"Going to the rehab"

During a trip to the USA (Boston area, Baltimore area and Chicago), a Dutch delegation of robotics researchers and entrepreneurs discovered a lot of "interfaces" for R&D and business collaboration. Common interests include surgical robotics, robotic-assisted rehabilitation training of stroke survivors, and development of advanced prostheses. Based on the delegation's impressions, this article offers a glimpse of cure and care robotics in the USA.

• *Hans van Eerden* •

Nowadays, consensus exists that robotic technology has the potential to address social and economic issues related to an ageing population and a decreasing workforce. As the emerging technology in health care fields such as surgery and rehabilitation, robotics can offer new and improved surgical procedures, better training results and enhanced comfort and safety for patients. This trend is founded in mechatronics, with mechanical, electronic and software engineering as the underlying disciplines. After many years of fundamental research and clinical trials, robotic technology will now have to mature and enter the operating theatre and the clinic for routine application.

Revolutionizing Prosthetics

A large proportion of American robotics research – as well as research in many other fields – is (in)directly funded by the Department of Defense. Currently, Iraq and Afghanistan act as "drivers" for robot-related research. For example, DARPA (Defense Advanced Research Projects Agency) has initiated the Revolutionizing Prosthetics (RP) research programs. Preceded by the RP2007 program, the $70 million RP2009 program aims to restore limb function and quality of life to military and civilian amputees by developing a fully integrated upper extremity prosthesis; see Figure 1.

Figure 1. Non-invasively controlled advanced prosthetics developed under DARPA's RP2007 program. (Source: www.darpa.mil/news_images/prosthetics.html)

One of the participants is the Applied Physics Laboratory (APL), a research and development division (4,500 staff members) of Johns Hopkins University, Baltimore, Maryland. The RP2009 work is performed by members of the Biomedicine Branch of APL's National Security Technology Department. APL is the lead system integrator for the more than thirty national and international research groups who are involved in the RP2009 program. Recently, the APL team demonstrated the first fully integrated prosthetic arm that can be controlled naturally, provide sensory feedback and allow for over twenty degrees of freedom.

Surgical robots

With a nearly 15 years of history in robotics research, Johns Hopkins University (JHU) in 2007 founded the Laboratory for Computational Sensing and Robotics (LCSR). The lab (95 staff members) is characterized by a "horizontal" collaboration on robotics, including JHU's medical school.

The research focuses on robotics for health care and biomedical applications, autonomous systems for safety and surveillance, and human-machine interaction. Subjects include the design of sensor-based robot control systems based on how animals process sensory information to control their motion; haptics to enable robots to explore the world through touch, and also to add the sense of touch to virtual and tele-operated environments for humans; computer integrated interventional systems (surgical robotics, anatomical modeling, and treatment planning, ultimately aimed at achieving "closed-loop interventional medicine"); and visual imaging and surgical robotics; see Figure 3.

