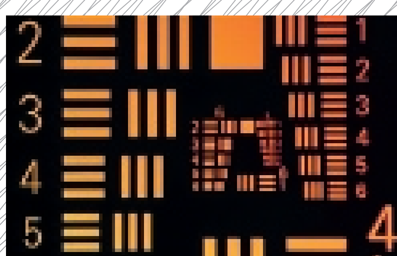
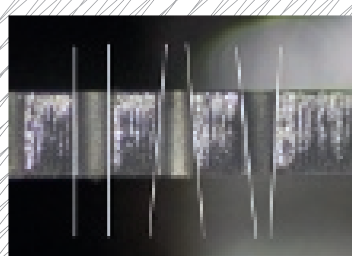
PROFESSIONAL JOURNAL ON PRECISION ENGINEERING

μ MIKRONIEK

ISSUE 6
2015
(VOL. 55)

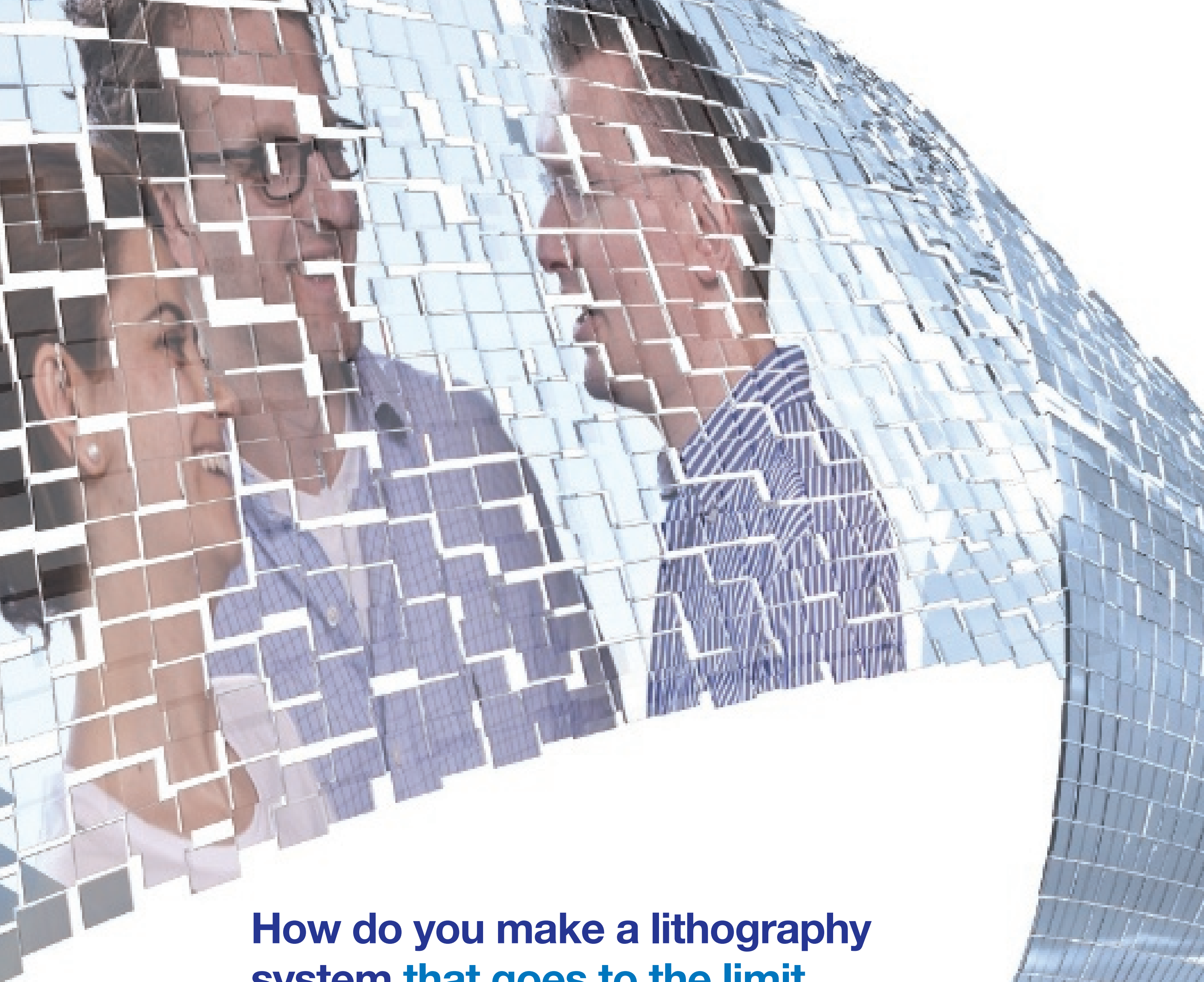
- THEME: **ROBOTICS**
- **LASER-BASED** ULTRA PRECISION PRODUCTION
- **PRECISION FAIR** REPORT
- **MULTI-METAL** PRINTERS
- CLEANING





Mikroniek is a publication of the DUTCH SOCIETY FOR PRECISION ENGINEERING www.dspe.nl

DSPE



PUBLICATION INFORMATION

Objective
Professional journal on precision engineering and the official organ of DSPE, the Dutch Society for Precision Engineering. Mikroniek provides current information about scientific, technical and business developments in the fields of precision engineering, mechatronics and optics.
The journal is read by researchers and professionals in charge of the development and realisation of advanced precision machinery.

60th anniversary DSPE YOUR PRECISION PORTAL

Publisher
DSPE
High Tech Campus 1, 5656 AE Eindhoven
PO Box 80036, 5600 JW Eindhoven
info@dspe.nl, www.dspe.nl

Editor
Hans van Eerden, hans.vaneerden@dspe.nl

Advertising canvasser
Gerrit Kulsdom, Sales & Services
+31 (0)229 – 211 211, gerrit@salesandservices.nl

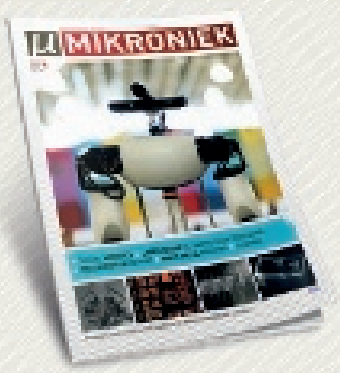
Design and realisation
Twin Media, Culemborg
+31 (0)345 – 470 500, info@twinmediabv.nl

Subscription costs

The Netherlands	€ 70.00 (excl. VAT) per year
Europe	€ 80.00 (excl. VAT) per year
Outside Europe	€ 70.00 + postage (excl. VAT) per year

Mikroniek appears six times a year.

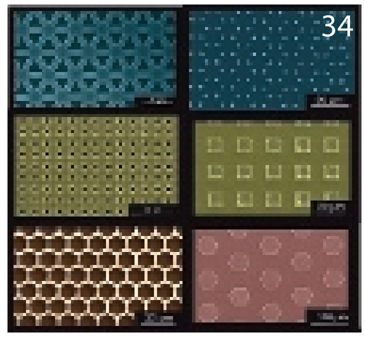
ISSN 0026-3699



The main cover photo (featuring the Amigo home robot of Eindhoven University of Technology) is courtesy of Bart van Overbeeke. Read the editorial on page 4.

IN THIS ISSUE

ISSUE 6
2015



FEATURES

THE ART OF ROBOT DESIGN?

The field of robotics is developing at a rapid pace. Looking at the developments covered in this issue of Mikroniek, it is fascinating to see how varied the views on robot development can be. The EUrobotics Roadmap and the Strategic Research Agenda also provide a fantastic insight into the latest trends and the evolution in requirements and the availability/readiness of specific technologies.

The number of disciplines involved is also increasing rapidly, and as an engineer I will soon experience the limits of pure engineering skills. Engineers in mechanics, electronics, mechatronics and software are trained to design products properly, but the more human-robot interaction is involved, the more difficult it will become to design the right robot to fulfil the written, and even the unwritten, requirements. Tablet- or PDA-like examples of accepted robot products are still very rare.

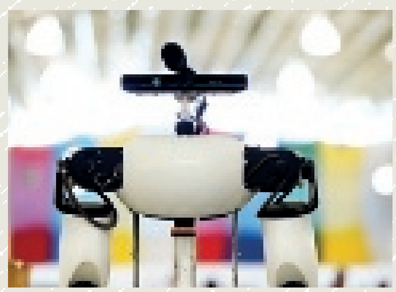
I've had good experiences in industry in the past when working with industrial designers and with health technology engineers, both trained in extracting the required functionalities from real-life situations and validating them when testing the product. The discussion between all the engineering and design disciplines and potential users is a very interesting one to set up and resolve successfully. It may not be an easy task, but the need for it is becoming clearer by the day.

Although a lot of technology is available, engineering and working processes in development are still a point of interest. Systems engineering as a way of structuring thoughts on engineering and development processes without adjusting its potential rigidity will help to accelerate innovation in multidisciplinary and multi-party development and engineering projects. Given the lack of hierarchy in the Netherlands and the ease with which we adopt the expertise we lack ourselves, we are in a potentially strong position in the Netherlands for these types of processes. On the other hand, we Dutch also tend to find things less interesting when feasibility has been proven.

At Avans University of Applied Sciences, we will include communication and multimedia design plus healthcare specialists in our robotic applied research projects so that we can translate human-robot interaction into engineering requirements and also be able to validate them later on. I expect this to be a fruitful cooperation. We will also involve the Avans Art Academy to amplify or over-exaggerate specific thoughts/restrictions/concepts in order to make the engineers and society as a whole more aware of the effects of robotics and what we expect from them. In this way, we hope to get a better understanding of how to design excellent robots that will indeed fulfil societal requirements.

The art of robot design – design a robot with the help of art!

Jos Gunsing,
Professor of Robotics & Mechatronics at Avans University of Applied Sciences,
founder/owner of MaromeTech, a technology & innovation support provider



When human-robot interaction can be controlled satisfactorily, the robot can enter the home environment.
Here, the Amigo home robot of Eindhoven University of Technology at the RoboCup in Brazil, 2014. (Photo: Bart van Overbeeke)

DEALING WITH DEFORMABLE PARTS

The robotised assembly of products that contain deformable parts is especially challenging, since the robot interactions with the deformable parts have to be controlled in addition to the robot motions. We investigate the feasibility of a robotised system for automated mounting of flexible rubber seals onto solid objects, such as car doors or windows. The key is in using models to understand and clarify the deformation physics, which facilitates the selection of a robot system and tools, and the design of motion and interaction control algorithms for the robot.

DRAGAN KOSTIĆ, BART BASTINGS, PATRICK SMULDERS AND HENK NIJMEIJER

Introduction

Development of mechatronics systems featuring interaction of controlled processes is one of the priorities of Segula Technologies Netherlands. Examples are control of motion, temperature, force, pressure, contamination, humidity, etc. These examples are relevant in many industries and different applications including production automation.

A particular problem of interest is robotised assembly of complex products. Instead of human workers, robots perform grasping and manipulation of the product parts during their assembly. If besides rigid parts, also deformable parts have to be manipulated and assembled, the robot has to control interactions and motions with the deformable objects. A need for interaction control makes production automation even more challenging and demands advanced solutions. This problem is especially relevant in the smart industry context of production automation using advanced robotics [1].

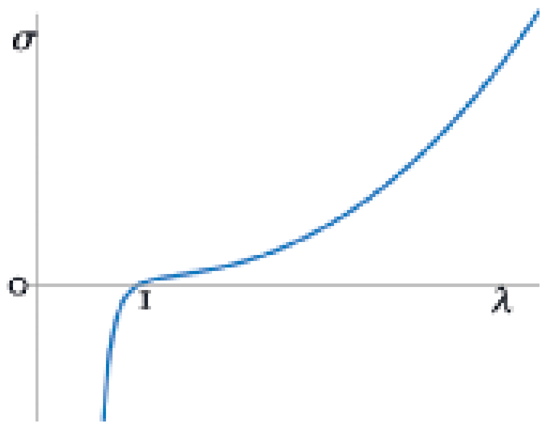
A specific application is the mounting of flexible rubber seals onto 3D-curved edges of solid objects, such as doors or windows in cars. Currently, this sealing activity is carried out manually by highly skilled workers who need to pass a special training. Since only a few workers are skilled enough for such delicate manual manipulations under pressing time constraints, the throughput of a complete production line is very much sensitive to the availability and efficiency of the skilled workers.

AUTHORS' NOTE

Dragan Kostić (mechatronics architect), Bart Bastings (mechatronics engineer) and Patrick Smulders (director of system architecture) work for Segula Technologies Netherlands, based in Eindhoven. Prof. Henk Nijmeijer is the head of the Dynamics and Control group in the Department of Mechanical Engineering at Eindhoven University of Technology.

dragan.kostic@segula.nl
www.segula.nl
www.tue.nl

Furthermore, since even the most skilled workers do not have identical mounting skills and each one of them can make mistakes during the sealing, the assembled products have recurring issues in terms of non-uniform sealing accuracy and aesthetic inconsistencies.
Consequently, there is a need to improve the process of sealing which will uniformly guarantee the desired product quality and the required throughput. A potential solution is



1 *Typical hyperelastic stress-stretch behaviour of a rubber.*

to develop a robotised system that, instead of human workers, mounts the seals onto different products. The key drivers for the automatic sealing are the throughput increase, uniform product quality, and reduction of production costs.

The feasibility of a robotised sealing system is investigated. The key is in using models to understand the physics of deformation of the rubber seals. That knowledge is instructive for an optimal choice of the robot system and tools needed to perform the sealing. Furthermore, these models greatly facilitate the design of motion and interaction control algorithms for the robot.

First, several phases of modelling a representative rubber seal, the so-called weatherstrip, are explained. After that, a model-based control design of the motion/interaction robot controllers is addressed. Quality of the control design is illustrated by servo-control simulations of the sealing process performed by an industrial robot arm. Finally, the conclusions and future perspectives are presented.

Weatherstrip modelling

Rubber shows some specific behaviour as compared to more common engineering materials such as metals, ceramics or fibre composites. Hence, it is necessary to have a good understanding of effects inherent to the rubber materials that are relevant for the sealing process. These aspects are embedded in a model which can be used for robot control design and servo-control simulations of the sealing process performed by the robot.

Hyperelasticity

The elastic stress-stretch response of rubber can be nonlinear and may cover very large deformations. A typical nonlinear elastic stress-stretch response of a rubber is shown in Figure 1. In this figure, λ and σ denote the stretch ratio and the stress, respectively. In the one-dimensional case of a rubber strip with nominal length L_0, λ is the ratio between the deformed length L of that strip and L_0:

$$\lambda = \frac{L}{L_0} \tag{1}$$

Unlike metals or ceramics, rubbers show elastic behaviour for large stretch ratios (even $\lambda > 5$), which is called hyperelasticity. There are different methods available for modelling hyperelastic materials. An overview of different hyperelastic models can be found in [2]. In principle, it is more challenging to model behaviour of hyperelastic than of linear elastic materials.

To model the hyperelastic behaviour of a rubber strip, we use a strain energy function $W(\lambda)$. The particular form of this function depends on the type of hyperelastic model chosen to describe elastic behaviour of a given strip. The function $W(\lambda)$ is used to calculate the stress σ in the material:

$$\sigma = \frac{dW}{d\lambda}\lambda \tag{2}$$

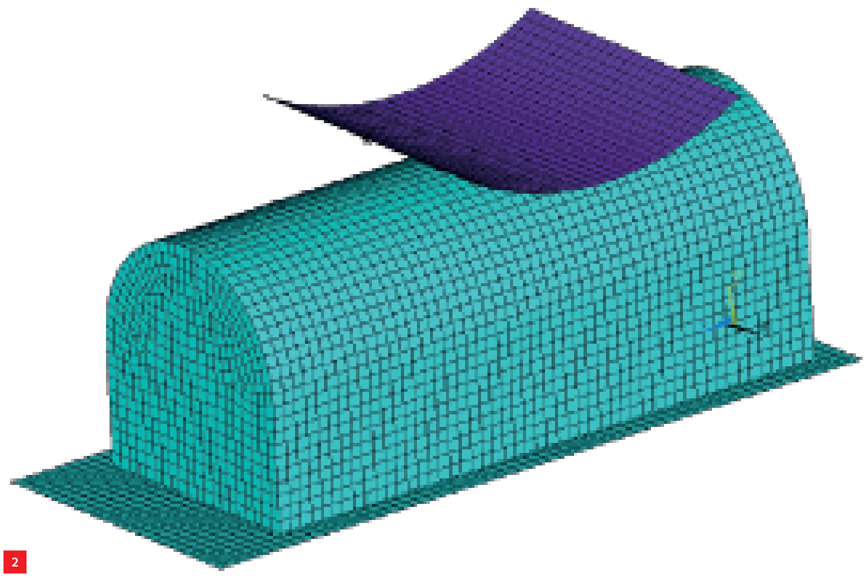
We use a three-term Ogden model [2] since it nicely captures hyperelastic behaviour of rubber strips:

$$W = \sum_{i=1}^{3} \frac{\mu_i}{\alpha_i}\left(\lambda_1^{\alpha_i} + \lambda_2^{\alpha_i} + \lambda_3^{\alpha_i} - 3\right) \tag{3}$$

Here, μ_i and α_i are the material parameters and λ_1, λ_2, λ_3 are the stretch ratios in the principal directions. As a case study, we consider the material parameters that are taken from [3]. In practice, these parameters have to be measured on a physical weatherstrip since they depend on the specific rubber composition. Since the model (3) is a multivariable function of the stretch ratios, calculation of the stress in not that straightforward as in the one-dimensional case (1),(2). More details on the stress calculations for the multivariable strain energy functions can be found in [4].

Finite-element model

Modelling of the weatherstrip is carried out to obtain a deeper understanding of the physics of the deformation but also to specify and sharpen the requirements on a robotic system that should perform the sealing. To analyse the deformation physics, we create a finite-element model of the weatherstrip using FEM software package ANSYS [5]. The strain energy function (3) is used in this model. The geometry and finite-element mesh of the weatherstrip are shown in Figure 2. The purple cylindrical part on the top of the weatherstrip belongs to an applicator wheel, which applies pressure onto the weatherstrip during its mounting on a solid surface.



