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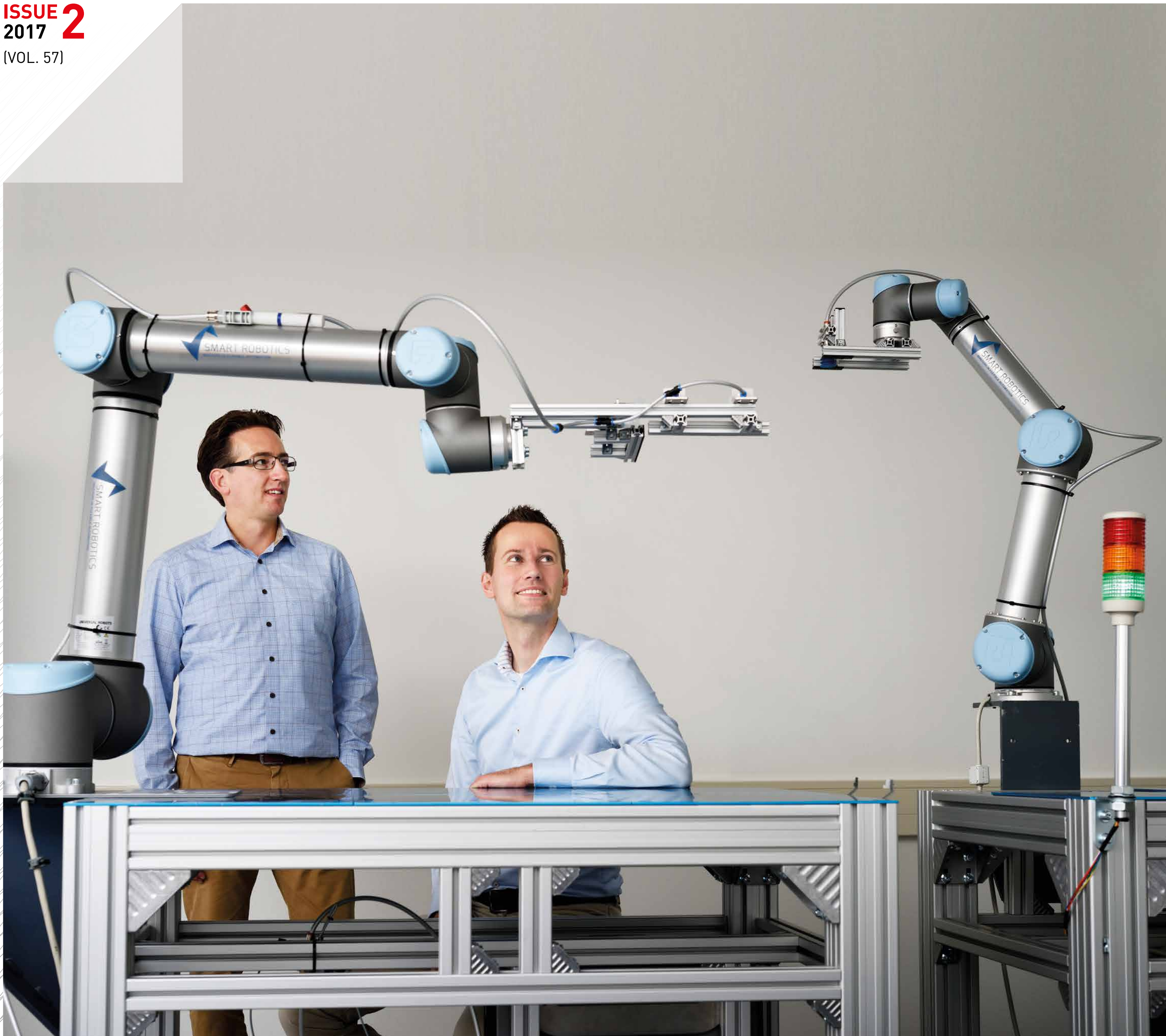
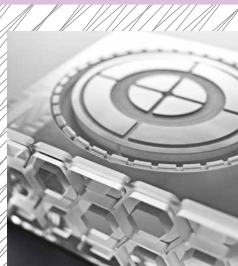


- THEME: **(SOFT) ROBOTICS**
- PRECISION IN **GLASS AND CERAMICS**
- **MAGNETIC** VIBRATION ISOLATION
- DEMOWEEK 2017: **THAT'S HOW YOU MAKE IT**

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The main cover photo (featuring the Smart Robotics founders, Mark Menting (left) and Heico Sandee) is courtesy of Bart van Overbeeke. Read the article on page 18 ff.