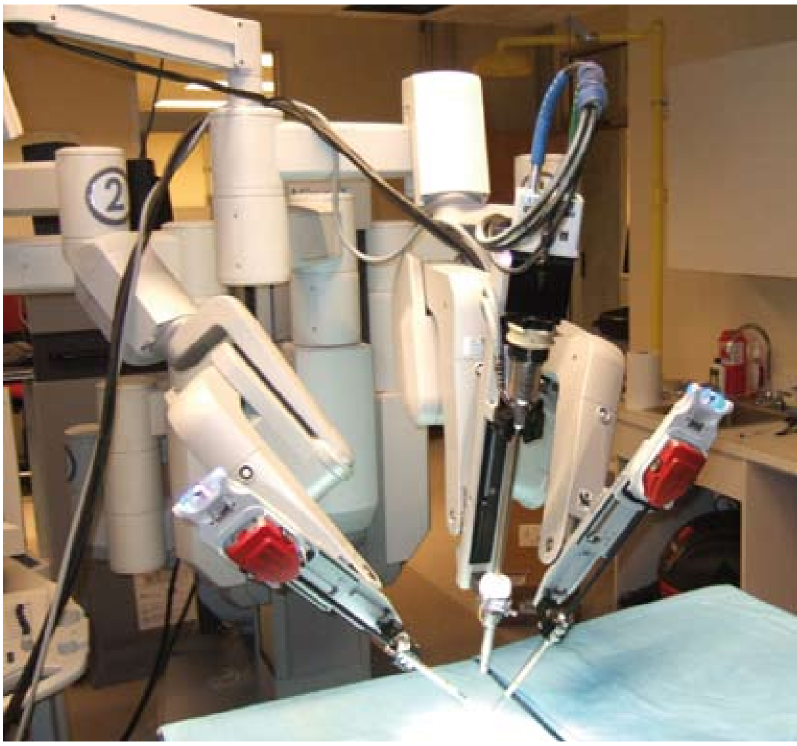

Figure 3. In the LCSR research, extensive use is made of the Da Vinci surgical robot.

Dutch delegation visits USA

Scientists, entrepreneurs and business developers of various organisations from Twente / the Eastern Netherlands participated in the Cure and Care Robotics Mission USA 2009, which was organised last November in close collaboration with the Netherlands Office of Science and Technology in Washington, DC. One of the driving forces behind this trip was the Advanced Robotics & Mechatronics Foundation (Romech), which in 2008 launched an initiative to strengthen education, research and business collaboration in the area of robotics, especially humanoids and home robotics, in the Twente region.

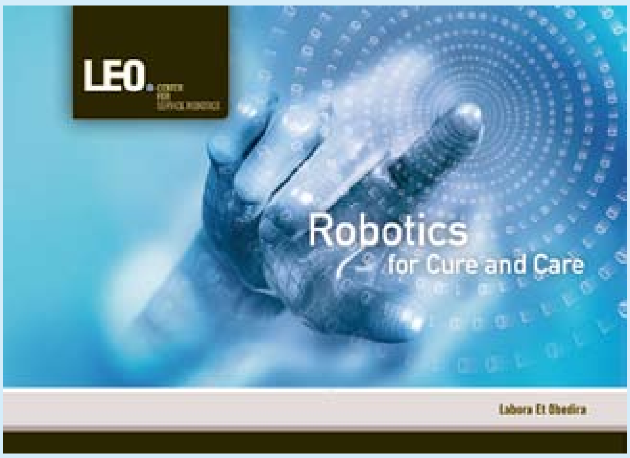

Figure 2. The full report on the Cure and Care Robotics Mission USA 2009 will be available through the Romech website.

As the framework for this initiative, the LEO Center for Service Robotics will serve. LEO will have Twente / the Eastern Netherlands as a natural home base, because of its many key players (University of Twente, Roessingh Rehabilitation Centre R&D, high-tech mechatronic and medical companies), its advanced facilities (such as for medical imaging, rapid prototyping, and virtual reality), and – with respect to medical robotics – the unique discipline of Technical Medicine at the University of Twente.

www.romech.nl
www.leo-robotics.eu
www.twanetwerk.nl (Netherlands Office of Science and Technology)

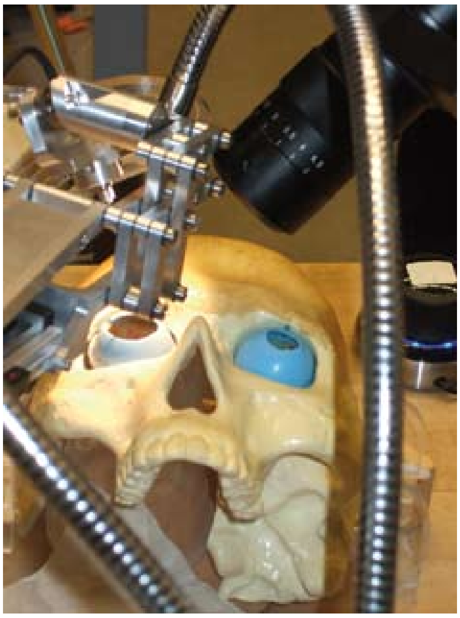

Figure 4. Experimental set-up in LCSR for robotic-assisted retinal microsurgery.