2

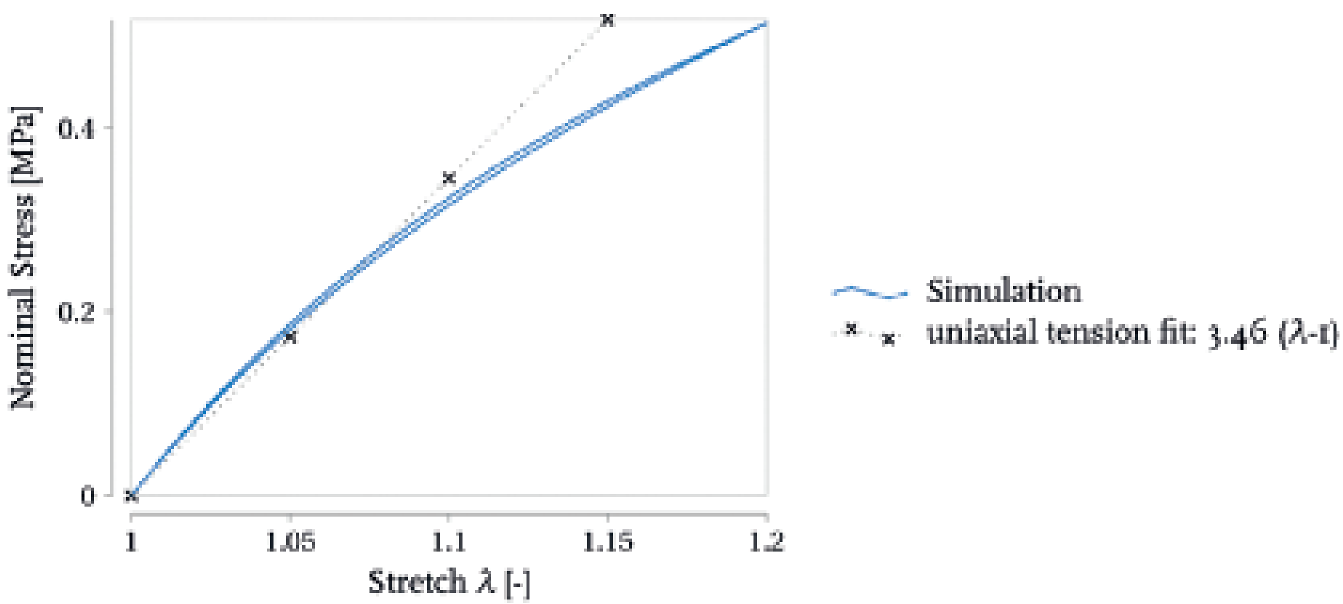
Although the FEM model is suitable for analysis of the elastic behaviour, it is less practical for engineering the requirements on the robot, because of its low compatibility with common tools for robot modelling, control design, and simulation, such as Matlab/Simulink [6]. That is why we need to convert the FEM model into a computationally advantageous linear state-space representation that can be used to make the optimal choice for the robotic system, design the robot controllers and perform servo-control simulations in Matlab/Simulink.

2 *Geometry and finite-element mesh of the weatherstrip.*
3 *Simulation of uni-axial tension.*

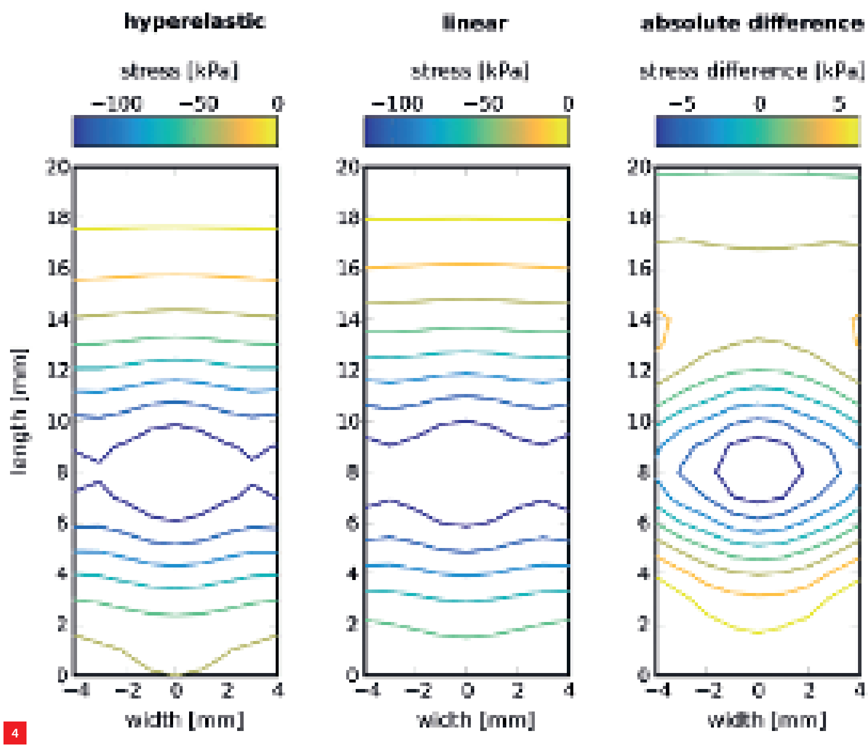
To create a linear state-space model, we need to linearise the hyperelastic FEM model first. This can be done by linearising the material behaviour about $\lambda = 1$. In Figure 3, we show the stress-stretch relationships computed with the hyperelastic FEM model (blue line) and with the corresponding linear model (dotted line). One can observe that for a small stretch ratio ($\lambda < 1.1$), the hyperelastic material behaviour can be quite well approximated by the linear model. Since in industrial practice, during the sealing only small elastic deformations of a weatherstrip are allowed, it is justified to use the resulting linear FEM model.

State-space model

From the linear FEM model, we export the mass and stiffness matrices into Matlab to create the corresponding state-space model. This model is of a high order (around 3,500), which is not adequate for time-efficient simulations in Matlab. Hence, an order reduction of the state-space model is carried out using the balanced truncation method, as described in [7]. The resulting state-space model has 250 states and around 220 inputs and 290 outputs that are needed for interaction with the environment, in particular, to model contacts of the weatherstrip with the solid surface and with the applicator wheel. The order of the resulting model mainly depends on the specific geometry of the weatherstrip. Hence, any other weatherstrip geometry may require a customised model reduction.



3



4 Comparison between the hyperelastic FEM and linear state-space models of the weatherstrip.

In Figure 4, the hyperelastic FEM model of the rubber strip is compared in simulation with the reduced state-space model. The first two subfigures show the pressure distributions at the bottom of the strip, over the contact surface with the solid object, resulting from the pressure of the applicator wheel on the top of the strip. Since only small absolute differences between the two pressure distributions can be observed on the right-hand side in Figure 4, we can conclude that both models are in good agreement. Hence, the reduced order linear state-space model can be used for control design and servo-control simulations in Matlab.

Control design

When the robot is mounting the weatherstrip, it has to exert a certain force onto the applicator wheel to achieve the desired pressure at the bottom of the strip. In order to measure the exerted force for the sake of servo control, the robot has to be equipped with a force gauge. For robot control, we use a standard hybrid impedance controller from [8], since it allows simultaneous regulation of the motion of the applicator wheel and of the force the applicator exerts on the weatherstrip during the mounting.

For convenience, we explain this controller here in short terms. For a standard industrial robot arm with six actuated joints, joint motions can be described by a 6-dimensional column vector $\boldsymbol{q}$. The motion of the robot end-effector that manipulates the applicator wheel can also be described by a 6-dimensional column vector $\boldsymbol{X}$ which contains three Cartesian and three angular coordinates of the end-effector in the task space of the robot. Acceleration $\ddot{\boldsymbol{X}}$ of the end-effector is related with the joint motions $\boldsymbol{q}$, speeds $\dot{\boldsymbol{q}}$, and accelerations $\ddot{\boldsymbol{q}}$ as follows:

$$\ddot{\boldsymbol{X}} = \boldsymbol{J}(\boldsymbol{q})\ddot{\boldsymbol{q}} + \dot{\boldsymbol{J}}(\boldsymbol{q})\dot{\boldsymbol{q}} \tag{4}$$

Here, $\boldsymbol{J}$ is the Jacobian matrix and $\dot{\boldsymbol{J}}$ is the time-derivative of this matrix.

During the weatherstrip mounting, the robot end-effector is in stiff contact with the applicator wheel of mass m_w, while the applicator has a force interaction with the weatherstrip. Dynamics of the robot during that interaction can be described by the following model [8]:

$$\boldsymbol{M}(\boldsymbol{q})\ddot{\boldsymbol{q}} + \boldsymbol{h}(\boldsymbol{q},\dot{\boldsymbol{q}}) + \boldsymbol{J}^T(\boldsymbol{q})\boldsymbol{F}_e = \boldsymbol{u} \tag{5}$$

Here $\boldsymbol{M}$ is a 6 x 6 inertia matrix, $\boldsymbol{h}$ describes centripetal/Coriolis, gravity and friction effects, $\boldsymbol{F}_e$ represents interaction forces between the end-effector and the environment that are measured by the force gauge, and $\boldsymbol{u}$ contains control torques/forces that actuate the robot joints; variables $\boldsymbol{h}$, $\boldsymbol{F}_e$, and $\boldsymbol{u}$ are 6-dimensional column vectors.

The actual geometry of a solid object to be sealed and its position relative to the robot determine Cartesian directions along which the force interaction between the applicator wheel and the weatherstrip should occur. The objective of the hybrid impedance control is to regulate the interaction forces along those Cartesian directions and motions of the end-effector along the remaining coordinates of $\boldsymbol{X}$. That is achieved by appropriate control of the end-effector acceleration vector $\ddot{\boldsymbol{X}}$:

$$\ddot{\boldsymbol{X}} = \boldsymbol{a}_x \tag{6}$$

where $\boldsymbol{a}_x$ is a 6-dimensional column vector of control laws for force and motion directions of the end-effector.

The hybrid impedance controller has the form:

$$\boldsymbol{u} = \boldsymbol{M}(\boldsymbol{q})\left[\boldsymbol{J}^{-1}(\boldsymbol{q})\left(\boldsymbol{a}_x - \dot{\boldsymbol{J}}(\boldsymbol{q})\dot{\boldsymbol{q}}\right)\right] + \boldsymbol{h}(\boldsymbol{q},\dot{\boldsymbol{q}}) + \boldsymbol{J}^T(\boldsymbol{q})\boldsymbol{F}_e \tag{7}$$

Denote by x_i and $a_{x,i}$ the i-th component of vectors $\boldsymbol{X}$ and $\boldsymbol{a}_x$, respectively, where $i \in \{1, ..., 6\}$. Then, force control along the desired Cartesian directions is achieved by means of the following control law:

$$a_{x,i} = \frac{m_w}{m_{d,i}}\left(F_{r,i} - F_{e,i}\right) - \frac{m_w}{m_{d,i}} b_{d,i}\dot{x}_i \tag{8}$$

5 *Simulated case-study: a weatherstrip subject to the pressure from the applicator wheel.*
6 *A piece of the weatherstrip sealed on a solid surface with a bump.*

Here, $F_{r,i}$ and $F_{e,i}$ are the setpoint and measured force in the given Cartesian direction, respectively, $\dot{x}_i$ is Cartesian speed, and $b_{d,i} > 0$ and $m_{d,i} > 0$ are the feedback gains that are chosen according to the desired impedance properties of the end-effector under the force interaction. Along the Cartesian and angular directions where the force interaction between the end-effector and weatherstrip is not desired, we only use a motion controller:

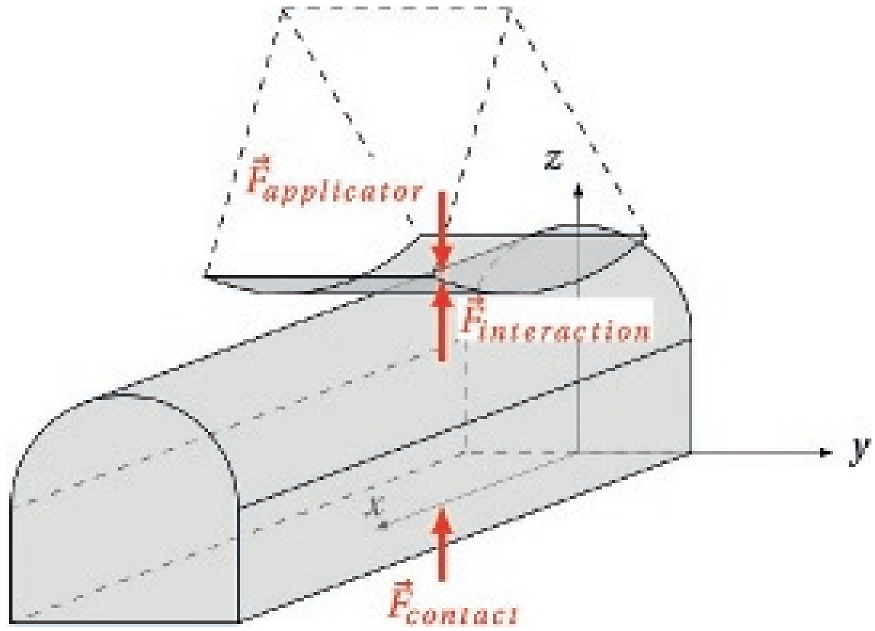
$$a_{x,i} = \ddot{x}_{r,i} + k_{d,i}(\dot{x}_{r,i} - \dot{x}_i) + k_{p,i}(x_{r,i} - x_i) \qquad (9)$$

Here, $x_{r,i}$, $\dot{x}_{r,i}$, and $\ddot{x}_{r,i}$ are the setpoint motion, speed and acceleration of the end-effector, respectively, x_i and $\dot{x}_i$ are the actual motion and speed of the end-effector, respectively, and $k_{p,i} > 0$ and $k_{d,i} > 0$ are feedback gains.

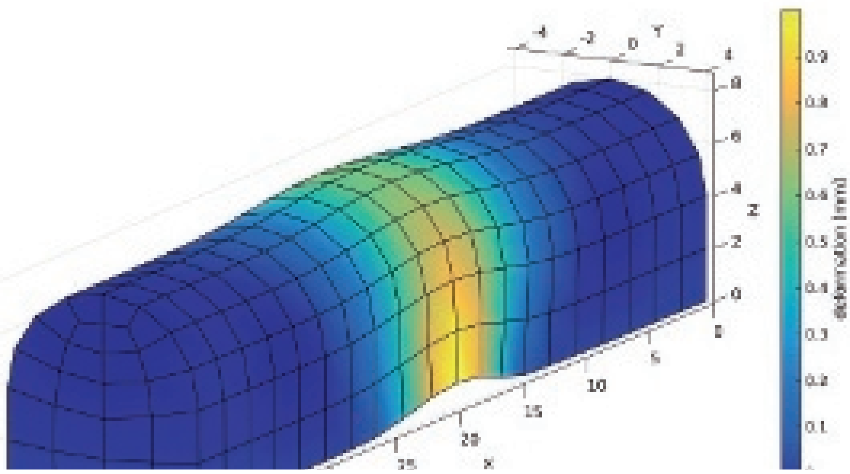
Case study

The state-space model of the rubber weatherstrip is implemented in Matlab together with the model (5) of an industrial robot arm. An off-the-shelf robot is selected according to the following criteria: its work range is large enough to access edges of the solid object (car door or window) to be sealed, it can supply the required sealing forces, and has hardware and software infrastructure for force control. Then, a simulation case study is carried out to verify the feasibility of the robotised sealing. In this study, the robot is subject to the control law (7)-(9) in order to mount the considered weatherstrip on the solid surface.

The weatherstrip subject to the pressure from the applicator wheel is depicted in Figure 5. The force acting on the applicator, the interaction force between the applicator and the top of the weatherstrip, as well as the contact force between the bottom of the weatherstrip and the solid surfaces are shown in the same figure. We consider a realistic scenario where the solid surface has a 3D-shaped form, represented by a small bump which makes the sealing process more challenging.



5


6

The result of the servo-control simulation of the robotised sealing process is shown in Figure 6. Here, we see a piece of the weatherstrip which is mounted on the surface with the bump. Figure 7 presents three snapshots of the sealing process at different locations in the longitudinal direction of the strip. The upper part of each snapshot represents a cross-section of the weatherstrip before (nominal) and after (displaced) application of the pressure from the applicator wheel. Differences between the nominal and displaced cross-sections show realistic elastic deformations on top of the weatherstrip. The bottom parts of the snapshots represent contact forces between the weatherstrip and the solid surface. The net sum of these forces has to be equal to the force setpoint which is selected according to the requirements of a realistic sealing process.

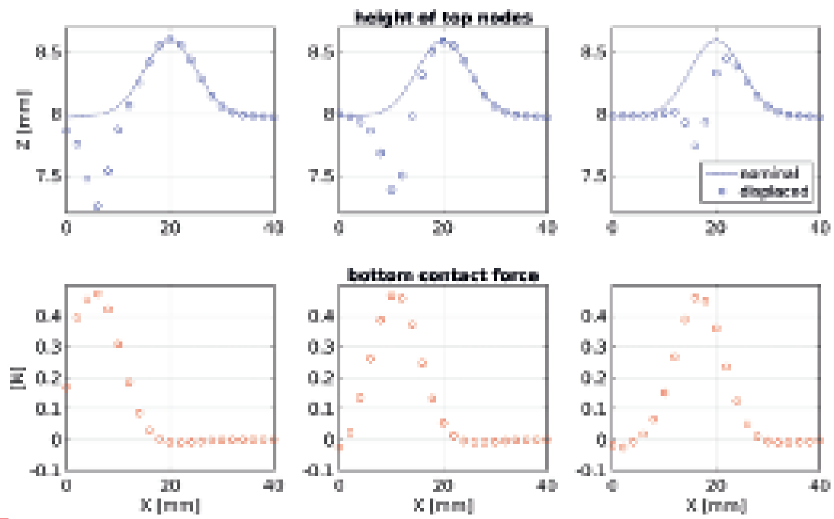
Figure 8 shows the force setpoint and the net reaction forces at the top and bottom sides of the weatherstrip. The differences between the setpoint and obtained net forces are shown in the same figure. The small force differences show that the desired contact forces are achieved along the complete length of the strip despite presence of the bump. This confirms the quality of the applied robot control design and illustrates feasibility of the robotised sealing.

