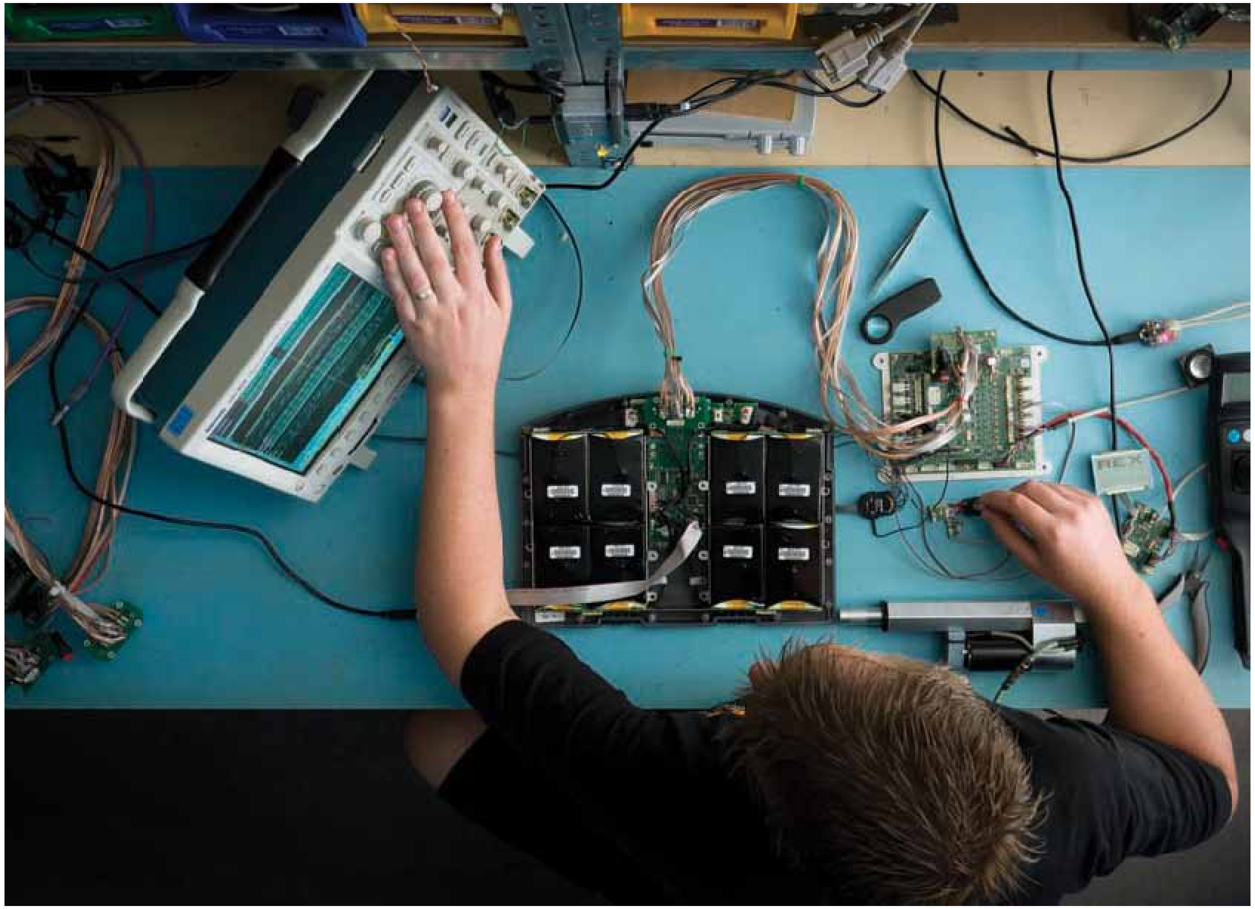
REX THE ROBOTIC EXOSKELETON

Liberty, Autonomy, Indepenence

Racing speedway bikes was Hayden Allen's top priority. Nothing could beat the thrill of lapping an oval racetrack faster than anyone else. But after a road crash left him paralysed from the chest down, doctors said it was all over: he'd never ride speedway again. So he set out to prove them wrong. Three years later he was lapping Rosebank Speedway on an alcohol-burning sidecar bike. Racing ruled.