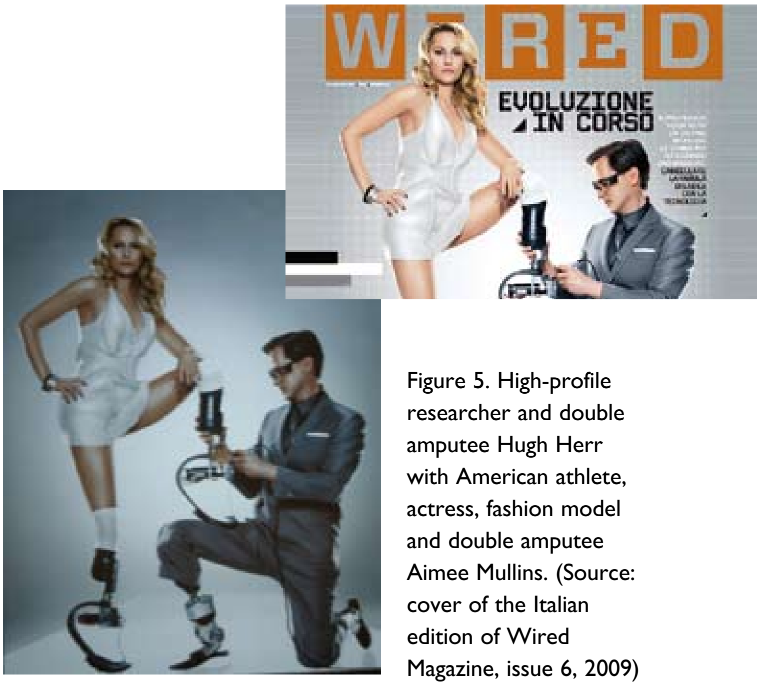

Figure 5. High-profile researcher and double amputee Hugh Herr with American athlete, actress, fashion model and double amputee Aimee Mullins. (Source: cover of the Italian edition of Wired Magazine, issue 6, 2009)

For example, research on robotic-assisted retinal microsurgery focuses on micro-force sensing for giving the surgeon feedback; see Figure 4. To that end, optical fibre Bragg grating strain gauges were enclosed inside the instrument. 3D tremor compensation is achieved with piezo-electric actuators.

Biomechatronics

Prosthetics development is also undertaken at the Massachusetts Institute of Technology's Media Lab, in the Biomechatronics group, directed by high-profile researcher and associate professor Hugh Herr, who is wearing two knee-foot prostheses of his own make; see Figure 5. The scientific programs of the group, based in Cambridge, Massachusetts, center on organismal biomechanics and control, and on skeletal muscle biomechanics and control. Key issues, with respect to the design of artificial limbs or limb supports, that have been studied include angular momentum regulation in human walking, and humanoid balance control using contact and non-contact limbs. The technological programs include prostheses, orthoses, and exoskeletons.

The basic architecture of an active (powered) foot-ankle prosthesis was designed as a unidirectional spring, configured in parallel with a force-controllable actuator with series elasticity. With this architecture, the ankle-foot prosthesis matches the size and weight of the human ankle and foot, and is also capable of delivering high mechanical power and torque as observed in normal human walking. A biomimetic control scheme was proposed to allow the prosthesis to mimic the normal human ankle behavior during walking.