Conclusion

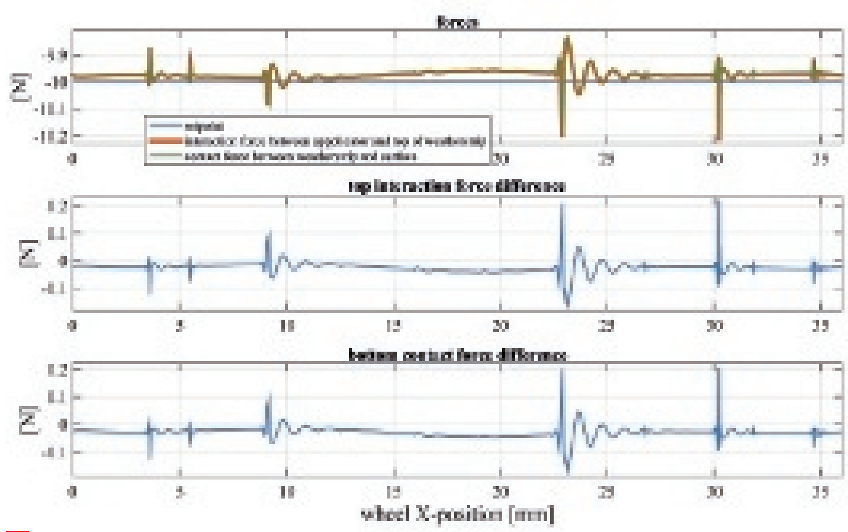
Automation of craftsmanship is another challenge of industrial robotics. The problem of mounting rubber weatherstrips onto solid surfaces is especially interesting, since its automation can boost productivity which is currently limited by scarce availability of highly skilled manufacturing workers that perform this task manually.

In this article we show feasibility of robotised sealing by means of simulation. Thanks to FEM and dynamical modelling, we clarify mechanisms of deformation of the weatherstrip that are relevant for selection of an appropriate robot system and design of the robot motion and force control algorithms. Servo-control simulations with a model of an industrial robot arm verify feasibility of the automated sealing process and help us make the optimal selection of the components of the robot system.

In the meantime, we have measured material parameters of several specific physical weatherstrips, so we can implement these parameters and their geometries into the hyperelastic FEM models. Then we can proceed with physical realisation of the robot system and practically demonstrate its potential in terms of throughput increase, uniform product quality, and reduction of production costs. ■



7



8

7 *Elastic deformation of the weatherstrip during sealing and contact forces on the solid surface with a bump.*

8 *Interaction forces between the wheeled applicator, weatherstrip, and solid surface.*

REFERENCES

[1] Smart Industry, www.smartindustry.nl

[2] G. Marckmann and E. Verron, "Comparison of Hyperelastic Models for Rubber-Like Materials", *Rubber Chem. Technol.*, vol. 79, no. 5, pp. 835-858, 2006.

[3] M. Cheng and W. Chen, "Experimental investigation of the stress-stretch behaviour of EPDM rubber with loading rate effects", *Int. J. Solids Struct.*, vol. 40, no. 18, pp. 4749-4768, 2003.

[4] A. Stenti, D. Moens, P. Sas and W. Desmet, "Low-frequency dynamic analysis of automotive door weather-strip seals", *Mech. Syst. Signal Process.*, vol. 22, no. 5, pp. 1248-1260, 2008.

[5] ANSYS Mechanical APDL Theory Reference, www.ansys.com

[6] www.mathworks.com

[7] B. Besselink, U. Tabak, A. Lutowska, N. van de Wouw, H. Nijmeijer, D.J. Rixen, M.E. Hochstenbach and W.H.A. Schilders, "A comparison of model reduction techniques from structural dynamics, numerical mathematics and systems and control", *J. Sound Vib.*, vol. 332, no. 19, pp. 4403-4422, 2013.

[8] M.W. Spong, S. Hutchinson, and M. Vidyasagar, *Robot modeling and control*, Hoboken, NJ: John Wiley & Sons, 2006.

PREPARING A PIZZA

In order to provide a robot with the knowledge required for competently performing everyday human-scale manipulation activities such as preparing a simple meal in an ordinary kitchen environment, the European research project RoboHow investigates methods such as learning from natural language instruction texts, simulation, and kinesthetic teaching. RoboHow pursues a knowledge-enabled and plan-based approach to robot programming and control.

MICHAEL BEETZ AND HAGEN LANGER

AUTHORS' NOTE

Michael Beetz is a professor of Computer Science in the Faculty of Informatics at the University of Bremen, Germany, and head of the Institute for Artificial Intelligence. He is the scientific coordinator of the RoboHow project. Hagen Langer is senior researcher at the University of Bremen. He is the technical coordinator of RoboHow. This article is in part based on a presentation at High-Tech Systems 2015.

coord@robohow.eu
robohow.eu

RoboHow is a four-year European research project that started in February 2012. It aims at enabling robots to competently perform everyday human-scale manipulation activities – both in human working and living environments. The vision of the project is that of a cognitive robot that autonomously performs complex everyday manipulation tasks and extends its repertoire of such by acquiring new skills using web-enabled and experience-based learning as well as by observing humans.

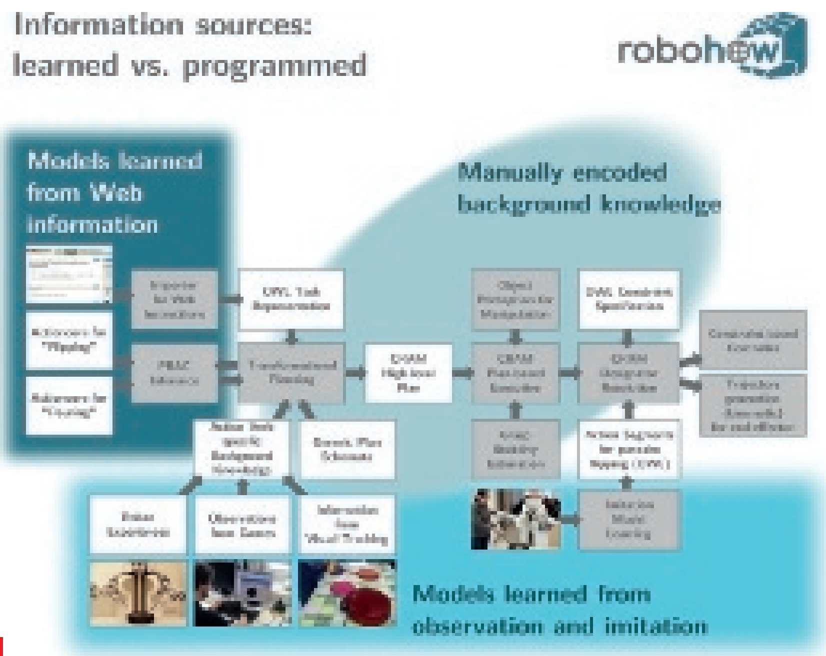
RoboHow investigates a knowledge-enabled and plan-based approach to robot programming and control. Knowledge for accomplishing everyday manipulation tasks such as cooking a simple meal or clearing a table is semi-automatically acquired from instructions in the world wide web, by visual observation of human demonstrations, and from haptic demonstrations. The project develops methods for constraint- and optimisation-based movement specification and execution that will build a sustainable bridge between symbolic high-level control and the continuous time and space of the robot's motion and perception.

Learning from textual instructions

The world wide web provides huge amounts of knowledge about objects, events, and processes. For the purpose of enabling a robot to perform new tasks it would be extremely useful to build upon these existing resources and to make them available to the robot in an appropriate way. There are many websites [1] that give users access to detailed instructions on how to achieve a broad variety of goals, such as 'knit a scarf', 'clarify butter', 'dilute an acid', etc. The instructions are typically given as natural language texts, often accompanied by additional videos or pictures.

The RoboHow consortium

- Universität Bremen, Germany (coordinator)
- Centre National de la Recherche Scientifique (CNRS), France
- École Polytechnique Federale de Lausanne (EPFL), Switzerland
- Kungliga Tekniska Högskolan, Sweden
- Katholieke Universiteit Leuven, Belgium
- Foundation for Research and Technology - Hellas (FORTH), Greece
- Universiteit Leiden, the Netherlands
- Aldebaran Robotics, France
- Technische Universität München, Germany (former consortium member)



1

Natural language texts such as wikihow instructions, cooking recipes, user manuals, and lab protocols can, however, be incomplete, ambiguous, inaccurate, and inconsistent. To transform such an instruction into an executable plan is a nontrivial task. In RoboHow a very expressive representation language is used for this purpose, Markov Logic Networks (MLN). MLNs are a combination of First Order Logic (FOL) and probabilistic reasoning.

Different pieces of information are needed for the complex task of disambiguating and augmenting incomplete instructions: syntactic information such as the part-of-speech tags of the words in the instruction and the grammatical function of phrases (e.g., direct object), as well as semantic information about the actions and the objects involved are represented within the uniform MLN framework. The instruction interpretation engine PRAC (Probabilistic Action Cores) is available as part of the openEASE knowledge service [2].

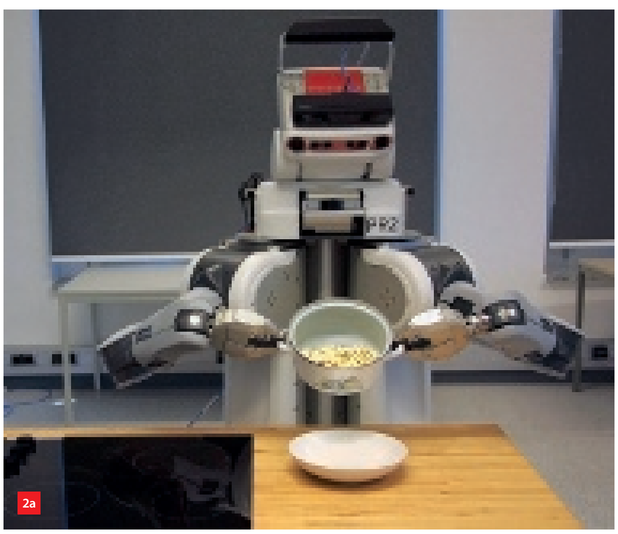
1 *The RoboHow concept of robot learning, from a natural language instruction imported from the Web all the way to trajectory generation. See text for explanation. PRAC = Probabilistic Action Cores CRAM = Cognitive Robot Abstract Machine OWL = Web Ontology Language*

2 *The PR2 robot in action.*
(a) Making popcorn.
(b) Learning to flip a pancake by human guidance.

Figure 1 gives an overview of the RoboHow concept of robot learning. Starting with a natural language instruction text from the Web, standard linguistic analysis tools are used such as the Stanford parser and the WordNet lexical knowledge base as well as the PRAC knowledge base to disambiguate and augment the instruction. Additional knowledge sources include ontologies and CAD models of the respective objects, observations from VR games, etc. The aim is to find a plan which is precise and complete enough to enable the robot to execute the initial instruction successfully.

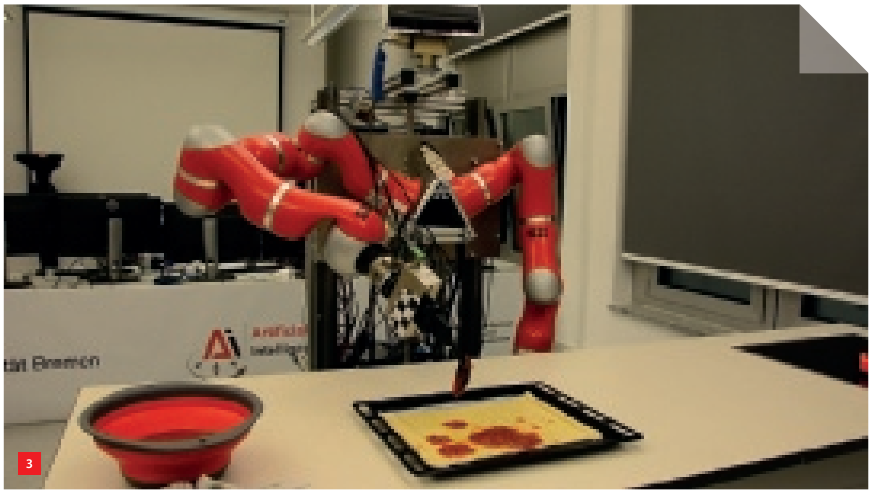
OpenEASE

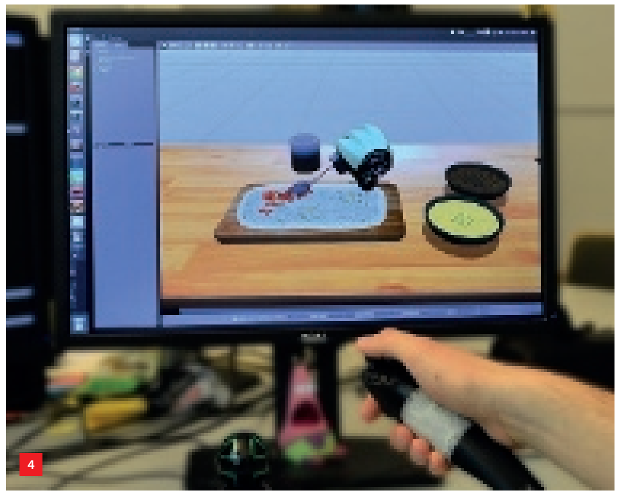
The activity data from the RoboHow experiments (and also from experiments of related projects) are made available through the web-based knowledge service openEASE, an analysis tool for robot experience data [3]. It contains semantically annotated data of manipulation actions, including the environment the agent is acting in, the objects it manipulates, the task it performs, and the behaviour it generates. The episode representations can include images captured by the robot, other sensor data streams as well as full-body poses. A powerful Prolog-based query language and inference tools allow reasoning about the data and retrieving requested information based on symbolic queries. Based on the data and using the inference tools robots can answer queries regarding to what they did, why and how, what happened, and what they saw.



2a

2b





3 *The Boxy robot with KUKA lightweight arms is preparing a pizza.*
4 *Pizza making in a simulation experiment.*

OpenEASE can be used by humans using a browser-based query and visualisation interface, but also remotely by robots via a webSocket API.

The pizza experiment

The RoboHow pizza experiment consists of three actions centred around preparing a pizza:

- Fetching and placing tools, ingredients and the finished pizza.
- Rolling out the dough.
- Placing the toppings.

One of the robots used in the RoboHow experiments is the Willow Garage PR2 (Personal Robot 2), equipped with two 7-DoF arms (DoF = degree of freedom) and a variety of sensors, including a tilting laser scanner, several cameras, and a head-mounted Kinect 2 as its main perception device. The robot is running the open-source Robot Operating System (ROS) [4].

Previous experiments were performed with one robot (Figure 2): making popcorn and learning how to perform the complex task of flipping a pancake by human guidance (kinesthetic teaching). In contrast, the even more complex task of preparing a pizza is not performed by a single robot, but by two collaborating robots. The second robot is 'Boxy' (Figure 3), designed in-house with two KUKA LWR-4+ manipulators, a holonomic platform using mecanum wheels, a movable torso, and two parallel-finger grippers.

Raphael, the PR2 robot, was in charge of fetching and bringing tools and ingredients, and Boxy manipulated the pizza dough and added the ingredients. Various knowledge bases for the experiments are provided through the openEASE web platform.

Simulation

Before being executed by the real robot, motion sequences can be tested in a simulated environment (Figure 4). In this experiment the (virtual) robot hand is guided by a human using a game controller. The data generated by simulation experiments can be used as training material for Machine Learning algorithms.

Conclusion

RoboHow is a European research project aimed at enabling robots to competently perform everyday human-scale manipulation activities such as preparing a simple meal in an ordinary kitchen environment. In order to provide the robot with the necessary knowledge RoboHow investigates methods such as learning from natural language instruction texts, simulation, and kinesthetic teaching. The data from RoboHow experiments such as pizza making are available via the web-based knowledge service openEASE.

Acknowledgement

The work reported in this article has been supported by the EU FP7 Project RoboHow (grant number 288533). ■

REFERENCES
[1] Examples: www.wikihow.com, www.ehow.com
[2] data.open-ease.org/prac/pracinfer
[3] www.open-ease.org
[4] www.ros.org

PARALLEL ROBOTS WITH CONFIGURABLE PLATFORMS

Conventional parallel robots are formed by several independent serial chains, connecting in-parallel a single rigid platform, or end-effector, to the base. The novel concept behind a parallel robot with configurable platform is that the rigid end-effector is replaced by a closed-loop chain, which can provide additional grasping capability or additional rotational degrees of freedom, while all motors remain on the base. Fundamental aspects of parallel robots with configurable platforms are presented, as well as two functional prototypes based on this concept.

PATRICE LAMBERT AND JUST HERDER

Introduction

The majority of current industrial robots are based on a serial structure that resembles a human arm. The rigid links and the joints are assembled in a serial chain where each joint must be actuated to fully control an end-effector relative to a base. The main drawback of such open-loop structures is that each motor must carry the weight and inertia of the motors further in the serial chain. Mechanically, a serial chain is also in general less stiff than a closed-loop structure. High inertia and low stiffness lead to a low mechanical bandwidth that ultimately limits the dynamic performance of the robot.

Alternatively, it is possible to use a mechanical structure in which the links and joints are assembled into closed loops. By using a so-called parallel architecture [1], it is possible to fully control the whole mechanism by placing motors on only a subset of the joints. Preferably, actuated joints are located on or near the base of the robot so that the motors give little contribution to the global inertia and heavier, more powerful motors can then be used. In addition, the parallel mechanical structure between the base and the end-effector will have in general a better mechanical stiffness than a comparable serial structure. Lower inertia and higher stiffness both lead to a higher mechanical bandwidth.

Parallel robots are generally used for applications in which high mechanical bandwidth is needed, such as flight simulators, high-speed pick-and-place robots, and haptic devices. They are commonly used to position a single rigid body, the end-effector, in six or less than six degrees of freedom (DoFs). However, in certain tasks where the interaction with the environment requires multiple contact points, for example when mechanical grasping is needed, additional end-effectors as well as additional controlled DoFs between them must be provided from the mechanical architecture.

Robotic grasping

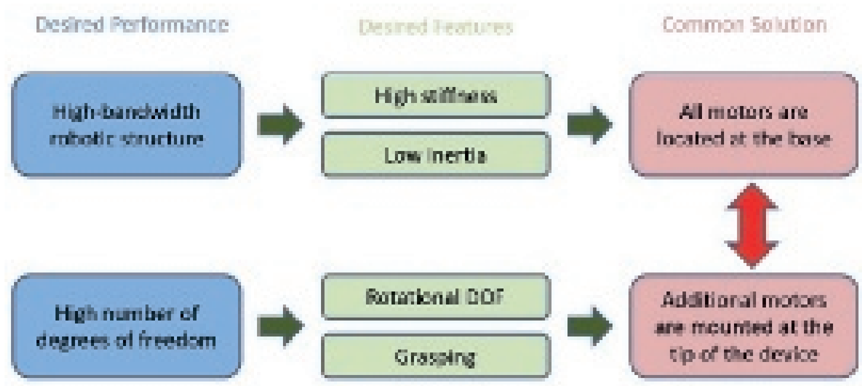
As an example, in the pick-and-place industry, where the common solutions to handle products rely on vacuum gripping when the product has a flat surface, mechanical grippers are needed for other products that have a surface which is rough, porous or not flat, or has holes. For haptic interfaces, a trend in the field is the development of interfaces that provide multiple points of contact to the operator, allowing them to use their fingers to grasp virtual objects in order to feel their shape and stiffness, which results in a much more natural interaction with the virtual or remote environment than a single contact point.