That was before Mr Allen met Rex, his walking robot – a robotic exoskeleton. It looks like a pair of steel trousers with waist-high handlebars. Mr Allen transfers into it, straps it on and controls it with a joystick on the right handlebar. He can then walk on flat and sloping surfaces, climb stairs, and work on his motorcycle. Being able to stand at his workbench makes it easier and safer to use power tools such as a bench grinder, which tends to spray sparks and debris toward the eyes of a seated user. Mr Allen liked the exoskeleton so much that in February 2010 he joined the staff of its Albany-based manufacturer, Rex Bionics. Now speedway racing takes second place. Mr Allen loves helping wheelchair users stand up and walk.



Development

Rex Bionics was established by two Scottish engineers who migrated to Auckland in the mid-1990s. In 2003, Richard Little and Robert Irving decided to build a set of robotic legs to provide greater freedom for wheelchair users. The idea developed from very personal circumstances: their mothers both use wheelchairs. That same year, Mr Irving was diagnosed with multiple sclerosis, an incurable condition that could eventually force him into a wheelchair as well.

After researching the number of wheelchair users worldwide, the pair knew their robotic legs could help a lot of people. In the United States (US), for example, more than five million people use wheelchairs. Some may not be able to use robotic legs, but there are millions who probably can.

Beyond the obvious benefit of superior mobility, Mr Little says a robotic exoskeleton would improve a user's health by reducing or eliminating complications from sitting all the time.

The potential benefits vary widely, because every wheelchair user has a unique combination of lifestyle and disability, but some problems are widespread. Pressure ulcers, for example, debilitate many otherwise independent wheelchair users. They are caused by poor blood circulation, which deprives the affected area of oxygen. Serious cases require hospital treatment, as they can be life-threatening. By moving a user's legs, as if they were walking, an exoskeleton helps increase blood circulation and reduces the risk of pressure ulcers. Treating a single pressure ulcer costs an average of about $US70,000 in the US.

According to Mr Little, the idea of a mechanical exoskeleton has been around for about a century, and some concepts were patented decades ago. United States' companies Lockheed-Martin and Raytheon recently demonstrated hydraulic exoskeletons that can boost the strength or endurance of able-bodied users. But devices such as Lockheed's Human Universal Load Carrier (HULC) mimic the user's body movements: they cannot stand or walk on their own.

Design issues

It's far more difficult to develop an exoskeleton for a wheelchair user. The machine must be able to stand, turn, walk, and climb stairs without relying on the user's sense of balance. Nor can it rely on their upper body strength, because according to Mr Little, "about 50 per cent of manual wheelchair users have shoulder injuries at any one time". The machine is classified as a medical device, and medical ethics demand that such devices shall not harm their users. This means, for example, that the device must not fall over if it develops a fault, such as a software glitch.

Because the user's legs are firmly strapped into the robot, the exoskeleton's steel bones cannot be connected with simple ball-joints. The human hip joint, for example, pivots around a natural ball-joint deep inside the hip area. An exoskeleton must rotate about a virtual pivot coinciding with the user's hip joint. On top of these challenges, the device should be light and strong – hardly a trivial requirement considering the actuators would be connected to the short ends of long levers. According to Mr Little, a human hip joint carries a force equivalent to at least 500 kilograms.

When they got going on their idea, Mr Little and Mr Irving's priority was to build a working prototype. They knew they'd need outside investment to commercialise the device, and a successful prototype would make it easier to convince investors they could deliver on their plans.

Building a prototype

Prototype testing emphasised the importance of working closely with potential users: "It's all about walking," Mr Little says. "You learn nothing designing, or even prototyping, without the real user in the device... you can't simulate that... quite often we used to spend a lot of time building stuff, and then we'd get somebody in to try it and they'd... walk completely different."

The machine evolved joint by joint. "When we started building it we built the knee, we actuated the knee, then we controlled the knee. We built an ankle...".

Each joint presented a complex geometric problem, because the exoskeleton's "bones" swivel around virtual pivots. A single joint needs several precisely orchestrated actuators. Pneumatic actuators were found to be too imprecise. Off-the-shelf hydraulic components were unsuitable, and developing custom hydraulic components was going to be difficult. Eventually, the device was built around custom-designed electromechanical actuators.

The design specification evolved alongside the prototypes. When a new employee asked about the design requirements, they were told: "it goes up and down slopes and it goes backwards and forwards," Mr Little says. "That was the level we were working at... and luckily we had really highly skilled people."

By late 2007 a complete working prototype was ready, and the company, Rex Bionics Limited, was established. Mr Little seems to enjoy swinging from the robot's hips, like a gymnast on a vaulting horse. Even though it is switched off, the machine is stable enough to cope with his antics. However, as soon as he moves it from the flat workshop floor to a sloping ramp, its high centre of gravity takes over. With a lithium-ion battery inside the carbon-fibre hips, the robot easily topples if it leans too far. But as soon as Mr Little activates the machine's balance system, it rotates its ankles and stands up straight.