PowerFoot One

The technological work on active ankle-foot prostheses is commercialized through Cambridge-based iWalk. Founded in 2006, it started with introducing PowerFoot One, the world's first actively powered prosthetic ankle and foot; see Figure 6. PowerFoot One is a completely self-contained robotic system, equipped with two microprocessors and six environmental sensors for continuous evaluation and adjustment of ankle position, stiffness, damping and power. Control algorithms generate human-like force while traversing level ground, slopes and stairs, providing active amputees with near-normal gait and lower energy expenditure compared to state-of-the-art passive prosthetics, so iWalk claims. Series-elastic actuators and energy control strategies allow for efficient use of light, high-power batteries. Novel materials have been included in the design, such as metallic crystals and carbon fibers for lightweight, high-strength springs and structural components.

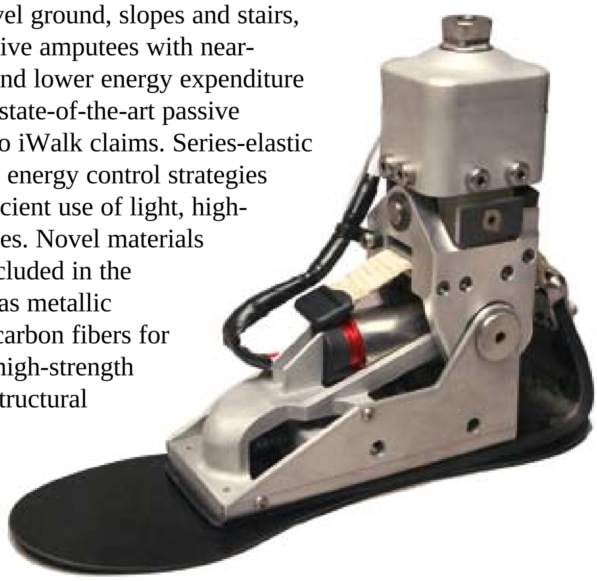

Figure 6. The PowerFoot One ankle-foot prosthesis was developed in the Biomechatronics group at MIT's Media Lab and was commercialized by iWalk. (Source: www.iwalkpro.com/products.html)

Robot therapy

MIT's Newman Laboratory for Biomechanics and Human Rehabilitation, led by Prof. Neville Hogan, is dedicated to technology for enhancing human performance. The initial focus was on stroke, resulting in the development of the well-known MIT Manus, used for assessing the feasibility of robot therapy for stroke survivors. Current research is devoted to the development of other robots (for example, for robot-aided wrist and grasp rehabilitation), therapy design, movement analysis, motor learning, and semi-active variable-impedance materials (for shock absorption in biomechanical applications).

Much attention is devoted to new designs of actuators for neurological rehabilitation robots and similar "high force haptic" devices. These applications require actuators with high force/weight ratio and low mechanical impedance. Conventional actuators with high force capacity generally either are extremely heavy (e.g. electromagnetic actuators) or have high endpoint impedance (such as geared actuators), and in general are inadequate when the device kinematics are complicated.

Another "research product" of the Newman Lab is the MIT-Skywalker, a device that delivers gait therapy without imposing rigid kinematics patterns of normal gait on impaired walkers, as opposed to previous approaches in mechanized gait therapy. Instead, the MIT-Skywalker takes advantage of the concept of passive walkers and the natural dynamics of the lower extremity in order to deliver more "ecological" therapy.

Stroke survivors

At Northwestern University, research in the Chicago-based NeuroImaging and Motor Control Laboratory, led by associate professor Jules Dewald, is dedicated to understanding motor recovery following stroke. The aim is to conduct basic science before designing robots, making the use of robotics in rehabilitation science-underpinned. The focus is on learning the role of brain plasticity in recovery, and on developing novel therapeutic training techniques to improve arm function following a cerebrovascular accident. The lab's biomechanics research is concerned with the basic mechanisms of movement disorder following stroke. Closely related to this approach is the research on rehabilitation and neurotherapeutic training, aimed at developing and validating novel training programs to enhance functional recovery after stroke.