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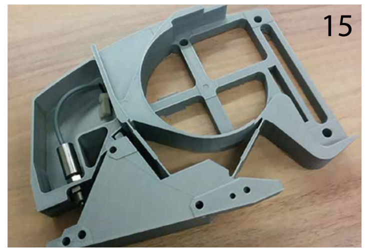

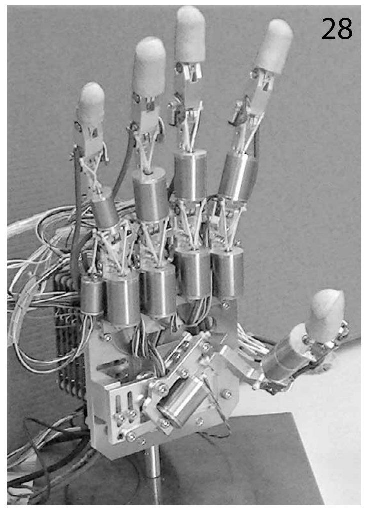

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DUTCH ROBOTICS

Robotics is hot... again. Over the past years, it has been hot, and then not. A lot has happened since a first series of Unimate robots were deployed at a General Motors factory in 1961. Even before, robots were described and created, and in 1941 Isaac Asimov published his three laws to ensure autonomous robots would not harm human beings. We have seen robots massively deployed in manufacturing, for increasingly more advanced tasks. Recently, the aspect of autonomy has been given more attention, leading to more advanced robots on the one hand, and to societal discussions on the aspect of robots taking over our jobs on the other. In addition to supplementing our human abilities in physical labour and dexterity, now also our cognitive and mental skills are at risk of becoming supplemented by autonomous robotic systems.

Most of the recent hot news on robotics does not come from the Netherlands; although we do have good examples of robotics technology, we're not a leader in the field at the moment. That being said, we do have a lot of ingredients and a historical basis to play a significant role in robotics.

One of these ingredients is the long standing tradition in advanced technology. A variety of Dutch companies like DAF, Philips, Stork and Océ in the past century have laid a foundation of advanced technologies for products and production; technologies that are still relevant and world leading. At the same time, a basis was created at the universities (of technology) to support the industrial activities with more advanced technologies.

Automation has been a vital part of Dutch industrial activities, and in the case of precision engineering it has been an inspiration for research as well. Professor Wim van der Hoek has based his expertise and research in precision engineering on industrial automation within Philips. Dutch precision engineering has not evolved out of watch making or optics, but rather out of relentless industrial automation: increasingly accurate and faster machines, to economically manufacture more and more advanced products – the pinnacle of this development being ASML.

Over the years, companies like ASML, together with the technology institutes and their suppliers, have developed a system approach to master the design of the very complex (automation) equipment. It is a rare combination of a collection of technical skill sets, a model-based engineering approach rooted in feedback control systems (also known as mechatronics) and a mental and interpersonal attitude to challenge and aim for understanding.

The combination of automation equipment design, precision engineering and a unique system approach gives us a strong position, even internationally. We understand the application of advanced robotics in the (further) automation of manufacturing processes, we have the precision engineering capabilities required for highly advanced robotic systems and, last but not least, we have our unique approach to system design, which suits well the field of advanced robotics. However, in order to also develop intelligent and autonomous robotics, we have to further integrate disciplines such as machine learning and artificial intelligence into our system design capabilities. This integration will only happen properly if it is driven by (local) OEMs which aim for intelligent robotic products.