Driving Rex

Each exoskeleton is custom-fitted to its user's body. The length of the "bones" must match the user's skeleton, and the harness straps are also custom-fitted. The device is designed for users up to 100 kilograms, and between 1.46 metres(m) and 1.95m tall. At 1.95m, Mr Allen is right on that upper limit.

Mr Allen usually parks his robot in an armchair. To get into the device, he puts his wheelchair alongside the armchair, then lifts himself from wheelchair to robot. While he straps in his thighs, an assistant straps in his lower legs. His feet ride on top of the robot's aluminium feet. His body is supported by a seat-belt-like harness attached to the robot's hips.

Gripping the handlebars, he leans forward as the robot stands up. When he pushes the joystick forward, the robot whines like a fleet of power tools as it leans dramatically, shifting the combined centre of gravity above one foot. Then it lifts the other foot and steps forward. Mr Allen stops mid-stride, demonstrating how he and his robot will not topple over, even if the software crashes, or if someone inadvertently steps into his path. Completing the stride, the robot swings vertically, leans the other way and lifts the opposite foot.

Mr Allen explains it takes about an hour of practice to become accustomed to the robot's curious gait. Although it seems slow, he says his robot is fast enough to scare first-time users, so he adjusts new machines to walk about a third slower than his does. But even that can seem too fast for someone who has been using a wheelchair for years. He demonstrates Rex's moves further, flicking the joystick sideways so the robot pivots like a basketball player, shuffling one leg forward and rotating about the heel of the other.

Walking on an uneven surface, the machine waggles its foot, feeling for resistance and systematically finding a firm footing. Sensors in the ankle and foot allow the robot to adapt to surface conditions, and the control system ensures the moving foot is firmly grounded before putting weight on it. Besides the weight-sensing load cells, the balance system uses data from several accelerometers and three miniature gyroscopes.

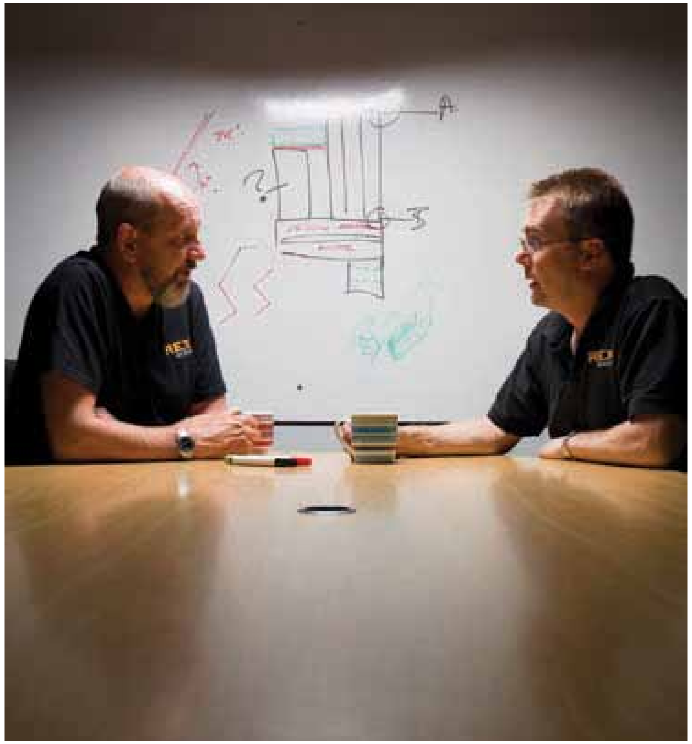
Controlling the complex machine takes the combined computing power of a team of micro-controllers. Mr Little explains there are many sensors and feedback loops. Flexing a single joint is a complex computing problem. Moving forward requires simultaneous control of all six joints. While that is happening, the system must compensate for the user's body movements without falling over, while keeping track of other important parameters. It also must prioritise between a signal from the battery controller warning of overheating in the lithium-ion battery, and a signal from the balance system warning that the machine is nearing the limit of stability. Safetycritical signals take priority. Rex Bionics developed and patented a specialised networking system to link the various controllers together. Its rapid response time ensures the robot responds within milliseconds, which feels instantaneous.