A common solution to provide robotic grasping in a parallel robot is to mount an additional actuator and robotic gripper at the tip of the already existing robot. However, in case of parallel robots, their main advantages rely on the fact that all the motors are located on the base and that only

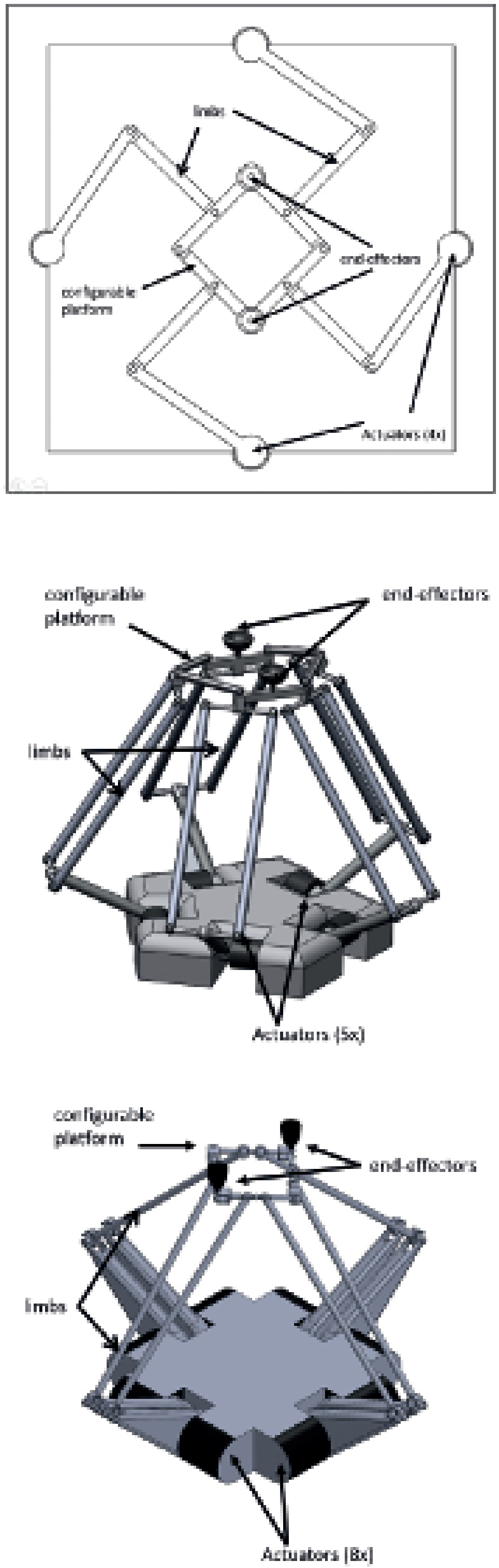
AUTHORS' NOTE

Patrice Lambert is a postdoctoral researcher in the Precision and Microsystem Engineering department (PME) at Delft University of Technology, the Netherlands. Just Herder is professor in the PME department and at the University of Twente in the field of interactive mechanisms, mechatronics and robotics.

p.lambert@tudelft.nl
www.pme.tudelft.nl
www.utwente.nl/ctw/wa



1 *The current solution for mechanical grasping consists of locating additional motors at the distal end of the robotic device, which conflicts with the desire of having high stiffness and low inertia.*



2 *Parallel robots with configurable platforms with, from top to bottom, four, five and seven DoFs, respectively. Each robot is formed by a set of base-located motors, a configurable platform hosting two end-effectors, and a set of parallel limbs connecting the motors to the configurable platform.*

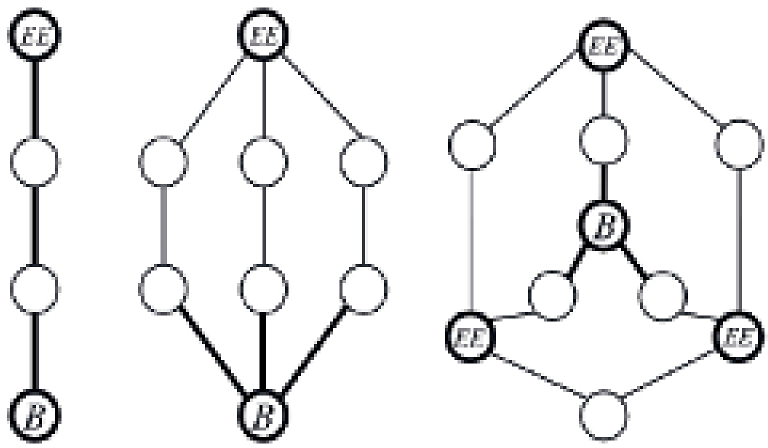
mechanical links connect the end-effector with its base. Adding a grasping motor is increasing the mass of the structure at the worst possible location for its mechanical bandwidth, namely at the end-effector location where the weight of the motor must be carried over the whole workspace, resulting in lower dynamic performance of the robot.
Sometimes, motors are also mounted at the tip of the robot to provide additional rotational DoFs. This is commonly known as a robotic wrist mechanism. Figure 1 shows a schematic representation of the problem.

The relatively new class of parallel robots described in this article, parallel robots with configurable platforms (PRCPs), retains the advantages of classical parallel robots, i.e. that all the motors are grounded on the base, while offering mechanical grasping capabilities via multiple contact points.

PRCP architecture

Conventional parallel mechanisms are formed by two rigid links, the base and the end-effector connected in parallel by serial chains, called limbs. The concept behind parallel mechanisms with configurable platforms [2],[3] is that the rigid-link (non-configurable) end-effector is replaced by an additional closed-loop chain (i.e. the configurable platform). Some of the links of this closed loop are attached to the limbs so that both the pose and the configuration of the configurable platform (CP) can be fully controlled by the motors located on the base.

The use of a closed loop instead of a rigid end-effector allows the robot to interact with the environment from multiple contact points on the platform. The contact points have a relative mobility between each other that can be fully controlled by the actuators located on the base. This results in a robot that can combine motions and grasping capabilities into a structure that provides an inherent high structural stiffness since all the actuators are located on the



3 *From left to right: graph representation of a particular serial robot, a parallel robot, and a parallel robot with a configurable platform. The actuated joints (in bold edges) are used to fully control the motion of each end-effector (EE) relatively to the base (B).*

base. High-speed pick-and-place robots and haptic interfaces are examples of applications which can benefit from this type of architecture. Figure 2 shows three PRCP examples with four, five and seven DoFs, respectively.

In the planar 4-DoF robot, three DoFs are used to position the platform and the fourth DoF is used to vary the distance between the two end-effectors. Similarly, the configurable platform of the 5-DoF robot can move in three translation directions, while two internal DoFs in the platform provide rotation and grasping. Finally, the platform of the 7-DoF robot can move in any position/orientation and provide one DoF grasping, while using a redundant actuation scheme with eight motors to avoid singularities and increase the effective workspace.

To illustrate some fundamental difference of PRCP with other classes of robot architectures, it is interesting to analyse their topology with a graph representation. The term 'mechanism topology' refers here to the network of joint connections between the various rigid links of the robot, regardless of the type of joint, their specific position and orientation on the links, or which joint is actuated. The topology of a mechanism ultimately determines which formula and methods are used in order to calculate its kinematic relations, and can be used to classify different types of robotic architectures. In a graph representation of a mechanism, each edge is a joint and each vertex is a rigid link. Figure 3 shows a graph representation of a serial robot, a parallel robot, and a parallel robot with a configurable platform, respectively.

Kinematic model

The kinematic model of a mechanism describes the relations between the relative motion of the various rigid bodies of the system. Of special interest is the motion mapping between the joints equipped with motors/sensors and the end-effector parts, which interact with the environment. These relations directly influence the precision, workspace, force transmission, stiffness and dexterity of the device.

Inverse kinematics

The inverse position kinematics (IPK) is the non-linear relation that describes the position of the motors as a function of the end-effector position. This relation is needed to control the robot in position. While the inverse position kinematics in conventional parallel robots can be calculated independently for each limb, the IPK of PRCP involves a two-step method where the IPK of the CP (configurable platform) must be calculated separately from the IPK of each leg. The same holds for the linear inverse velocity kinematics calculation leading to the Jacobian matrix, where the inverse platform Jacobian J_p^{-1} must be first computed.

For a PRCP with n limbs and m DoFs, given that $\dot{\chi}$ is a vector representing the end-effector's velocity and $\$_{cj}$ is the twist representing the velocity $\dot{c}_i$ – the velocity vector of the limb attach point on the platform – with respect to the DoF j, we have:

$$\dot{c} = J_p^{-1}\dot{\chi}$$

$$\begin{bmatrix} \dot{c}_1 \\ \vdots \\ \dot{c}_n \end{bmatrix}_{6n,1} = \begin{bmatrix} \$_{c11} & \cdots & \$_{c1m} \\ \vdots & \ddots & \vdots \\ \$_{cn1} & \cdots & \$_{cnm} \end{bmatrix}_{6n,m} \dot{\chi}$$

The second step is to connect the various Jacobian matrices J_{lj}^{-1} of the limbs j to the platform Jacobian J_p^{-1} to obtain the full inverse Jacobian J^{-1} such that:

$$J^{-1} = \begin{bmatrix} J_{l1}^{-1}J_{p1}^{-1} \\ \vdots \\ J_{lm}^{-1}J_{pm}^{-1} \end{bmatrix}_{m,m}$$

Here, J_{pj}^{-1} is the column j of J_p^{-1}. The velocity of the motors $\dot{q}$ is then described by :

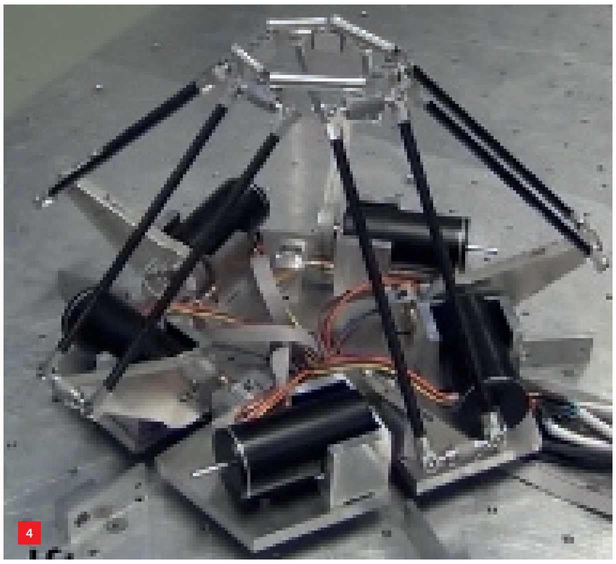
$$\dot{q} = J^{-1}\dot{\chi}$$

Statics and stiffness

Employing the power conservation principle, the transpose of the inverse Jacobian matrix J^{-T} can be used to describe the mapping of the vector of motor torques τ to the vector of end-effector forces f:

$$f = J^{-T}\tau$$

$$J^{-T} = \left[J_{p1}^{-T}J_{l1}^{-T} \quad \cdots \quad J_{pm}^{-T}J_{lm}^{-T} \right]$$



4 *The 5-DoF PentaG haptic master device.*

5 *PentaG device in its pick-and-place version.*

It is also possible to derive a formulation for the stiffness matrix of a general PRCP using the analytical expressions of the platform Jacobian J_p^{-1} and the leg's Jacobian J_l^{-1}. If all actuators are locked and have a linear stiffness k, the stiffness matrix K, mapping a small displacement $\Delta\chi$ of the end-effectors to the end-effector reaction force f is given by:

$$f = K\Delta\chi$$

$$K = kJ^{-T}J = k\sum_{i=1}^{m}\left[J_{pi}^{-T}J_{li}^{-T}J_{li}^{-1}J_{pi}^{-1}\right]_{m,m}$$

Two examples

Example 1: The PentaG robot

The PentaG robot [4] is a 5-DoF parallel robot with a configurable platform, combining three translational DoFs, one rotational DoF around the vertical axis and one grasping DoF. All five motors are fixed on the base, resulting in a very light moving structure and an inherently high structural stiffness. It was initially developed as a haptic device for tele-operation in micro-assembly. Figure 4 shows a fully functional prototype of the PentaG.

The various kinematics parameters of this device have been optimised to maximise the kinematic force mapping and precision sensing while preserving a large workspace in comparison with the size of the structure, i.e. its compactness. The other design parameters (that do not influence the kinematics) have been optimised for low inertia while preserving a certain stiffness.

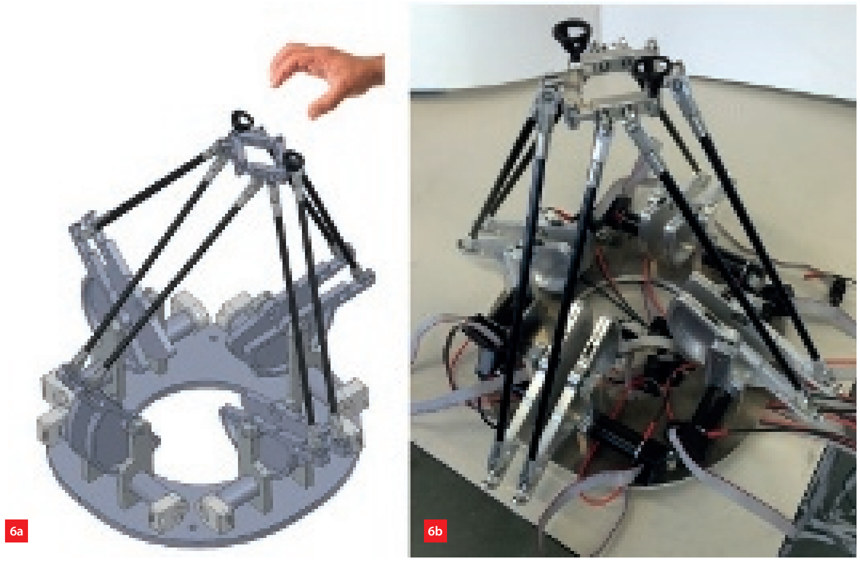
More information on the PentaG device, including a video of the prototype, can be found on the Delft Haptic Lab website [5].

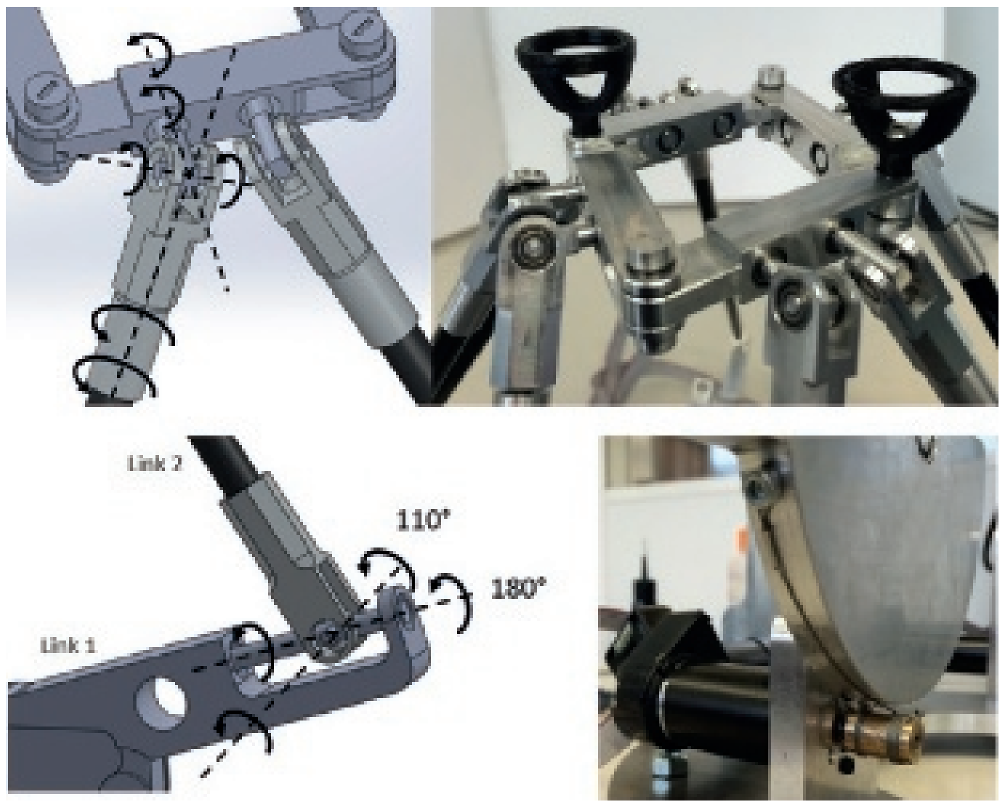
High-speed pick-and-place applications may also benefit from a PRCP architecture since they require high mechanical bandwidth to achieve a certain number of cycles per second and require sometimes a mechanical gripper to handle products. The PentaG prototype has also been tested as a pick-and-place device by replacing the finger tips used in the haptic application by a mechanical gripper and by using the device upside-down. This is shown in Figure 5. This application for the PentaG is currently investigated by the company Penta Robotics [6], which holds the patent rights.

Example 2: 7-DoF parallel haptic device

The 7-DoF parallel haptic device [7] is a second prototype based on a PRCP structure, providing three translational DoFs, three rotational DoFs and one grasping DoF. It is the first and only 7-DoF parallel robot in which all the motors are located on the base, using only mechanical links and bearings between the motors and the end-effectors. Both the position/orientation and the grasping configuration of the platform are fully controlled by the combined action of the eight motors located at the base. Actuation redundancy (more motors than the number of DoFs) was selected in this design for purposes of symmetry, homogeneity of performance, improved force transmission, and manufacturability. Figure 6 shows a 3D model of the device and its prototype fully assembled.

Each of the eight limbs is composed of a series of one rotation joint, one universal joint, and one spherical joint. The rotation joints are connected to the motors on the base by a capstan drive, allowing a gearing ratio without backlash and friction. The universal joints have been especially designed with an elongated pin, allowing a greater angular workspace than that of commercially available universal





6 *The 7-DoF haptic device.*
(a) Model drawing.
(b) Realisation.

7 *Figure 7. Joints configuration of the 7-DoF haptic device (model drawing on the left, realisation on the right).*
Top: three intersecting rotation joints provide the spherical attach joint for each limb on the configurable platform.
Bottom: the universal joint and the capstan-driven rotation joint of each leg.

joints. Finally, the spherical joints are emulated by three intersecting pairs of revolute joints, instead of conventional ball-and-socket joints, increasing the angular workspace and reducing friction. Figure 7 shows the various joints of each leg as well as the assembly of the eight spherical joints on the platform.