So, it is time to seriously start working on our next pinnacle in autonomous robotic technologies.

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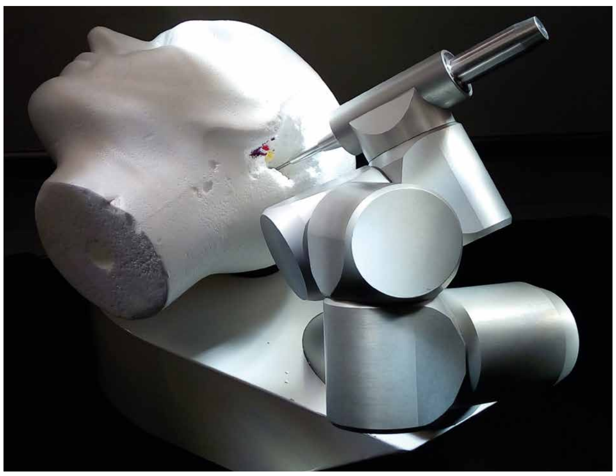
ADDING ROBOTICS SKILLS FOR REMOVING BONE

A new surgical robot, aptly named RoBoSculpt (Robotic Bone Sculpturer), which in fact is an advanced seven-axis milling robotic arm, can assist surgeons during complex bone removal procedures to potentially help more patients with better outcomes. The robot is being developed for compactness, precision and stability under load. It has a modular serial kinematic design and can use images to work autonomously. Currently, the first prototype is being built and first pre-clinical tests are scheduled in the Radboudumc in Nijmegen, the Netherlands, this year.

JORDAN BOS



We are all getting older and excessively loud sounds in daily life cause noise trauma in an increasing number of individuals. It is therefore not surprising to learn that the incidence of deafness is rising. The WHO estimates that 360 million men and women, including 32 million children, suffer from a disabling hearing loss [1]. The main reason is the loss of hearing functionality of the inner ear, the 'cochlea'.

The estimate is that only one in ten persons with severe to profound hearing loss can currently be helped with surgery [1]. One of the issues which might be solved using RoBoSculpt, is the limited number of surgical experts who can perform the complex hearing restoration procedures. RoBoSculpt can also aid in locating benign and malignant tumours in the ear and head region more effectively, as this usually involves extensive and time-consuming surgery.

The new RoBoSculpt surgical robot, which is patented and currently being developed at the Eindhoven University of Technology (TU/e), can aid surgeons to reduce risks, reduce invasiveness and reduce surgery time in the future. The aim is for RoBoSculpt to enable more surgeons to perform these crucial procedures and thus more patients can be helped with potentially better outcomes. The robot is in fact an advanced seven-axis computer numerical controlled (CNC) milling robot, which can use images to work autonomously.

This project was initiated when ENT (ear, nose and throat) surgeon Dirk Kunst from the Radboudumc Nijmegen, the Radboud university medical center, asked for help from the Control Systems Technology Group of Prof. Maarten Steinbuch at the TU/e. This group, already known for the development of the SOFIE [2], Preceyes [3] [4] [5] and MicroSure [6] [7] surgical robots, accepted the challenge via a Ph.D. project.

Medical problem

Procedures in the ear area for cancer removal, hearing restoration or infection removal often require bone to be physically removed with submillimeter accuracy within millimeters of critical structures. Currently, razor-sharp spherical drill bits, rotating with speeds up to 80,000 rpm, are used to remove this bone. The surgeon manually steers this drill bit while looking through a microscope. However, all structures are hidden in the bone and only become visible when structures are almost touched by the drill bit. Critical structures include the nerves responsible for facial expression and taste, a vein, an artery, the hearing and balance organs. If the surgeon hits the facial nerve, for

AUTHOR'S NOTE

Jordan Bos graduated cum laude in Mechanical Engineering at the Eindhoven University of Technology (TU/e), the Netherlands, and won multiple prizes for his graduation project. He started his Ph.D. project on RoBoSculpt in the Control Systems Technology group at the TU/e in 2013.