Figure 7. A test subject using the ACT3D. (Source: www.dlrehab.com/rehab.htm)

ACT3D robot

Projects involve the development and validation of training programs that seek to diminish abnormal constraints on torque generation in the impaired limb. Providing feedback to the subject via a virtual arm displayed on a monitor in front of them, a robot system creates a virtual environment for the subject to interact with, and can be programmed to provide varying levels of support/gravity compensation, shoulder torque load (as if the subject were lifting an object), or to prescribe alternate planes of motion. The spin-off of this research is being commercialized as the ACT3D robot (Arm Coordinated Training Device in Three Dimensions) through D.L. Rehab Technology. ACT3D is based on Moog FCS's HapticMaster, a force-controlled robot acting as a haptic interface, in combination with a chair belonging to Biodex Medical Devices's single-link robotic system, which is often used for sports rehabilitation; see Figure 7.

Rehabilitation Institute of Chicago

The Sensory Motor Performance Program (SMPP) at the Rehabilitation Institute of Chicago (RIC) counts 29 faculty, mostly from Northwestern University (see above), and 200 staff in total. SMPP is devoted to the study of musculoskeletal, neuromuscular and sensory disorders that are associated with abnormal control of posture and movement. The research is aimed at understanding the sensory-motor system through close interaction with artificial systems and determining how the brain acquires, organizes and executes motor behaviors. Robotic

Figure 8. The Lokomat rehabilitation training robot in Spaulding's Motion Analysis Laboratory.

technologies are being used to investigate how humans adapt to radical changes in body mechanics.

The ultimate aim is to help restore motor functions in individuals with neurological disorders and to create systems that can learn and adapt to their users. Over fifteen laboratories/centers participate in the SMPP research, covering, amongst others, robotics, biodynamics, upper-extremity mechanics, biomechatronics development, neural engineering for artificial limbs, and neuromechanics of impaired locomotion. The Neurolocomotion Lab, for example, comprises three Lokomat rehabilitation training robots, for clinical use (motion/gait analysis), neuro-research and research on the effect of training and medication. Other research equipment includes the KineAssist (see below, Kinea Design) and the MACARM (see below, Intelligent Automation, Inc.).

Lokomat therapy

The Motion Analysis Laboratory in Spaulding Rehabilitation Hospital, Boston, Massachusetts, combines laboratory and field assessments to enhance mobility in individuals with mobility limiting conditions caused by age, illness, or trauma. This lab also works with the Lokomat, see Figure 8, which not only has a positive effect on the recovery of stroke survivors but also relieves the physical load of their therapists during training. Further, the device is used in studies of motor learning paradigms, and in collaboration with its supplier, Hocoma, motivational graphics for biofeedback during Lokomat training are being developed.

Biorobotics

At Harvard University, Cambridge, research in the BioRobotics Laboratory, directed by Prof. Robert Howe, focuses on the role of sensing and mechanical design in motor control, in both robots and humans. Applications of the research are found in biomedical instrumentation, tele-operated robots, and intelligent sensors.
In collaboration with the Boston-based Children's Hospital, research is conducted on image-guided intra-cardiac surgery for mitral valve repair in a beating heart. A handheld, lightweight robotic motion compensation instrument was designed, see Figure 9, that has sufficient bandwidth to compensate for the fast-moving structures in the heart, as well as a sufficient force output to perform suturing and stapling tasks on heart tissue. This instrument, operating within the limited confines of the heart, has made valve repair, which compared to valve replacement is more difficult but has a lower mortality, a more viable option. To enable motion compensation during operation, real-time instrument and tissue tracking is performed using 3D ultrasound. Because of the time delay introduced by data processing, a dynamic feedforward is introduced in the procedure.

Figure 9. The lightweight robotic motion compensation instrument for mitral valve repair.

As a supplement to the visual feedback that is, for example, provided by 3D ultrasound images, the introduction of force feedback is studied. Haptic (or force) feedback can improve task performance during surgical tele-operation using a master-slave system with non-ideal properties. For example, tip sensors may offer benefits during tele-operation with a flexible slave (because surgical instruments are becoming very thin).