The kinematic design of the 7-DoF haptic device was complicated by its high number of DoFs. The precision, force transmission, stiffness and dexterity are all dependent on the position within the workspace, and evaluating a particular set of kinematic parameters requires a computer-intensive sampling over the seven dimensions of the workspace.

Table 1. Specifications of the 7-DoF haptic device.

Specification		Value
Workspace	Vertical	150 mm
	Horizontal	300 mm
	Yaw	+/–60°
	Pitch/Roll	+/–45°
	Grasping	50 mm to 90 mm
Resolution	At sensor location	0.024°
	At end-effector, average	0.2 mm
Torque (actuator)	Average	0.4 Nm
	Maximum	3.2 Nm

In order to facilitate the design optimisation, a graphical user interface was developed to show various performance indices over some subspace of the total workspace as a function of the kinematic parameters. The specifications of the selected design are summarised in Table 1.

More information on the 7-DoF haptic device is available [8]. Further development on this device is now carried out by Heemskerk Innovative Technology [9], aiming at the conversion of the prototype into a commercial haptic device. ■

REFERENCES

[1] Merlet, J.-P., *Parallel robots*, Vol. 74., Springer Science & Business Media, 2012.

[2] Mohamed, M.G. and Gosselin, C.M., "Design and analysis of kinematically redundant parallel manipulators with configurable platforms", *IEEE Transactions on Robotics* 21, no. 3, 277-287, 2005.

[3] Lambert, P. and Herder, J.L., "Parallel robots with configurable platforms: Fundamental aspects of a new class of robotic architectures", *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*: 0954406215602511, 2015.

[4] Lambert, P., Langen, H. and Munnig Schmidt, R., "A novel 5 DOF fully parallel robot combining 3T1R motion and grasping". In *ASME 2010 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, pp. 1123-1130, American Society of Mechanical Engineers, 2010.

[5] www.delfthapticslab.nl/device/pentag-haptic-device

[6] pentarobotics.com

[7] Lambert, P. and Herder, J., "A novel parallel haptic device with 7 degrees of freedom". In *2015 IEEE World Haptics Conference*, pp. 183-188, IEEE, 2015.

[8] www.delfthapticslab.nl/device/parallel-haptic-device-with-7-degrees-of-freedom

[9] www.heemskerk-innovative.nl

ASSESSING THE ACCEPTANCE OF 3D PRINTING

To 3D print or not to 3D print? That's what we asked ourselves a year ago at the Precision Fair 2014. Now, in 2015, the fair has given us the opportunity to evaluate the acceptance of additive manufacturing once again. A quick scan of conventional milling and turning companies reveals that five are still not considering adopting 3D printing, six are already using it and four are thinking about applying this promising technology. Conclusion: hesitant acceptance.

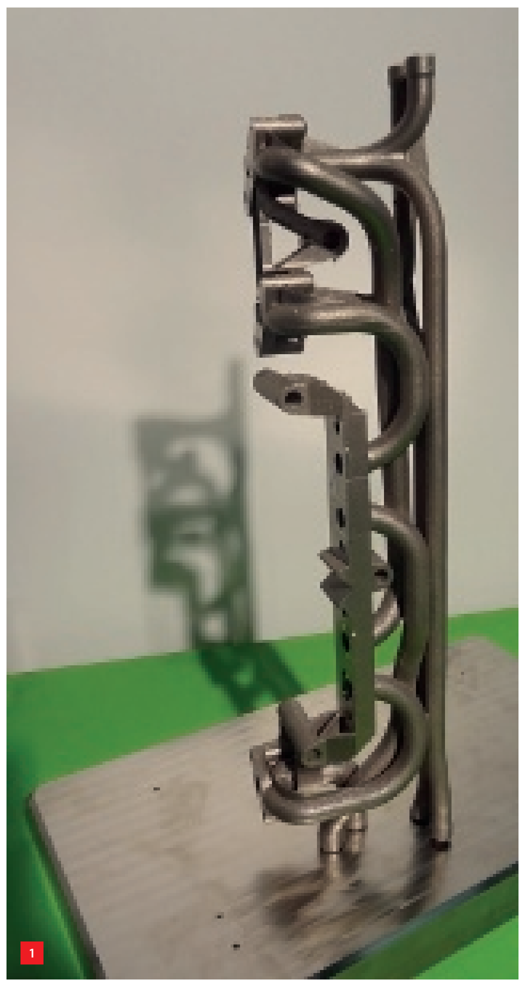
FRANS ZUURVEEN

Some cutting manufacturers are very clear about why they haven't embraced 3D printing, or additive manufacturing (AM): it's too expensive, takes too much time and particle dimensions prevent the realisation of high accuracies. But, in general, cutting specialists admit that some special products, especially those with internal cavities, are nearly impossible to manufacture conventionally. Take the heat-exchanging device shown by Wilting from Eindhoven for instance (see Figure 1).

Designing for AM

LayerWise, an early KU Leuven spin-off, is a pioneer in the 3D printing of metals. The Belgian company recently became part of US firm 3D Systems, which specialises in the 3D printing of plastics. Now, together with LayerWise, 3D Systems covers a wide range of materials, from titanium to cheap plastics.

The smallest particle dimension of the metallic materials applied by LayerWise goes down to 10 µm. Research aims to reduce this to the nanometer range, but one of the limiting factors is the operator's health. Although the actual 3D building process generally takes place in an inert argon or nitrogen environment, such extremely small particles diffuse easily into the atmosphere. LayerWise succeeds in manufacturing metal products with a density of 99.95%, making them applicable in high-vacuum environments.



1 *A complicated heat-exchanging device, for which additive manufacturing is the only relevant manufacturing technology.*

AUTHOR'S NOTE

Frans Zuurveen is a freelance text writer who lives in Vlissingen, the Netherlands.

LayerWise in Leuven has a wide range of additive manufacturing machines and you would be forgiven for thinking that clients contact LayerWise with ready-to-manufacture CAD files to be transformed immediately into a complicated product. LayerWise prefers to be involved in the design process as early as possible because 3D printing design rules differ from those for conventional milling and grinding procedures. Wilting, a firm that calls itself a LayerWise premium partner, confirms this. Wilting aims to act as an intermediary between product designers and LayerWise.

In its stand, Wilting used a product with parallel cooling channels separated by long slots to explain the adapted 3D design rules. When being milled, the product is assembled from two parts – a lower part with milled cooling channels and an upper cover. Both parts are to be leak-free welded together, with the obvious risk of leaking. When machined with an end-mill, the slots between the channels terminate in a circular curve, Romanesque style. But such circular curves are not as easily made by melting 3D printed powder. As a result, the 3D printing optimised product has slots ending in a point, Gothic style.

Variations on the AM theme

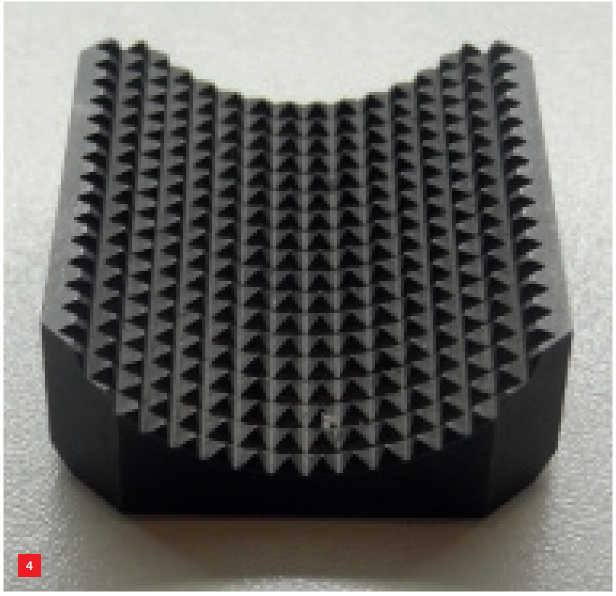
The Precision Fair 2015 (see Figure 2 for impressions) also saw some new deposition techniques for 3D printing. Without doubt, the most sophisticated one was the metal jet printer developed by Demcon and Océ. With its inkjet technology, jet printing specialist Océ helped provide fluid metallic droplets-on-demand. Demcon shared its mechatronic expertise in a machine that deposes up to 1,800 °C (!) hot droplets 60 μm in diameter. Lorentz forces, excited by a current through the molten metal and an external magnetic field, force the droplets out of the printing head. The complete machine has been delivered to the University of Nottingham's EPSRC (Engineering and Physical Sciences Research Council) Centre for Additive Manufacturing for research purposes (read the article on page 45 ff).

Another, albeit rougher, deposition technique was the one demonstrated by KMWE (see Figure 3). KMWE uses electron beam welding for the deposition of stainless steel and other materials in rather thick layers to provide a casting-like workpiece that requires less material than when milled from solid. KMWE doesn't want to share any details about the process, but a quick online search reveals that it is most likely the technology marketed by Sciaky in Chicago. Sciaky promises to realise a deposition rate that is ten times higher than conventional 3D printing techniques.

Ceratizit in Luxemburg is a worldwide provider of carbide base materials – also called hard metals – and products made from these extremely hard materials. It uses 200 different metallurgical procedures to manufacture customised carbides. Together with KU Leuven, Ceratizit

2 *Impressions from the Precision Fair 2015 exhibition floor. (Photos: Jan Pasman/ Mikrocentrum)*

3 *An electron beam welded product shown by KMWE in Eindhoven. On the right, the 'rough' product; on the left, the product after conventional machining.*



developed a 3D printer to make products from carbide by deposing the various elemental particles required. The particle dimensions are lower than 0.2 μm. Figure 4 shows a clamping device made from carbide by this 3D printer.

Much more than 3D printing

One of the unique things of the Precision Fair 2015 was the entrance exhibition of products that precision engineers are extremely proud of (Figure 5). These included a goniometer designed by Panalytical in Almelo, a stainless-steel vacuum recipient made by Hositrad in Hoevelaken (see Figure 6), an example of glass-to-metal technology with electrical and optical feedthroughs for vacuum application made by LouwersHanique in Hapert (see Figure 7) and a cross-section of a Carl Zeiss Distagon objective.

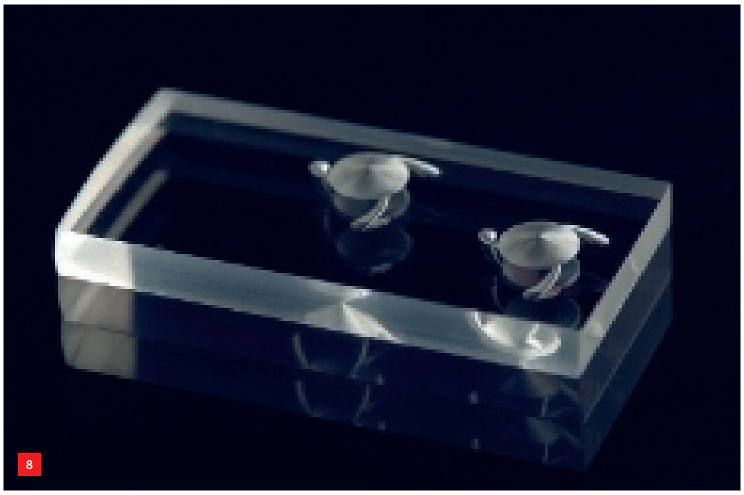
Continuing with the well-known Louwers glass-to-metal assembly craftsmanship, we first have to explain that its merger with Pulles and Hanique – which has given rise to the new name LouwersHanique – has extended the company's technological expertise to the field of quartz glass.

4 *A clamping device produced from carbide with a 3D printer designed and made by Ceratizit.*

5 *The entrance exhibition of precision engineering products. (Photo: Jan Pasman/Mikrocentrum)*

6 *A stainless-steel vacuum recipient made by Hositrad.*

7 *An assembly with electrical and optical feedthroughs for vacuum applications made by LouwersHanique.*



8 *Turbulence nozzles etched with SLE technology by LouwersHanique inside a quartz glass substrate.*

9 *A Mitutoyo Quick Vision ELF measuring machine with an accuracy of 2 μm within the measuring range of 200 x 200 x 250 mm³.*

LouwersHanique recently worked together with LightFab, an Aachen Fraunhofer Institute spin-off. With their SLE (selective laser-induced etching) technology, LouwersHanique is now able to micro-machine quartz glass and sapphire. When scanning a surface of these materials with a femtosecond pulsed laser with a spot diameter of 2-3 μm, the surface is modified so that it can be etched with potassium hydroxide. This technology is much more accurate than the conventional methods, which apply light-sensitive photoresists. LouwersHanique uses a LightFab machine for the SLE technology. The technology can also be used to make hollow channels below a surface, by focussing the spot inside transparent materials. Figure 8 shows tiny turbulence nozzles etched inside a quartz glass substrate using this technology.

Easy accurate measuring

There were many examples of precision measuring on show at the fair of course, including Renishaw and Heidenhain with their precision scales on metal and on glass. Being able to extensively interpolate between the scale divisional pitch is quite impressive. Renishaw scales with a pitch of 20 μm may have a resolution of even 1 nm, which means an interpolation factor of 20,000! Such scales are available on rolls and can be glued on machine slides relatively easily. Heidenhain can also interpolate between the scale pitch of course, but stresses that resolution differs from accuracy. Despite high interpolation, the ultimate accuracy of measurements with a scale depends on the accuracy of the scale divisions.

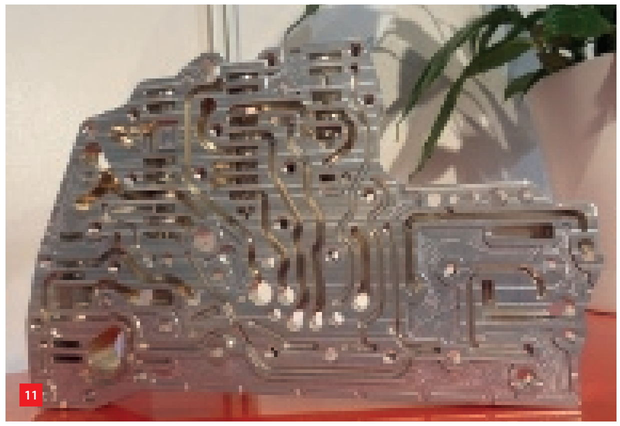
Mitutoyo once again had an impressive stand just near the entrance. The measuring machines from its Quick Vision series are beautifully designed (see Figure 9). The Quick Vision ELF has an accuracy of 2 μm within its horizontal range of 200 x 200 mm² and a measuring height of 250 mm. The procedure it uses to firstly measure the tilt of a workpiece for compensating tilt errors by software algorithms is remarkable.

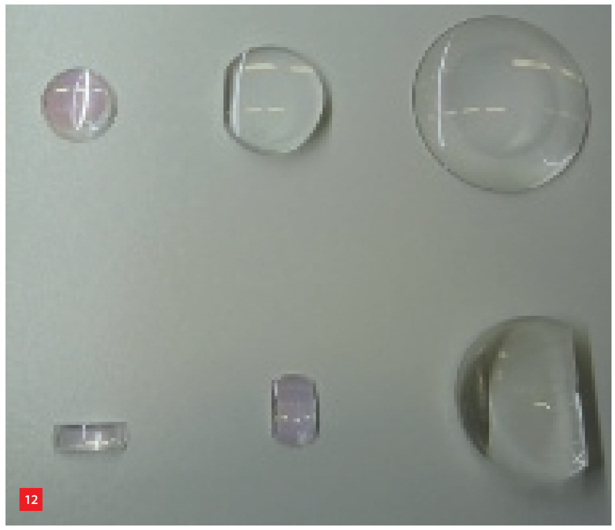
Another measuring machine manufacturer at the fair was Nikon, which had its Altera 10.7.6 machine on display. The leaflet on this machine doesn't reveal any accuracy values, but it does state that the (probably impressive) accuracy values are guaranteed for ten years. One of the reasons for this is the ceramic technology that is integrated into the machine by applying hollow ceramic, very accurately machined guideways with single-orifice, grooved wrap-around, preloaded air-bearings. Low weight, long-term dimensional stability and low thermal expansion are some of the advantages of this application of ceramics.

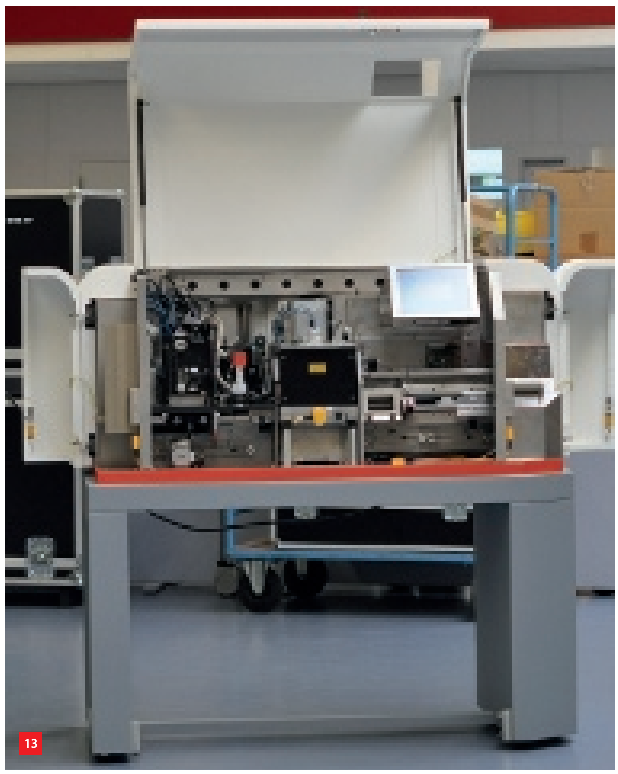
Miscellaneous

An estimated ten stands or more exhibited linear guides. One of them was LM Systems, which calls its supplier THK "a worldwide pioneer in the development of linear motion products" (see Figure 10).

As always, IBS (a supplier of measuring machines in the 10 nm range) was present at the fair. This time, however, it wasn't showing a new measuring instrument, but instead sharing its pride at having received an order from CERN. This order is the most expensive order CERN has ever placed with a company in the Netherlands. It includes a series of seven machines to be delivered to separate countries. Seven precision engineering companies are going to produce silicon arrays for the ALICE (A Large Ion Collider Experiment) detector in the CERN LHC (Large Hadron Collider). The machines have to accurately position CMOS chips on printed surface boards. After that, laser-melted droplets of tin have to be shot onto each connection point to provide a safe and faultless electrical output for the chip; quite a challenging task!







Vacom Vacuum Components from Holsbeek (Belgium) exhibited a high-vacuum assembly manufactured from aluminium. Al is not traditionally the preferred material for vacuum applications because of its poor outgassing properties, but Vacom succeeded in applying a heat treatment procedure to minimise outgassing. Low weight and low magnetic permeability are some of the advantages of Al vacuum assemblies.