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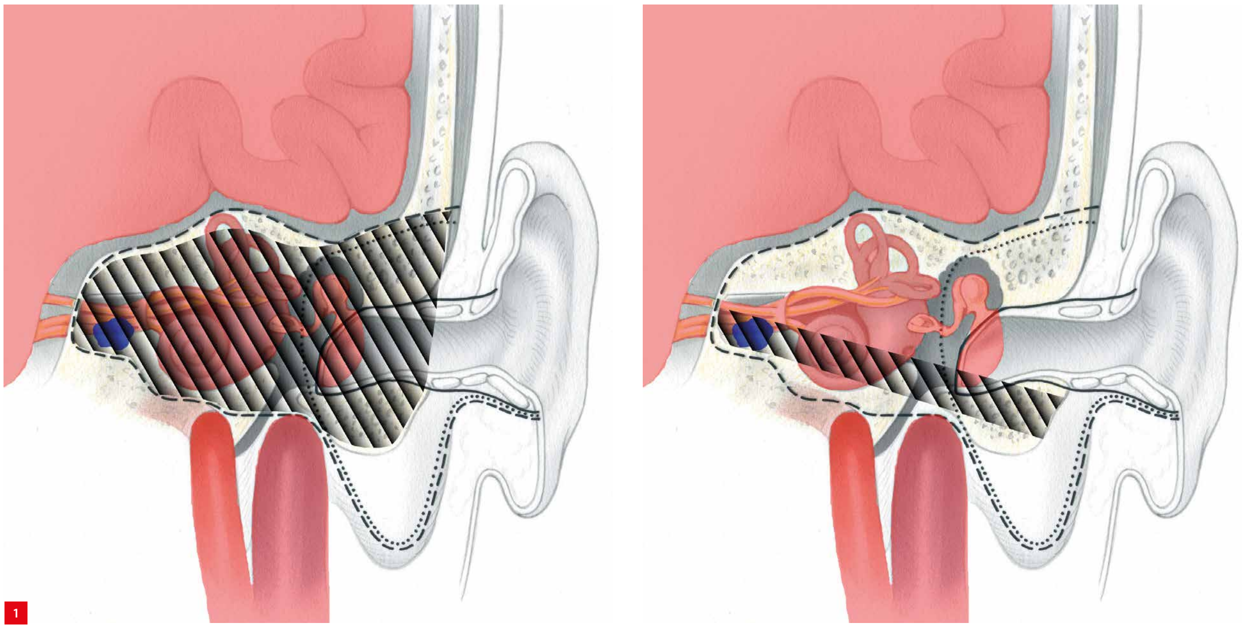
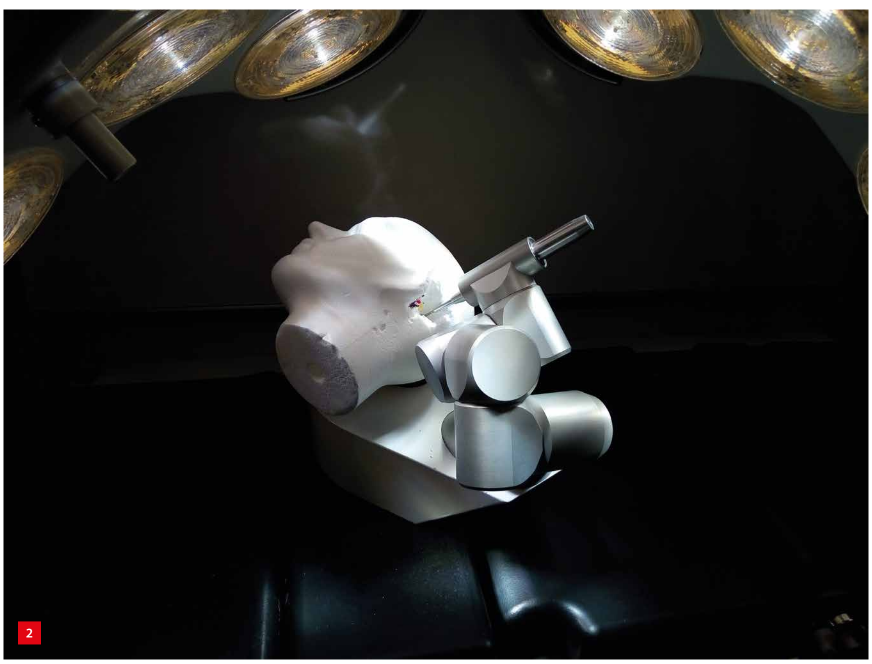