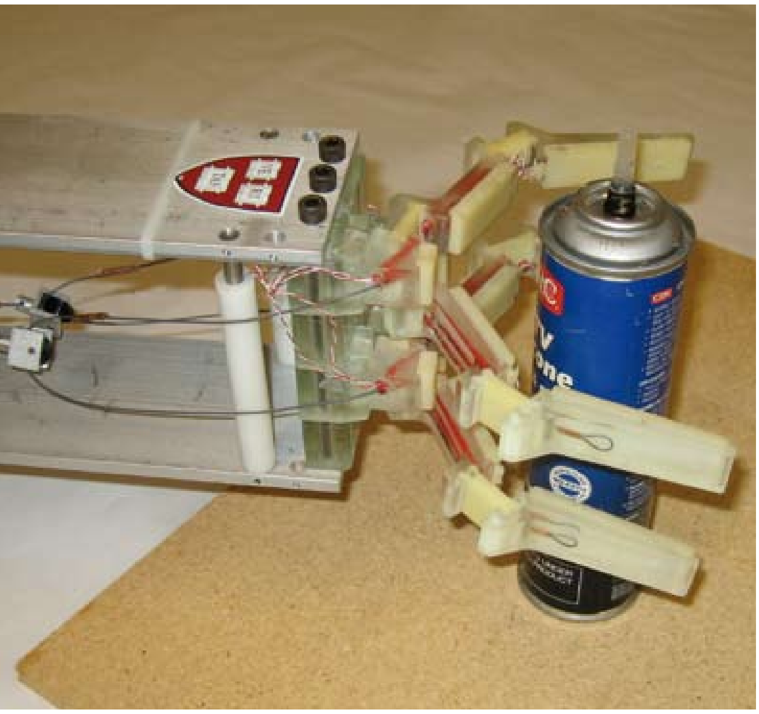

Figure 10. The one-piece, one-motor robot finger can be incorporated in a gripper.

Fingers

Another research subject is the design of a general purpose, robust robot hand, a simple gripper, having fingers each coming in one piece (combining hard plastic and soft rubber) with one motor; see Figure 10. Using Shape Deposition Manufacturing, which can alternate material deposition and machining, robot structures with compliant joints and embedded sensing and actuation elements can be produced. This contrasts with the anthropomorphic approach, which has been very popular, but to date primarily has yielded complex systems without much result. The design is now being commercialized by Barrett Technology; see below.

Whole Arm Manipulator

Barrett Technology, based in Cambridge, developed a highly dexterous, naturally backdrivable, haptic robot arm; see Figure 11. The WAM™ arm (Whole Arm Manipulator) has direct-drive capability supported by Transparent Dynamics™ between the motors and joints, using low-mass, high-tensile steel cables for transmission. Its design makes the control of contact forces robust – independent of mechanical force or torque sensors. The arm is available in two main configurations, having either 4 or 7 degrees of freedom, both with human-like kinematics. The joint ranges exceed those for conventional robotic arms. The redundancy of 7 instead of 6 degrees of freedom gives the arm's movements a natural "graceful" character instead of the conventional "robot jerkiness".

Figure 11. The WAM Arm demonstrating its skills. The arm on the left belongs to Barrett Technology founder and CEO, Bill Townsend.

Puck and Hand

The arm comes with the highest performance servo-electronics available in the world today, so Barrett Technology (now 15 employees) claims, referring to the so-called Puck™, an ultra-miniature brushless servo-electronics module that makes controller cabinets (internal or external to the arm) redundant. This Puck ("powerful universal controller") features ultra-low power consumption for safety and environmental benefit, as well as superior brushless-servo performance allowing applications such as force-field enabled medical surgery.