Manufacturing and distribution

Mr Allen's robot is one of eleven functioning prototypes. The market could realistically absorb millions of units. So although the prototypes have been handbuilt, many components are designed to suit high-volume manufacturing processes such as plastic injection moulding and high-pressure diecasting. Computer numerical controlled-machined aluminium components in the prototypes would be replaced in production machines with high-pressure die-castings.

The exoskeleton contains more than 4,700 components, many of which are custom-designed. Each electromechanical actuator, for instance, contains an off-the-shelf electric motor driving a train of custom-built gears and shafts, built into a housing made from custom-designed aluminium alloy components.

Because Rex is a medical device, the manufacturing system must ensure full traceability down to component level. This means that Rex Bionics must maintain detailed records allowing each part to be traced back to its original source,



ensuring the appropriate test and inspection records for any part of any individual exoskeleton can be retrieved.

Traceability works best if every item comes from a manufacturer who also provides full traceability. That's not always possible, so Rex Bionics tests some parts to verify they comply with relevant specifications: they test some of the steel that goes into their robot, for example, because the supplier does not provide full traceability.

With such a complex product, Rex Bionics depends on a large network of suppliers, such as the machine shop that makes their gears and gearbox housings. Many suppliers knew what they were making, but they were sworn to secrecy because of the paradox of patenting: To secure a patent, Rex Bionics had to publish a description of their product, which would give potential competitors enough information to copy the exoskeleton. Worse, the cost of lawyers, patent applications, and annual patent registrations would divert funds that would otherwise go into prototype development. So, until July 2010, Rex was one of Auckland's best-kept secrets. Dozens of people contributed to its development, but no one else knew what was happening. To balance these conflicting requirements, Mr Little explains the patent applications have been timed to coincide with the product launch. By the time patent specifications are published, real exoskeletons will be out in the market. There'd be little to stop a competitor acquiring a production model and pulling it apart. By then, however, Rex Bionics will be working on the "Mark II version".

After seven years and $10 million, Rex Bionics is preparing to put the robot into production. But first, they must prove their prototypes satisfy a plethora of type approval tests. There's never been anything quite like Rex, so test regimes designed for other medical products are being adapted for the task. To verify battery life, for example, Rex Bionics used a test designed for electric wheelchairs. Based on those results, they can guarantee at least two hours of battery life between charges. In real life, some users get up to five hours per charge. It depends how hard they work the robot. Other type approval tests cover the full gamut of technical issues including electrical and mechanical safety, toxicity, electromagnetic susceptibility and emissions.

The device has already been certified for sale in the European Union and Australia, and Rex Bionics is now working on Food and Drug Administration approval for the US market.

Rex Bionics planned to begin "Beta" sales in New Zealand in November 2010, and by November 2011 they hope to start selling the exoskeleton internationally, at a projected price of $US150,000. Medical ethics dictate Rex Bionics' approach to marketing their robot. They must not create unrealistic expectations in the minds of wheelchair users, because some may find they cannot use the machine. Clinicians understand the individuals they work with, so they are best qualified to advise potential users about the walking robot. Rex Bionics supplies clinical professionals with a "prescriber's guide" outlining the exoskeleton's key aspects.

Feedback

Besides Mr Allen, nine other people had been trained to use Rex Bionics' exoskeleton by early October 2010. As the company prepares to ramp up production for the New Zealand market, Rex Bionics has set aside an area specifically for training robot riders; users generally spend an hour or two each day using their robots at the factory. Although Mr Allen doesn't regularly take his robot home with him, he has made some public appearances and attended a company social at a bar.

Users have been reporting the kinds of benefit Mr Little and Mr Irving anticipated. Before he started using his robot, for instance, Mr Allen was changing his catheter every day or two: an uncomfortable procedure that left him feeling constantly unwell. Regular exercise in his machine has led to a dramatic improvement. Catheters now last more than a month, and he feels great.

Mr Little explains that while every exoskeleton user will have unique problems, he has been pleasantly surprised by some of the benefits they have experienced. Social interaction, for example, becomes far easier and more comfortable, as many wheelchair users suffer neck strain from continually looking up at people while chatting, so they find it far more comfortable to maintain eye contact if they are standing up like everyone else. They are also less likely to be ignored. People do not talk over the top of them, or talk down to them.

Mr Allen has been using the exoskeleton for about eight months, but his face lights up when he gets into his robot. It's not just that he can walk around, or safely handle an electric jug (they can present a serious hazard if used from a wheelchair), or gaze out of a window that would otherwise be too high for him to see out of. He just says: "It feels good".

Writer: Kevin Cudby