1 *A cross-section of the human ear. All vital structures are visible in red and a tumour is shown in blue. The striped pattern shows a 2D surface of bone milled away in current surgery (left) and the bone removal which could suffice with the help of RoBoSculpt (right).*

example, this can result in the permanent paralysis of half a face.

Surgeons currently do have access to CT and/or MRI data from a patient to plan the procedure. However, they cannot optimally map this information to the patient lying on the operating table. As a result, surgeons often have to remove an excessive amount of bone to explore the target, which can take up to six hours. An example is shown in Figure 1.

The solution seems simple: use a compact surgical robot, the medical equivalent of a CNC milling machine, which has high stability, guarantees accuracy, and can efficiently use existing Computed Tomography (CT) and/or Magnetic Resonance Imaging (MRI) data. An accurate 3D patient-specific map can be made from the location of all structures using image processing software. By connecting the patient to the robot with high stiffness and stability, it is possible to directly and accurately move towards the target with the potential of lower risks and shorter surgery time.



2 *The RoBoSculpt surgical robot from the TU/e is the medical equivalent of an advanced and compact seven-axis CNC-milling machine*

However, a robot which satisfies the demands cannot be found on the market yet. Furthermore, existing surgical robots such as MicroSure and Preceyes cannot be used, since they are not designed to withstand the relative high drilling and milling forces. Moreover, Preceyes and MicroSure are primarily focused on steering by the surgeon using a joystick; human motions are scaled and tremor is filtered. The biggest gains can, however, be achieved when a robot can remove bone autonomously with the surgeon still acting as supervisor. We aim to realise this with RoBoSculpt, from which the mock-up is visible in Figure 2.

Mechanical design

A schematic view of RoBoSculpt is shown in Figure 3. RoBoSculpt has seven degrees of freedom (DoFs) and fits inside a box measuring 160 x 180 x 200 mm^3. The mass is approx. 10 kg and the working volume of the robot is an ellipsoid with radii of 300 and 500 mm. The robot is designed to withstand forces up to 50 N. RoBoSculpt is designed for a repeatability of 50 μm. Besides precision, the robot is designed for human-robot interaction, safety and robustness.

In the remainder of this section, the design of RoBoSculpt will be discussed in a limited amount of detail. There are two reasons for this: 1) the patent portfolio is currently under expansion; 2) the Ph.D. thesis, which will be available at the end of this year, will be the first publication to present more detailed information.

IXI-PLAY, A SMART ROBOT COMPANION FOR KIDS

Robots are expected to change the world in the near future, but building a smart and agile robot appears to be a serious challenge. Due to the fast development of affordable electronics, the expectations are high, not only technology-wise, but also cost-wise. This article describes an attempt to develop and build a high-tech robot for consumer applications, showing the challenges and difficulties along the way.

BART DIRKX AND RUUD VAN DER AALST

AUTHORS' NOTE

Bart Dirkx and Ruud van der Aalst are the founders of WittyWorX, established in 2011. Their first product is IXI-Play, a robot companion for young kids. Currently, WittyWorX is operating as an engineering and project management service company.
The authors wish to acknowledge the support of TMC, Sioux Vietnam, TU/e, University of Twente, TU Delft, Leiden University, Fontys, KU Leuven, Avans, Gebrema, FabLab Eindhoven, Korein, Hurli and SensoRon.