The WAM Arm can be equipped with a BarrettHand™, a low-weight, multi-fingered programmable grasper; see Figure 12. It has the dexterity to secure target objects of different sizes, shapes, and orientations. Of its three multi-jointed fingers, two have an extra degree of freedom with 180 degrees of synchronous lateral mobility supporting a large variety of grasp types. Because of its flexibility, a BarrettHand offers an attractive alternative to cheap parallel-jaw grippers, as these have to be custom-designed and require exchange during work for different tasks.

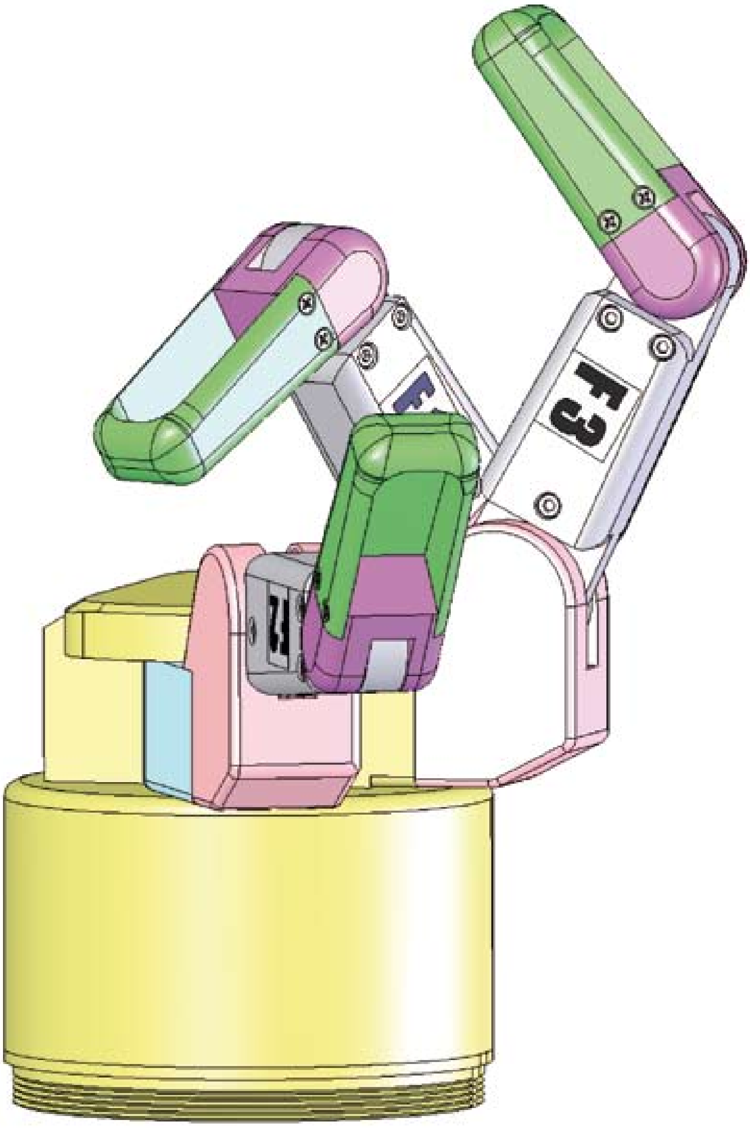

Figure 12. Design of the BarrettHand.
(Source: www.barrett.com/robot/products-hand.htm)

Up to now, Barrett's 100,000 US$+ robot arms are mainly used for research purposes, for example in the study of trends in emerging robotics applications and in understanding human/primate learning and motor control. Medical applications have also been developed, such as neuromuscular rehabilitation after stroke (at RIC), or providing assistance to a surgeon for improving knee-implant surgery (at Mako Surgical, Inc.).

Human-interactive mechatronics

Other companies consulted by the Dutch delegation, included Kinea Design, Intelligent Automation, Inc. (IAI), and AnthroTronix. Kinea Design, "innovators in human-interactive mechatronics", is based in Evanston, Illinois, and currently employs twelve people. As a design services firm collaborating with external engineering consultants and clinicians, they develop electro-mechanical devices, sensors, controls systems, haptic interfaces, and purely mechanical systems. A fine example of the Kinea design approach is the KineAssist™ for walking and balancing retraining of stroke survivors that was developed for RIC.