Many firms demonstrated their ability to accurately produce complicated products from solid. Figure 11 shows a workpiece with numerous curved channels of aluminium produced by Peters Metaalbewerking in Wanroij. Anteryon in Eindhoven meanwhile produces very different sophisticated products (see Figure 12). This company specialises in the design and manufacture of optical components with complicated forms. Basic glass substrates get a special aspheric or even free-formed surface by disposing a thin layer of transparent plastic on the glass, thanks to a negatively free-formed tool.

Xeryon in Leuven (Belgium), a KU Leuven spin-off, showed a rather innovative piezoelectric drive. The driving force originates from friction between a ceramic pin and a carefully machined straight ceramic strip. The pin describes a piezoelectrically driven elliptical orbit. The pin touches the strip only during a linear part of its trajectory in one direction. When returning in the opposite direction, the pin loses contact for a few nanoseconds. Thanks to the high ultrasonic frequency of the pin driving system (170 kHz), the slide movement stays quasi-uninterrupted uniform. With a maximum speed of 400 mm/s, the driving system conforms to high-vacuum requirements.

10 *A selection of linear motion products displayed bij LM Systems.*

11 *A complicated channelled workpiece from aluminium produced by Peters Metaalbewerking.*

12 *Sophisticated free-formed optical products manufactured by Anteryon.*

13 *The IAI BookMaster Pro passport printing and manufacturing machine with accurate product positioning systems designed by CCM.*

Mechatronic design expertise was on show thanks to, amongst others, CCM from Nuenen (member of the Sioux Group), which displayed the BookMaster Pro passport printing and manufacturing machine, designed by IAI Industrial Systems (Figure 13). CCM's contribution was the design of the highly accurate product positioning systems in the BookMaster Pro. The machine can print up to 200 customised passports an hour.

To conclude

The Precision Fair 2015 again demonstrated the challenging accuracies conventional cutting technology can achieve. If and when additive manufacturing techniques will approach these accuracies is an interesting question to ask – a development that depends on such things as the size of the applied material particles. It is undeniable, however, that this accuracy gap will gradually shrink. Moreover, 3D printing will become a more widely accepted technology when production times get shorter. But, 3D printing will certainly not see conventional turning and milling machines end up on the scrapheap. It is more likely that both technologies will compete in the coming years, each with their own merits.

The two fair days in Veldhoven, the Netherlands, attracted over 3,900 visitors and over 300 exhibitors and featured a conference programme with sixty speakers.
Next year, the Precision Fair 2016 will be held on 16 and 17 November. ■

INFORMATION
WWW.PRECISIEBEURS.NL

DSPE activities

At the Precision Fair, two award ceremonies were held under the auspices of DSPE; see page 26.
A joint DSPE/euspen symposium marked the launch of ECP², the European Certified Precision Engineering Course Program; see page 50.

AWARDS FOR PETER RUTGERS AND GIHIN MOK

During the Precision Fair 2015, two awards were handed out under the auspices of DSPE. Peter Rutgers, Technical Director of Demcon, was presented with the Rien Koster Award for his in-depth insight as well as the creativity, vigour, practical skills and openness he exhibits as a mechatronic designer. Gihin Mok received the Wim van der Hoek Award for his dissertation project at Delft University of Technology, entailing the design of a cost-effective planar precision stage.

The Rien Koster Award is given to a mechatronics engineer/designer who has made a significant contribution to the field of mechatronics and precision engineering. The award was handed out for the seventh time on Wednesday, 18 November, and this time the focus was on the depth and breadth of the mechatronic design discipline. On behalf of the judges chaired by Ton Peijnenburg, Manager Systems Engineering at VDL ETG, Rien Koster, after whom the award is named, presented the award to ir. Peter Rutgers, co-founder and Technical Director of Demcon (Figure 1).

1 *Winner of the 2015 Rien Koster Award Peter Rutgers, flanked on the right by the man after whom the award is named. On the left, Hans Krikhaar, President of initiator DSPE, shows the trophy associated with the award. (Photos: Jan Pasman/Mikrocentrum)*

Demcon

Peter Rutgers studied mechanical engineering at the University of Twente and carried out his dissertation project under Professor Rien Koster. He collaborated with Dennis Schipper, with whom he subsequently set up the Demcon mechatronic design studio. Their business has since developed into a high-end technology supplier. As of 2015, Demcon has 250 staff members and offices in Enschede, Eindhoven, Amsterdam, Groningen and Oldenzaal in the Netherlands and Münster in Germany. Demcon designs and produces high-tech systems, medical devices and industrial automation. Dennis Schipper still heads the commercial side of the business, and Peter Rutgers is still Demcon's technical 'brains'.

Openness

The panel of judges emphasise the fact that this is an award for Peter Rutgers' overall body of work, in recognition of his professional skill and the way in which he has used it to benefit the people around him, both within and outside of Demcon. "When embarking on new projects he quickly gets an idea of what options there are in order to devise solutions. He makes calculations, sketches, builds a test model, working into the evenings if necessary in his home workshop, thereby uncovering the risks and alternatives that the new project entails and coming up with solutions that provide promising responses to his customer's needs. He draws on knowledge not only from his original field but also from other disciplines, such as optics, electronics and software."

Thanks to this dedication, customers see genuine improvements to their products, say the judges, that bring real benefits to the world and that can be commercially successful as well. Finally, the judges praised Peter Rutgers' professionalism. "He's not one to keep his knowledge and insight to himself; indeed, he enjoys sharing it with those around him. Not by overwhelming them with science, but by giving them the insight that will enable them to solve the problem themselves." In the words of someone involved: "Peter's openness ensures that he makes the technical experts around him better."

The importance of designing

With its Rien Koster Award, DSPE wants to highlight the importance of designing to the precision industry. Globally, the Netherlands plays a leading role in this industry, which in broader terms can be dubbed the 'high-tech systems' sector. As a group leader at Philips CFT (Centrum voor Fabricagetechnologie [Centre for Manufacturing Technology]) and professor at the University of Twente, the award's namesake M.P. (Rien) Koster has made a major contribution to the Netherlands' position in this sector. Koster is also the author of the renowned book "Constructieprincipes voor het nauwkeurig bewegen en positioneren" [Construction principles for precision movement and positioning]. The Rien Koster Award comprises a sum of money, made available by The High Tech Institute, and a trophy made by students of the Leidse instrumentmakers School (LiS) [Leiden Instrument Makers School].

Design engineer award

The next day (Thursday 19 November) at the Precision Fair featured the presentation of the Wim van der Hoek Award. This award (also known as the Constructors Award) was introduced in 2006 to mark the 80th birthday of the doyen of design engineering principles Wim van der Hoek. The design engineering award is presented every year to the person with the best graduation project in the field of design in mechanical engineering at one of the three universities of technology. This award includes a certificate, a trophy made by LiS and a sum of money (sponsored by the 3TU Centre of Competence High Tech Systems).

Learned a lot

The 2015 Wim van der Hoek Award went to Gihin Mok, who studied mechanical engineering at Delft University of Technology. He worked on his dissertation project in the department of Precision and Microsystems Engineering, specialising in mechatronic system design. His dissertation project concerned the use of inexpensive optical sensors for computer mice in the design of a planar precision stage.

In the presence of the man after whom the award is named (Figure 2), the award was presented by chair of the panel of judges and DSPE board member Jos Gunsing, lecturer in mechatronics at Avans University of Applied Sciences in Breda and technology innovator at MaromeTech in Nijmegen. The judges were impressed by the sheer scope of Gihin Mok's work. "Once again we have learned a lot as judges. He has adopted a systematic, multidisciplinary approach, from specifications to draft to elaboration to testing. We'd be happy to have him in our company!" Gihin Mok is now working as a process control technologist at Shell. ■

INFORMATION

WWW.DSPE.NL/EVENTS/AWARDS
WWW.DEMCON.NL

2 Gihin Mok, winner of the 2015 Wim van der Hoek Award, looks at the trophy, which was made by the Leidse instrumentmakers School, together with the man after whom the award is named.

INTRODUCING R5-COP

The European manufacturing industry faces increasing product variances resulting from continuous innovation, short product lifecycles, small series production and ever-shorter production cycles. At the same time, production costs must be reduced. The answer to this lies in agile, transformable and reusable automation and robotics. That said, few robotic components are designed for easy adaptation and reuse. To resolve these shortcomings, the R5-COP European research project is focussing on agile manufacturing paradigms and modular robotic systems in particular.

RINI ZWIKKER

Current trends in the European manufacturing industry are part of what the Netherlands calls Smart Industry or, as the Germans call it, Industrie 4.0. In line with these trends, R5-COP helps achieve a higher task flexibility and easier reconfiguration of production facilities, as well as increase cooperation between humans and robots. Agile manufacturing processes are already or will become an element in an integrated chain of supply and consumption in which all devices are connected to share their data, i.e. the Internet of Things.

The acronym R5-COP stands for reconfigurable ROS-based resilient reasoning robotic cooperating systems. This is a 3-year ECSEL-JU project with a total budget of 13.1 million euros. ECSEL-JU is the public-private partnership Electronic Components and Systems for European Leadership – Joint Undertaking. The project started in February 2014, with 31 partners from 13 countries. The Netherlands is well represented with five partners. Drawing on the project description [1], this article provides an overview of the project objectives, how the project is structured, the Dutch contribution and the current status of the project.

During the negotiation phase, a number of the larger partners from several countries left the project because their national governments did not contribute any subsidies to 17% already received from the EU. The Netherlands was one such country where this happened – a great shame really for a project focussing on such an important trend in manufacturing.

AUTHOR'S NOTE

Rini Zwikker is a professor of Mechatronics at Saxion University of Applied Sciences in Enschede, the Netherlands

j.m.zwikker@saxion.nl

Objectives

What has to be done to achieve this? The main objective of the R5-COP project is to provide the means for fast and flexible adaption of robots to quickly changing environments and conditions, and to enable safe and direct human-robot cooperation and interaction at industrial scale. It aims to enable fast and flexible re-composition of software and hardware components of robotic systems, while ensuring robust and safe operation, through the modular design of components with formalised specifications and standardised interfaces.

Standardised yet flexible (re)configuration will be achieved using formal representations of configurable components and their relations for modelling hardware, and modelling applications on an app or skill level, while the use of advanced reconfigurable sensor system modules will ensure robust perception. Dedicated verification and validation techniques will support component and system certification for safe human-robot cooperation, while dedicated use cases from industrial and service domains will identify, model, develop and evaluate key hardware and software components.

Using existing interface and middleware standards, such as ROS (see text box), will help facilitate the integration of components from various suppliers. A modular approach such as this is not only flexible, but will also reduce design, set-up and maintenance costs. Living labs will be used to demonstrate the feasibility and capability in manufacturing and service demonstrator environments.

1 *The PIAP Scout mobile robot is designed for the quick reconnaissance of field and hard-to-access places.*

2 *The MiR100, a user-friendly and efficient mobile robot for automation of internal transport and logistics solutions.*

Focus

In the project name, 'cooperating' stands for safe and direct human-robot cooperation, but also for robust robot-robot cooperation. 'Resilient reasoning' is the robot's ability to adapt its actions autonomously, depending on parameters in process or environment. 'ROS-based' indicates the use of the Robot Operating System as the basis for most software components. 'Reconfigurable' means that one hardware and/or software component can be easily replaced by another to enable a different task.

The R5-COP project builds on the results of the successful Artemis project R3-COP, which ran from 2010 to 2013 with 26 partners. R3-COP stood for resilient reasoning robotic cooperating systems. For R5-COP, the reconfiguration and use of ROS have been added.

Project structure

R5-COP is divided into four linked sub-projects (SPs), following the chain of architecture to components, integration and applications. Each SP is subdivided into a number of work packages (WPs). These WPs provide a good overview of all aspects involved in modular robot development.

SP1 concerns the development of the common architecture concepts. Important WPs define standards for seamless interfacing and for dealing with configurability. SP2 is about developing the reconfigurable components and module library. These include the embedded computing platforms, environment sensors, actuation and manipulation (WP23), human-machine interface, perception and localisation, and reasoning and adaptation.

SP3 provides the platform environment and tools for system integration. Important WPs define the middleware layer, reliability and fault analysis, on-line verification and incremental behaviour testing, design and development tools, and the modular link framework.

SP4 brings everything together in living labs and applications. There are four application areas, namely industrial robots (WP41), professional service robots (WP42), field robots and mobile logistics robots. The EU has stressed that these applications must be realistic and commercially viable. Several use cases have been defined in each SP4 work package. These use cases are very concrete scenarios to demonstrate the results in a controlled manner.

Project partners

There are 31 partners in total (see website), with a balanced representation across academia and industry. The industrial partners range from Norwegian oil company Statoil to Spanish company EMTE Industrial Engineering, Polish company PIAP mobile robots (Figure 1) and Danish company Mobile Industrial Robots (Figure 2).

There are five partners from the Netherlands: Eindhoven University of Technology (TU/e), Alten Mechatronics, Smart Robotics, HU University of Applied Sciences (HU) and Saxion University of Applied Sciences. These partners are mainly involved in three WPs, namely WP23 on actuation and manipulation, and WP41 and WP42 on the development of demonstrators for the application areas for industrial robots and professional service robots, respectively. Smart Robotics acts as the Dutch coordinator of the R5-COP project. It is also the overall leader of SP4.

3 *An equiplet reconfigurable manufacturing platform from HU University of Applied Sciences.*
4 *The Amigo (autonomous mate for intelligent operations) robot from Eindhoven University of Technology. (Photo: Bart van Overbeeke)*
5 *The Dr Robot Jaguar, used by Saxion University of Applied Sciences, is a mobile robotic platform designed for indoor and outdoor operation.*

Dutch contribution

In WP23, TU/e uses its knowledge of whole-body motion control. In this approach, the robot motion is based on the potential field in which the different tasks and constraints are represented as virtual springs pulling or pushing on parts of the robot. This is instead of programming each joint separately. Alten also contributes to WP23 with a module for learning-by-demonstration.

One of the use cases in WP41 (industrial robots) is a module in the assembly line of electronic equipment: parts are picked up from a tray based on 3D vision and accurately processed. The modules from WP23 by TU/e and Alten will be demonstrated here; the complex robot movements are taught by a human operator and further optimised by the processing algorithms. WP41 also includes HU demonstrating its reconfigurable manufacturing platforms based on a hybrid architecture with ROS and agent technology, the so-called equiplets (Figure 3). For WP41, HU will validate whether the steps have been performed successfully and try to dynamically fix a problem if it is within the capabilities of the generic services that its equiplets provide. Smart Robotics is responsible for the full integration and testing of all modules in the application.

One of the use cases in WP42 (service robots) is to clear up the litter in the lunch area of a student restaurant using two cooperating robots, namely Amigo from TU/e (Figure 4) and Dr Robot Jaguar from Saxion (Figure 5). Both the AMIGO and Jaguar will use TU/e's environment descriptor (ED) world representation system.

ED is an object-based geometrical world representation. It allows the user to use object-based semantic statements such as "inspect the objects on top of the table" or "navigate to the couch", while the geometric representation allows the robot to still avoid obstacles – known and unknown – that it encounters on its path. In this respect, it differs from occupancy grids, OctoMaps, high-density monolithic meshes and the like. ED is one common description that can be used for a range of essential functionalities, instead of having separate ones for localisation, navigation, manipulation, and interaction. ED is used in the whole-body motion control of WP23 as well. Another module implemented in WP42 on the Amigo is Alten's learning-by-demonstration.

INFORMATION
WWW.R5-COP.EU

To conclude

The project is about half way through now and all the demonstrators' building blocks are starting to come together. The first cooperation between Amigo (TU/e) and Jaguar (Saxion) has just been realised!

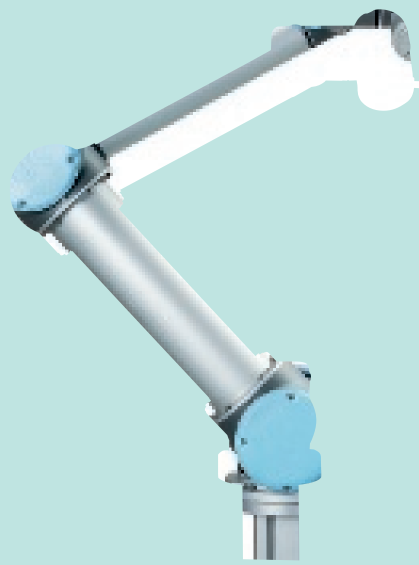
REFERENCES

[1] ARTEMIS, *Book of Projects Volume Three* (downloadable: artemis-ia.eu/publications.html). Article on R5-COP by Rainer Buchty, with additional input from Heico Sandee, Mark Geelen and Vítězslav Beran.

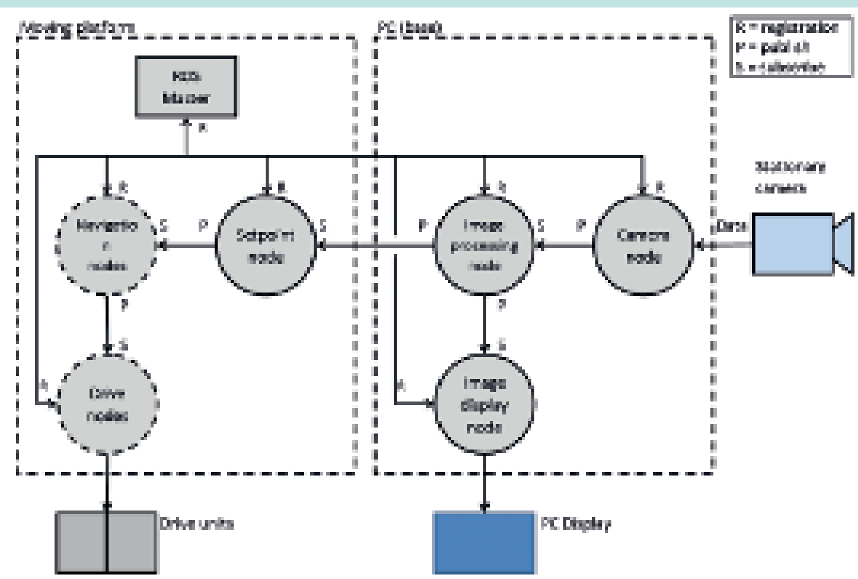
Robot Operating System (ROS)

ROS is a collection of software frameworks for robot software development. It provides operating-system-like functionality on a heterogeneous computer cluster. The ROS website provides a good introduction to its structure, applications and history. It is open-source software, and a large community of users is developing ROS packages for a wide variety of hardware and applications, which they share via the Github hosting site, something which in turn facilitates the re-use of code.