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Introduction

There is no doubt that robots are getting more and more interest. This is fueled by rapid technological development of robots and applications. In industry, robots have been successfully applied for a long time. In consumer applications however, only few robots have made ground so far. The main reason for this is that expectations are high, predominantly caused by the rapid development of cheap electronics and applications. Also, the film industry has made people to believe that robots are smart, sometimes even smarter than humans. The current reality however is that robots are expensive, clumsy and all but smart, even the most advanced.

Developing a useful robot is hard. Robots have to deal with real-world, physical applications. They have to sense the environment around them, classify and do something with that. This is much more complicated than virtual or screen applications where all of the environment is known beforehand and anything is possible. Even when a robot is correct most of the time, this is not enough to be convincing. Besides that, because robots have actuators, they tend to be expensive, especially when industrial-grade motors are used. IXI-Play is an attempt to develop a consumer robot that is both advanced and affordable.

Motors and gears

DC motors have many advantages. Therefore, it is no surprise that they are the most commonly used actuators around. DC motors are low-cost, powerful, and easy to control, but for robotic applications they have a few drawbacks. DC motors have maximum torque and efficiency at low rpm. However, to be able to deliver full power, they need to run at high rpm, typically half of their maximum speed. Robotic applications, however, typically require maximum power at low rpm.

To be able to also deliver high power at low speeds, often a gear box needs to be installed. This comes at a cost. Not only is a gear box expensive, in many cases as expensive as the motor itself, it also ruins dynamic performance. Gear boxes add backlash, noise and poor backdriveability. Preferably a low gear ratio is chosen, but this results in a large motor-gear combination. Many consumer robots are built using RC servo motors. These motors are a good example of high noise and poor dynamics, yet low cost.

Stepper motors have relatively high torque, but a more limited range than DC motors because their torque reduces quickly at higher speeds. They are also much heavier, bulkier and more expensive. A big advantage of stepper motors is that they can be used in open loop without losing position as long as the load is not too high. These motors are often seen in 3D printing applications.

Elliptec piezo motors

Piezo motors are known for their high accuracy and strength, but also high cost. One exception are the piezo motors from Elliptec. Because they use only one piezo, they can be produced at relatively low cost.

Advantages:

- Silent (operating frequency > human hearing frequency)
- High dynamics: < 100 μs response time
- Fast: 300 mm/s
- Compact and lightweight: 25 x 8 x 3 mm^3, 1.2 g
- Friction coupling (1 N)
- Suitable for both linear and rotary applications

Disadvantages:

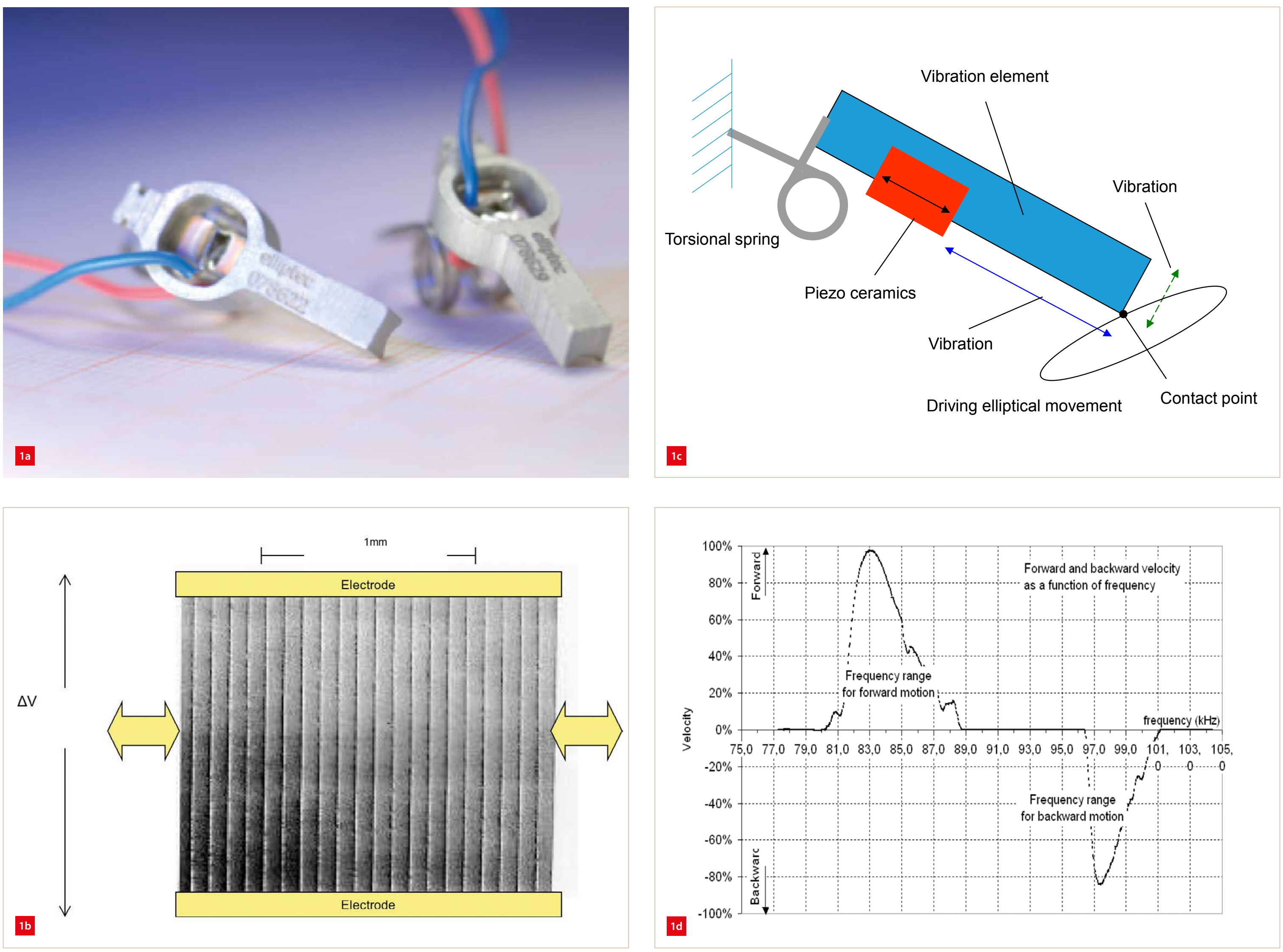
- Limited force (0.2 N)
- Hard to control
- More expensive than DC motors

Because of their properties, Elliptec motors (Figure 1) were chosen for IXI-Play.

Mechanism

To be able to provide a full set of motions, a 6-DoF parallel manipulator (DoF = degree of freedom), better known as Gough-Stewart platform (en.wikipedia.org/wiki/Stewart_platform) or hexapod, was chosen (Figure 2). This platform is statically determined, meaning that all motors can work in parallel without crosstalk. The challenge was to make this platform as compact as possible to keep the base of the robot small.

The first step was to transfer the linear motion of the Elliptec motor into a rotary motion and at the same time add a small transmission ratio to increase the applied force. For this a crankshaft mechanism was chosen. By putting the pushrod closer to the centre of the wheel the piezo motor force geared up to 0.3 N in zero position. When the wheel is rotated, the crankshaft mechanism increases the gear ratio up until the Top Dead Centre (TDC). At this point the gear ratio is infinite and vertical movement zero. This is also the case for the Bottom Dead Centre (BDC). Figure 3 shows the force diagram for an alternating constant wheel rotation giving a simple 0.5 Hz *Z*-movement.



1 The Elliptec piezo motor (Source: Elliptec)
(a) Physical appearance.
(b) The stacked piezo element, needed for driving the motor at 5 V.
(c) Motor principle: the piezo brings the motor in its eigenfrequency causing the tip to make an elliptic movement, which pushes the counterpart forward in the lower part and moves it back in the upper part of the ellipse.
(d) Forward motion is generated by triggering the first eigenfrequency (83 kHz), backward motion is triggered at 97 kHz. Speed is controlled by amplitude control.