Arm Rehabilitation Machine

IAI, headquartered in Rockville, Maryland, counts over 120 researchers and technical staff, and primarily serves as a R&D provider to the US government, major first-tier (defense-related) integrators, as well as to commercial firms within the USA and abroad. One of their products is the Multi-Axis Cartesian-based Arm Rehabilitation Machine (MACARM), used for therapy on stroke survivors in RIC. The unique feature of the MACARM is that it can provide full six degrees of freedom control over the patient arm's trajectory and mechanical environment, and thus enables the application of virtually any conceivable movement or force pattern to the impaired limb.

Interface technology

Founded in 1999, AnthroTronix has been working since as an engineering research and development firm focused on optimizing the interaction between people and technology. AnthroTronix is specialized in the development of advanced interface technology, wearable computing and robotic control systems, and simulation tools for training applications. The company, located in Silver Spring, Maryland, currently employs twelve people and has commercial as well as governmental customers in the fields of defense, space, medical rehabilitation and education.

AnthroTronix's first commercial product is the AcceleGlove™ (or iGlove™) instrumented gesture recognition glove; see Figure 13. The iGlove is a low-cost gesture recognition system that can detect the individual motions of finger, hand, wrist, and arm. It may serve as a robot controller, using the natural movements of the operator's hand/arm as the input to control both the movement of a robot (such as an unmanned vehicle) itself, as well as the movement of ancillary devices such as grasping and lifting arms.

Figure 13. AnthroTronix's first commercial product, the AcceleGlove. (Source: www.mydigitallife.info)

Clusters

The trip offered various opportunities to meet with regional robotics clusters. One example is the Massachusetts Robotics Cluster, facilitated by the Mass Technology Leadership Council (MassTLC). In 2009, MassTLC published a report on the robotics industry in the region: "Achieving Global Leadership: A Roadmap for Robotics in Massachusetts". The analysis revealed the cluster to contain the largest concentration of robotics companies in the USA, counting some 80 enterprises, 2,500 people and 1 billion US$ annual sales. Success factors that were identified included the total of 11 universities featuring 14 robotics research groups as well as the first-ever undergraduate robotics engineering program (Worcester Polytechnic Institute), the entrepreneurship culture (including companies spinning out spin-outs) and the region's strength in industry, with health care, defense and manufacturing driving robotics development.

Quality of Life Technology

The Technology Collaborative (TTC) aims at accelerating digital & robotics innovation. It is based in Pittsburgh, Pennsylvania, home to the Southwest Pennsylvania Robotics Cluster, which is centered around Carnegie Mellon University's Robotics Institute, featuring 8 research centers, 44 labs, 500 people, and a 55 million US$ annual budget. The cluster includes some 40 robotics companies, well-established companies such as Bombardier and McKesson Automation Solutions, as well "second generation" companies such as Redzone, Interbots and MobileFusion.

A fine example of interdisciplinary collaboration within the cluster between researchers, industry partners, clinicians and users, can be found in the Quality of Life Technology (QoLT) Center, an initiative of Carnegie Mellon University and Pittsburgh University. The center's mission is to improve the quality of life of people with reduced functional capabilities due to ageing or disability. So-called compassionate intelligent QoLT systems (including robotic systems) will be designed to monitor and communicate with a person, understand his or her daily needs and tasks, and provide reliable and happily-accepted assistance by compensating and substituting for diminished capabilities.

Author's note

Hans van Eerden is a freelance text writer in Winterswijk, the Netherlands, and editor of Mikroniek. At the invitation of Romech he participated in the trip to the USA. Photos without statement of source were taken by participants Bianca Screever, Stefano Stramigioli and Hans van Eerden.

Information

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