Many popular robots like Baxter, PR2 and NAO can be programmed via ROS, but the professional robotic arms of Universal Robots (Figure 6) and ABB are also supported. In the Netherlands, the R5-COP project partner Alten Mechatronics promotes ROS-Industrial, an open-source robotics software project based on qualified ROS packages, intended for professional use in such industries as manufacturing. From a technical perspective, a ROS application is constructed of a network of software nodes that exchange data messages. These nodes each perform a processing function. Nodes can publish messages and subscribe to receive messages from each other. The nodes may be distributed over multiple hardware platforms, e.g. cooperating robots. By adding or removing nodes, dynamic reconfiguration is also possible. A multi-master strategy is supported for increased robustness.



6 *A Universal Robots UR5 robot arm, used in WP41.*



7 *Example of a ROS architecture: simplified representation of a soccer robot player with fixed overhead camera.*

The diagram in Figure 7 presents a simple architecture with a single master for a moving platform controlled via a stationary camera and a base PC for the image processing.

WWW.ROS.ORG

UPCOMING **EVENTS**

1-3 March 2016, Veldhoven (NL)
RapidPro 2016
The annual event for the total additive manufacturing, rapid prototyping and rapid tooling chain, divided into RapidPro Industrial and RapidPro Home Professional.

WWW.RAPIDPRO.NL

15-18 March 2016, Utrecht (NL)
ESEF 2016
The largest and most important exhibition in the Benelux area in the field of supply, subcontracting and engineering.

WWW.ESEF.NL

17-18 March 2016, Prague (CZ)
Special Interest Group Meeting: Thermal Issues
Meeting organised by euspen, featuring sessions on modelling techniques & model reduction techniques, thermal control strategies, temperature measurement & control, thermal actuators, correction & compensation strategies, and thermal design principles.

WWW.EUSPEN.EU

22 March 2016, Delft (NL)
ZIE 2016
The Zuid-Holland Instrumentation Event 2016 is organised by Holland Instrumentation, a network of CEOs/CTOs from high-tech companies, institutes and universities in the Dutch province of Zuid-Holland, aimed at promoting the region's instrumentation industry

WWW.HOLLANDINSTRUMENTATION.NL

24 March 2016, Eindhoven (NL)
High-Tech Systems 2016
One-day conference and exhibition with the focus on high-tech systems and key enabling technologies. The conference programme of this fourth edition focusses on high-end system development for markets where smart engineering and technology make a difference. The event is aimed at developers, technical managers and decision makers.

WWW.HIGHTECHSYSTEMS.EU

12-13 April 2016, Aachen (DE)
Aachen – Polymer Optics Days 2016
International Conference featuring injection moulded optics, continuous production of planar optics and films, innovative optical grade polymers and applications, and light sources and optical systems. Organised by Fraunhofer IPT and ILT, and the Institute of Plastics Processing (IKV) in Industry and the Skilled Crafts at RWTH Aachen University.

WWW.IKV-AACHEN.DE

20-21 April 2016, Veldhoven (NL)
Materials 2016, engineering & technology
Trade fair, with exhibition and lecture programme, targeted at product developers, constructors and engineers. The focus is on properties - applications - solutions.

WWW.MATERIALS.NL

30 May - 3 June 2016, Nottingham (UK)
Euspen's 16th International Conference & Exhibition
This event will once again showcase the latest advances in traditional precision engineering fields such as metrology, ultra-precision machining, additive and replication processes, precision mechatronic systems & control and precision cutting processes. Furthermore, new topics will be addressed covering precision engineering for aerospace and applications of precision in biological sciences.

Euspen Conference venue, the East Midlands Conference Centre.

WWW.EUSPEN.EU

1-2 June 2016, Veldhoven (NL)
Vision, Robotics & Mechatronics 2016 / Photonics 2016
Combination of two events organised by Mikrocentrum.

WWW.VISION-ROBOTICS.NL
WWW.PHOTONICS-EVENT.NL

4-5 October 2016, Sint-Michielsgestel (NL)
DSPE Conference on Precision Mechatronics
Third edition of conference on precision mechatronics, organised by DSPE. The target group includes technologists, designers and architects in precision mechatronics, who are connected to DSPE, Brainport Industries, the mechatronics contact groups MCG/MSKE or selected companies or educational institutes. This year's theme is 'Farmers, Pioneers and Precision Engineers', inspired by the discussion about sustainable business and prosperity generated from precision engineering know-how and the role that (new) application areas play.
1 February 2016 is the deadline for short abstract submission.

DSPE Conference 2016
Conference on Precision Mechatronics

WWW.DSPE-CONFERENCE.NL

LASERS MERGING INDUSTRY AND ACADEMIA

Are lasers the solution to all Ultra Precision machining processes? It would be quite easy to believe this after the seminar on laser-based processes in Ultra Precision production that was organised last October in Coventry, UK. The event covered a broad range of laser-based applications, from marking and cutting to surface texturing and finishing to drilling and metrology, and attracted participants from academia as well as industry.

MARTIN O'HARA

AUTHOR'S NOTE

Martin O'Hara is National Strategy Manager for Ultra Precision at the EPSRC Centre for Innovative Manufacturing in the UK.

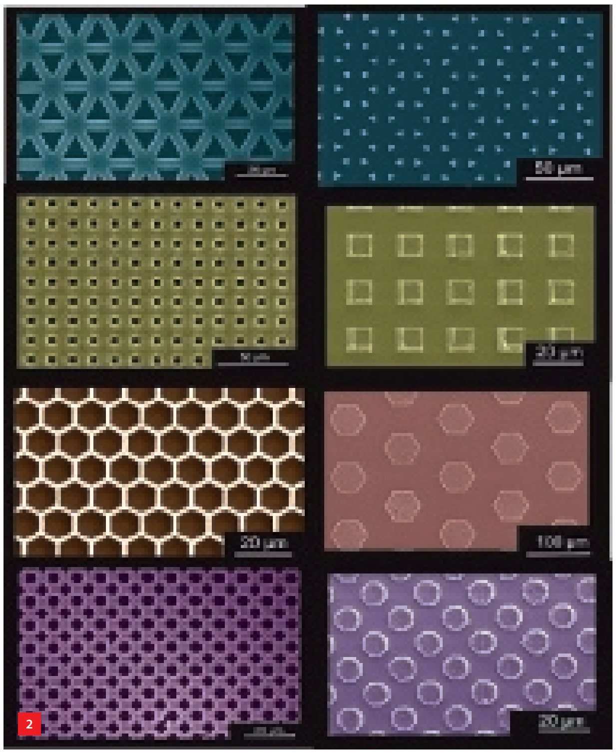
martin@ultraprecision.org
www.ultraprecision.org

The EPSRC Centre for Innovative Manufacturing (CIM) in Ultra Precision (UP) organised a one-day seminar at Photonex 2015 at the Ricoh Arena, Coventry, on the subject of Laser Processes in Ultra Precision Manufacturing. This was a joint event with the CIM in Laser Based Production Processes. The centres' events are usually held at locations where the attendees can visit either scientific facilities or see some industrial processes in action, hence the co-location with the Photonex 2015 exhibition dedicated to photonics and light technologies.

It was the first time such a networking event was run alongside a trade show, but its success suggests it may not be the last time (Figure 1). The event was the centres' final International Year of Light event.

After a brief introduction to the CIM UP (see also [1]), the keynote presentation was provided by Professor Bill O'Neill of Cambridge University, Institute for Manufacturing (IfM) on *Ultra Precision Machining Systems and Technologies* (Figure 2). This presentation gave a broad overview of some of the latest research being conducted at the IfM by some of

1 *The seminar was extremely well attended and drew a range of participants from industry and academia together.*



2 *The introductory presentation by Prof. O'Neill featured some of the CIM UP research portfolio, including ordered nanomaterials for field emission structures in X-ray applications.*

3 *Laser marking examples. (Photo courtesy of SPI Lasers)*

the centre's researchers on new laser-based processing systems and the laser-assisted focussed ion beam (FIB) research platform. This included new control methodologies and workpiece fixtures to enable relatively large substrates to undergo rapid production processing to deliver unparalleled throughput of sub-50nm features across 100's of millimeters of workpiece dimension.

Control

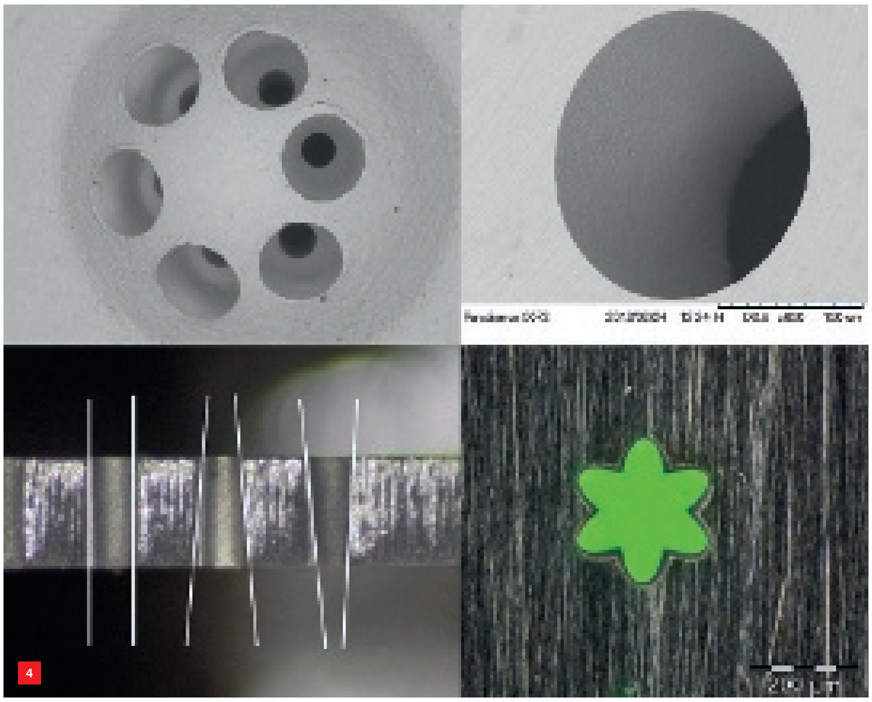
The first industrial contributor was Louise Partridge of SPI Lasers who presented *Versatility of ns Pulsed Fibre Lasers for Precision Manufacturing Applications*. Pulsed fibre lasers are seeing new application growth and it was suggested that pulse shape control would expand this further. Applications in marking (Figure 3), cutting and even creating coloured effects were shown and a discussion on the control of beam parameters to produce different processing effects was presented. Examples in several different metal materials were shown with examples on how beam quality impacts surface results and texture.

While the lasers themselves are of critical importance, so is the control mechanism for delivering their output and achieving a process solution. One of the CIM UP's researchers, Karen Yu, presented *Control System for Ultra Precision Processing*. While this explicitly covered the laser-assisted FIB platform introduced by Prof. O'Neill earlier, the questions from the floor clearly indicated the audience could see alternative applications for the control method and for the Optical Coherence Tomography (OCT) metrology that had been developed for this platform. The laser-FIB also includes Digital Holographic Microscopy (DHM) and the combined use of the two metrology techniques on a single platform was presented [2].

Trends and advances

New Trends in Ultrafast Material Processing was presented by Frank Gäbler of Coherent Inc. (Figure 4). This gave a general overview of the application ranges for ultra-fast (pico- and femtosecond lasers) and the impact of pulse duration on the heat-affected zone (HAZ). The presentation went wider than just the technical issues and considered some of the cost and quality issues, but the primary focus was on the ablation capability of this type of laser. Energy-duration trade-offs were discussed and presented and the trend in cost reduction for lasers was also covered in this wide-ranging talk.

Oxford Lasers provides laser-machining centres, hence Andrew Kearsley presented on *Advances in Laser Micromachining*. This presentation focussed on the process itself, rather than the laser, to achieve high-quality finished micro-machining. In particular the pulse duration was suggested as being secondary to the process in the quality and that any laser could, if incorrectly applied, produce a poor quality finish. This had been intimated earlier in a question session where asked if the material was as critical, another speaker had also suggested the process was the most critical factor. Kearsley managed not only to reiterate


4

4 *Various examples of laser hole drilling applications using femtosecond lasers. (Photo courtesy of Coherent Inc.).*

5 *Plasma distribution 1,000 ns after a train of laser pulses has interacted with a material. (Image courtesy of Dr K. Pangovski, CIM in Laser Based Production Processes, www.fourier.domains)*

this, but could also show examples to demonstrate the principle.

Additive manufacturing

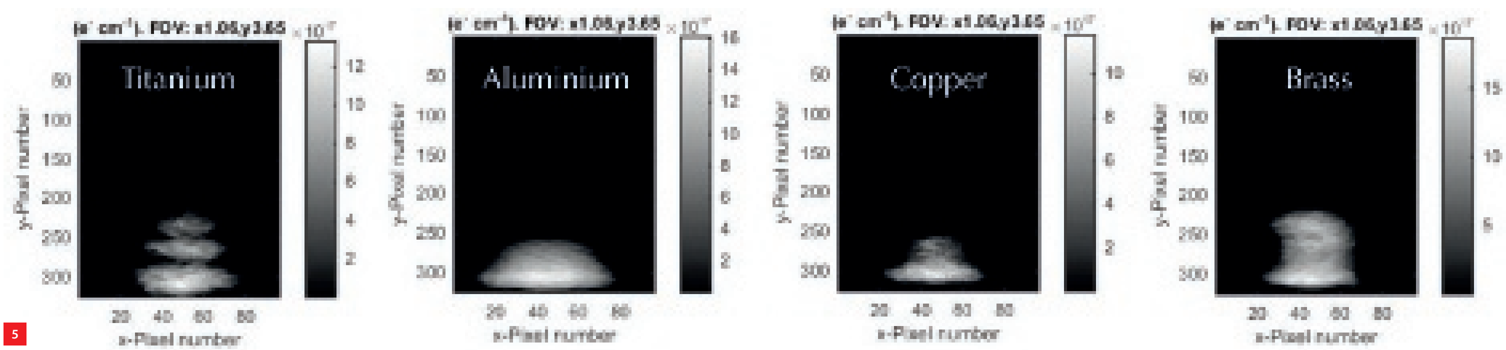
Presenting research performed in the CIM in Laser Based Production Processes, Wojciech Gora in his presentation *Laser Finishing – Improving the Surface Quality of Additively Manufactured Components* showed how using specific surface melting treatments, mostly on aerospace-grade titanium-aluminium-vanadium (Ti6Al4V), allowed superior surface topography. The presentation did not omit some of the issues that can be created with such processes, including step profiles, needles and ripples, and also addressed issues regarding undercut. Some possible solutions were presented, including finishing the surface during the manufacturing process for additively manufactured parts; in particular this allows undercuts and non-accessible surfaces to be treated and finished in a way not possible with mechanical finishing, and more selectively than can be achieved with chemical processing.

In a second look at laser-based additively manufactured parts, Dr Renaud Jourdain of Cranfield University presented *An Approach for Laser Finishing of Wire + Arc Additive Manufacturing Components*. This presentation followed on from the previous one, looking at significantly larger parts, manufactured using an additive welding process for airframe and large metal components, including titanium again. The issues of the metrology for determining the correct measurement method going either across the weld-bead or along the axis of construction was considered. The end results presented suggested surface topology improvements of 70% in both form and roughness were possible with a laser finishing process, once laser fluence and beam overlap parameters had been optimised.

Plasma plumes

The final presentation was *Investigation into the Ablation Mechanisms of Titanium, Aluminium, Copper and Brass in Percussion Drilling Operations using Ultra-High Speed Digital Holography*, which was to some extent a look at the plasma plume around a laser drilling site with a high-speed holographic camera taking 1 billion frames/second (Figure 5). Presented by Dr Krste (Kris) Pangovski of Cambridge University, this featured a comparison of the laser ablation plasma plumes around the different metals and a consideration of why they were so significantly different once the plume had formed, and examined the mechanisms for understanding plume formation. This should help in pre-determining beam parameters for drilling processes.

It was certainly a very interesting presentation and the considerable differences in plume formation were initially difficult to understand from the material viewpoint, although the formation theory was relatively straight-forward to follow. This is an extremely interesting area of research and it should directly help feed the early industrial



5

presentations on designing laser beam parametric control and selection of different pulse durations for this laser-based process.

To conclude

Although the presentations had come in completely independently, there was a general theme on the day pointing at the process and control of the laser itself still requiring some research before its application is fully understood in all these manufacturing processes. While the laser is obviously not a new tool in the manufacturer's arsenal of processing technologies, there is still quite a lot of work still ongoing to fully characterise the parametric optimisation of lasers for specific processes and specific materials and it was encouraging to see so much of this manufacturing research ongoing in UK universities and research groups, and the application by the industrial laser suppliers.

The event was very well attended and delegates were provided with an extended lunch period to visit the Photonex exhibition in an adjacent hall. The feedback from delegates was extremely positive and there would appear to be a good appetite for advances in laser processing for UP manufacturing in the UK, both in industry and academia. Networking events such as this seminar are intended to help bridge that gap, showcasing both academic research and industrial application of emergent technologies.

It would be quite easy to come away from this event, covering such a broad range of laser-based applications – marking, cutting, surface texturing and finishing, drilling and metrology –, believing that lasers were the solution to all Ultra Precision machining processes. But there are still application areas and requirements that can't be met by laser-based processes alone and the centre, CIM UP, will be visiting some of these subjects in 2016 [3]. ■

REFERENCES

[1] M. O'Hara, "What's UP? – Ultra Precision Manufacturing in the UK", *Mikroniek* 55 (1), pp. 18-21, 2015.

[2] K. Yu, M. Sparkes and W. O'Neill, "OCT and DHM – Control system for ultra-precision laser processing", *Mikroniek* 55 (5), pp. 32-34, 2015.

[3] www.ultraprecision.org

PICKING **ROBOTICS** **RESEARCH** PARTNERS

In the Dutch high-mix, low-volume manufacturing industry, the robotisation of parts handling using classic industrial robots is not a straightforward matter. One promising automation concept is that of a simple-to-install bin-picking robot that picks randomly placed and stacked parts from a bin. This is the focus of the Dutch so-called RAAK bin-picking research project. The Danish Technological Institute (DTI) was identified as an additional, highly qualified international research partner.

HENK KIELA

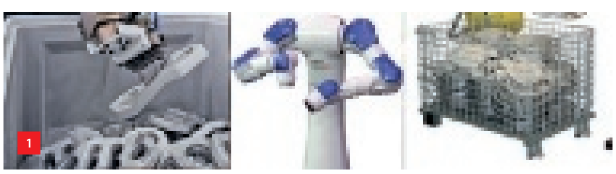
AUTHOR'S NOTE

Henk Kiela is a professor of Applied Mechatronics and Robotics at Fontys University of Applied Sciences in Eindhoven, the Netherlands.

h.kiela@fontys.nl
www.fontys.nl

At least some 20-30% of production time in the Dutch manufacturing industry is spent on moving goods at the work place or on the factory floor between work places. In many cases, this work is performed by skilled machine or process operators. The variation in high-quality complex products and the relatively small production volumes means that robotisation using classic industrial robots is not easy and often not feasible. Potential solutions include mobile robots for automating goods movement between work places or simple-to-install bin-picking robots that pick randomly placed and stacked parts from a bin and put them in a machine.

This latter option is the focus of the so-called RAAK bin-picking project. RAAK is a Dutch government funding programme for universities of applied sciences to carry out applied research projects. RAAK stands for regional attention and action for knowledge circulation. The two-year RAAK projects are typically run with at least ten SMEs and several universities and universities of applied sciences.



1 *Signature illustration of the Bin-picking project.*

The bin-picking project is run by the School of Engineering of Fontys University of Applied Sciences (UAS) in Eindhoven together with UAS Avans (Prof. Jos Gunsing) in Breda, HU UAS in Utrecht (Prof. Erik Puik) and Eindhoven University of Technology (Prof. Henk Nijmeijer). The project seeks to demonstrate how to build a practical robotised bin-picking cell that can be operated safely in collaboration with workers (Figure 1). This is the so-called cobot concept.

DTI

A lot of research into robots is being conducted in Europe. DTI in Odense in Denmark runs quite a few robot projects that have a lot in common with the RAAK project.
With a staff of more than sixty robotic experts in the manufacturing industry and service industries, DTI is a leading European robotics innovator.

DTI is an independent, non-profit institute providing services in a wide range of industries. It is active in industrial technology, robotics, the food industry, transport, energy and other sectors and has a number of projects that cross domains, for example the R5-COP project that joins robotics and logistics solutions for the manufacturing industry and agribusiness (read the article on page 28).
DTI provides companies with robotic solutions that help improve quality, productivity and the work environment. Many DTI projects are EU-funded. Partners from the manufacturing industry and research bodies work together on these projects.

DTI's robotics-related technologies and expertise

- Industrial manipulators
- Grippers and grasp planning
- Robot programming
- Simulation and virtual production
- Service robotics (mobile, drones, underwater)
- Sensors (e.g. cameras, lasers, ultrasound, thermography for object recognition and inspection/quality control)
- Human-robot interaction
- Shared/assisted autonomy
- Optimisation of production (Lean)
- Manufacturing Intelligence

DTI's robotics-related activities

- Implementation of robot and automation solutions in the manufacturing industry.
- Sharing knowledge, training and education on new robot technologies with the manufacturing industry.
- Analysis and consultancy on strategic automation and choice of technologies.
- Research into, development and innovation of robot technology.

Topics

RAAK partners visited DTI in June 2015 to discuss relevant projects and a possible collaboration between the partners in the RAAK project and DTI projects. Below is a selection of the topics that were discussed.

Robot CoWorker is a project aimed at demonstrating how to assemble complex-shaped cast parts into a subassembly [1]. An interesting parallel development for this is the unified software for programming a robot cell with multiple robots, sensors, cameras, clamps, all in the same environment. The system acts as a graphic configuration layer on top of the Robot Operating System (ROS). As ROS strongly supports robot hardware abstraction, the programming/configuration software holds the promise that robot cells will be easy to configure. While this way of configuration allows people on the shop floor to configure a robot cell quickly for a new task, development is still ongoing.

Another relevant DTI research area is the work it is doing on 2D and 3D sensors and processes in relation to bin-picking. An example is the ScanLab platform for sorting, handling and recognition technologies. Research includes computer vision development and experimentation with material characterisation, object recognition and classification with sensor fusion, and grip planning for differently shaped objects.

2 *DTI's service robotics research areas.*

Another promising programme is that of service robotics (see Figure 2). In particular, the mobile robots developed with industrial partners as part of the R5-COP project may provide interesting solutions for goods movement between work places on the shop floor.

To conclude

The visit to DTI has provided the RAAK research partners with additional solutions and information regarding 2D/3D vision, grasping, programming of robot cells, etc. It was concluded that the people at DTI are involved in a lot of interesting robot research projects and that there are lots of opportunities to share knowledge and experience. DTI's ambitions fit perfectly with the ambitions of the RAAK partners in terms of their respective regional industries. ■

REFERENCES

[1] www.youtube.com/watch?v=L9v2n60-CEk

INFORMATION

For any questions, contact the author or go to the RAAK Aerobics website.

H.KIELA@FONTYS.NL
WWW.RAAKAEROBICS.NL

PUPPETS ON A STRING

There's one mechanical element that most people use every day and have been doing so for over 10,000 years. It's cheap, easy to handle and, thanks to ongoing research, it has become even stronger and more lightweight over the millennia. This element is the cable, present versions of which have superb properties. For nearly twenty years, a community of engineering researchers has been using simple cables for sophisticated purposes, to develop and build extremely large and fast robots that open up new branches of automation.

TOBIAS BRUCKMANN, JEAN-PIERRE MERLET, STEFAN SPANJER AND JUST HERDER

Robots have changed production processes. Whenever the assembly of a product consists of repetitive steps, it is likely that something like an articulated robot or a SCARA can do the job fast, precisely and reliably. But when you look more closely, there are drawbacks. The mass of the moving robot is usually a multiple of the payload. This increases power consumption and limits acceleration and speed capabilities. Additionally, the use of this type of robot is limited depending on the size of the workspace. If the manipulator arms are longer than several meters, they become extremely heavy and elasticity begins to dominate the dynamic behaviour of the manipulator.

From a kinematic point of view, there is a different class of manipulators that also performs very well in terms of precision and velocity. This class comprises parallel kinematic manipulators, i.e. systems where the end-effector is connected to the base via multiple kinematic chains. The most dynamic robots on the market use parallel structures, like the delta robot that has been sold as the FlexPicker since 1999. But classic parallel kinematics reveal drawbacks that limit their application range. Compared to the construction space, the volume of the workspace is usually quite small because the strokes of linear actuators or the crank lengths of rotary drives, respectively, are limited. What's more, some types of parallel robots use sophisticated joints and actuators, something that increases manufacturing costs.

Cable robots

That said, there is a simple solution to eliminate both drawbacks. The stiff links can be replaced by cables, the joints replaced by pulleys and the actuators substituted by winches [1]. This creates a cable-driven parallel kinematic manipulator – in short, a cable robot – that has a number of interesting properties:

- An extremely large workspace
  Since the cable lengths are virtually infinite, very long distances can be spanned. Think of suspended cameras in a sports stadium; tens of meters can be easily bridged.
- Super-lightweight
  Steel cables, but even more modern fibre cables can carry enormous loads compared to their own weight. This facilitates building robots where (nearly) only the payload needs to be moved.
- Mechanically simple and reliable
  Only drums and motors are needed to build a winch. Winches have been used for thousands of years. They can be produced as identical modules. To build a wire robot, the only additional things required are cables, pulleys, sensors and a control system.

Engineers have been using cables for ages to lift heavy objects, e.g. to raise trade goods or submarines off the sea bed or to build ski lifts to reach the top of a mountain. Modern theatres use dozens of cables and winches to magically move objects and actors on the stage. And every day, millions of people put their lives into the hands of elevators, contraptions that are suspended for hundreds of meters.

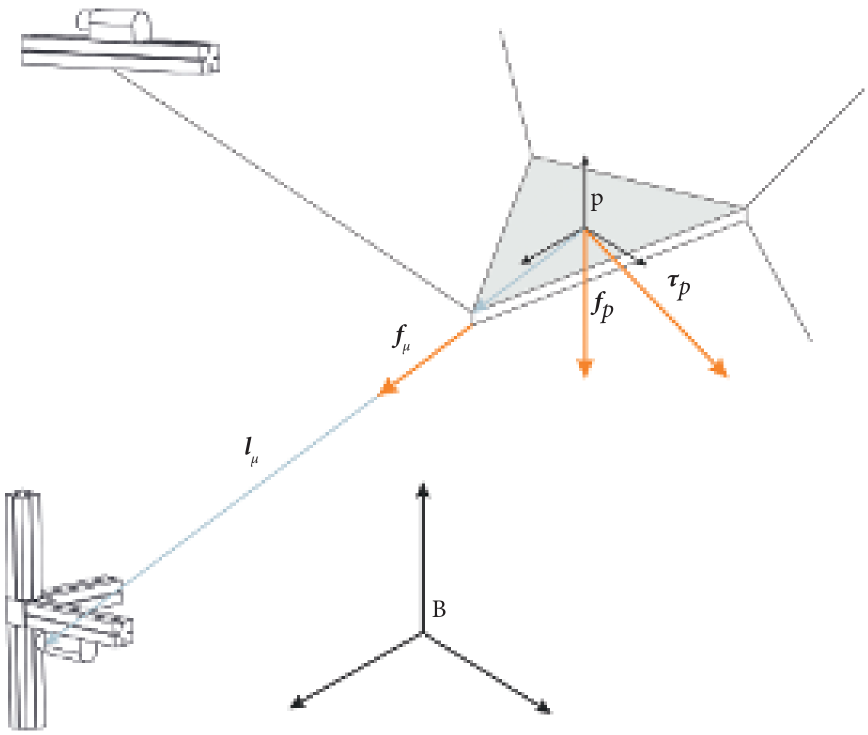
Operation

Interestingly, the number of cables in use may vary. From a certain point of view, a crane suspending a load is the simplest cable robot possible. Obviously in this case the payload is prone to oscillations, which makes it difficult to use cranes for automated tasks. The simplest approach is to

AUTHORS' NOTE

Dr.-Ing. Tobias Bruckmann is a Senior Researcher at the University of Duisburg-Essen, Germany, leading the group for Robotics Research at the Chair of Mechatronics. Dr. Jean-Pierre Merlet is Research Director and Senior Researcher at Inria, France. Ir. Stefan Spanjer is a graduate of the University of Twente and is founder and director of Kite Robotics, based in Enschede, the Netherlands. Dr.ir. Just Herder is professor of Mechanical Engineering at the universities of Delft and Twente.

bruckmann@mechatronik.uni-duisburg.de
www.mechatronik.uni-duisburg.de



1

1 *Definition of forces and geometry of the moving platform.*

add cables. To guide a point-shaped payload with three degrees of freedom in space, three cables are required – but only if it can be guaranteed that the cables are tensed by an external force, e.g. gravity. This is due to the fact that cables can only pull, but never push, meaning they introduce only a unilateral constraint on the point's movement. Accordingly, a cable should always be tensed, otherwise it is rendered useless.

It follows that for the suspended way of operating a cable robot – called a suspended robot, with n degrees of freedom, operated using m cables – appropriate external forces like gravity are needed. In practical terms, these robots are able to oscillate if disturbance forces occur. To suppress oscillations, tension in the cables is necessary. This can be realised by additional cables fixed to the moving platform (Figure 1).

In a proper arrangement, the cables in certain areas of the workspace are able to pull against the other cables. Assuming a control system that maintains tension in all the cables (combined with a cascaded pose or cable length control, respectively), an inner tension can be created. This may increase stiffness, prevent cable slackness and suppress oscillations. A robot using wires that pull against each other is called a fully constrained robot; it needs $m \geq n + 1$ cables under tension. Many designs used in suspended configurations may also fulfil the latter condition, but to allow for a workspace containing constrained platform poses, the aforementioned condition is required.

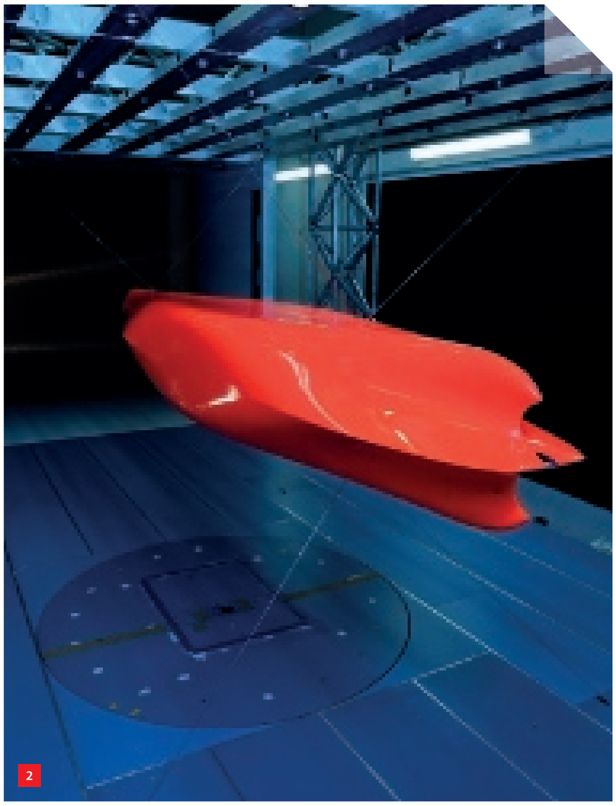
Control

While the mechanical components are simple, the control needs to ensure that the cables have an appropriate tension to support the payload or process forces at all poses and can accelerate or brake. Assuming vectors $\boldsymbol{l}_\mu$ ($\mu = 1, \ldots, m$) from the platform to the pulleys, cable forces f_μ and a vector of platform forces and torques $\boldsymbol{w}$ (including inertia and gravity), it holds [2]:

$$\underbrace{\begin{bmatrix} \boldsymbol{v}_1 & \cdots & \boldsymbol{v}_m \\ \boldsymbol{p}_1 \times \boldsymbol{v}_1 & \cdots & \boldsymbol{p}_m \times \boldsymbol{v}_m \end{bmatrix}}_{\boldsymbol{A}^T} \underbrace{\begin{bmatrix} f_1 \\ \vdots \\ f_m \end{bmatrix}}_{\boldsymbol{f}} + \underbrace{\begin{bmatrix} \boldsymbol{f}_p \\ \boldsymbol{\tau}_p \end{bmatrix}}_{\boldsymbol{w}} = \boldsymbol{0},$$

$$\text{where } \boldsymbol{v}_\mu = \frac{\boldsymbol{l}_\mu}{\|\boldsymbol{l}_\mu\|_2}$$

Assuming a robot with $m \geq n + 1$ cables under tension for a given pose and platform wrench, the computation of a set of cable forces where all cables maintain a minimum tension level f_{min} (to avoid slackness and minimise sagging) at least, but do not exceed the maximum workload f_{max} or the maximum torque of the drives, respectively, already presents an underdetermined problem. In this case, the inner tension can be varied, e.g. to save energy. This variation needs to ensure continuous results and consider



2 *Wind tunnel suspension system. (Courtesy of the Institute for Fluid Dynamics and Ship Theory, Hamburg University of Technology)*

3 *Artist impression of a green energy field with wind turbines and the NEMOS wave energy harvesters which are the yellow buoys with cables connecting generators and the seabed. (Courtesy of NEMOS)*

the minimum and maximum force limits at the same time. This results in a constrained optimisation problem:

$$\text{minimize } g(\boldsymbol{f}) = \|\boldsymbol{f}\|_2 = \sqrt[2]{\sum_{\mu=1}^{m} f_\mu^2} = \sqrt[2]{f_1^2 + f_2^2 + \cdots + f_m^2}$$

$$\text{subject to } 0 < f_{\min} \le f_\mu \le f_{\max}$$

While this ensures the appropriate tension level, a robot is usually expected to maintain a certain movement precision. Here, even the computation of the actual platform pose only using cable lengths – called forward kinematics – is already computationally demanding for most cable robot designs. Currently, the computation of forward kinematics using more realistic cable models, including elasticity and sagging, is the subject of ongoing research [3].

The need for tension control as well as elasticity introduces additional difficulties for precise motions. French researchers built a large prototype (15 m × 11 m × 6 m) and demonstrated a remarkable repeatability of a few millimeters, with an accuracy of approximately few centimeters [4]. Therefore, for precision applications, external pose measurements and high controller frequencies are recommended.

Projects

Nowadays, these challenges have been addressed extensively. The required control algorithms are available on modern industrial control hardware [5]. Analysis and design software for workspace computations [6] [7] has been developed, and even verified results for forward kinematics are available [8]. On the practical side, a couple of application prototypes have been developed, where European researchers played an important role.

Cable robots have been the subject of research at the University of Duisburg-Essen in Germany since the late 1990s, where prototyping was always focussed on evaluating developed algorithms. In 2011, a first application was realised in cooperation with the Hamburg University of Technology. In this case, a wind tunnel suspension system based on cable robot technology was realised to move aerodynamic probes of up to 150 kg (Figure 2). Actually, there is no other concept available that is able to move these probes without disturbing the air flow.

In 2013, the research team in Duisburg realised a cable robot control system for the prototype of a wave energy harvesting system developed by the company NEMOS (Figure 3). In the project, energy conversion realised though a floating buoy was drastically improved by replacing the single cable of conventional approaches by a wire robot with three cables. A scaled prototype is currently being tested in Denmark and a full-size version can be expected soon.

A demonstrator of a cable-driven high-rack storage and retrieval machine was built in Duisburg in early 2012 in

close industry cooperation (Figure 4). In this case, several advantages of a cable robot could be used. Instead of moving a massive lifter device in a rail in front of a high rack, only the payload is moved by a tensed system of cables. This drastically reduces the moving masses and allows for extremely high dynamics or a decrease in energy consumption. A prototype 12 m long and 6 m high has been tested extensively since 2014.

To conclude

This technology is driven towards applications at a European level too. A consortium of academic institutions and industry parties looked at applications in the domain of large-scale handling and manipulation, e.g. for aircraft maintenance, as part of the CableBOT project[9]. The idea behind the project is to identify application potential in industrial sectors that could not accommodate automation up to now due to the required robot sizes.

4 *Cable-driven storage and retrieval machine at the University of Duisburg-Essen. The moving platform is in stand-by position on the ground. Boxes can be picked from and stored to the shelves, respectively, using a push-and-pull device on the platform.*

Autonomous window-cleaning robot

University of Twente spin-off KITE Robotics was founded in 2012, and together with the Laboratory of Mechanical Automation and Mechatronics (Prof. Just Herder, Dr Volkert van der Wijk and Kevin Voss, M.Sc.), it has conducted research into cable-driven robots. This November, a milestone was celebrated: the first building was cleaned using a cable-driven robot. The building in question was the almost entirely glass Spiegel building at the entrance of the university campus.

A system of four cables was developed to steer the robot on the building. By manipulating the cables, the position of the robot changes and the robot moves across the entire building. Apart from positioning the robot, one of the other challenges was how to ensure a high level of cleaning. As such, the KITE robot was given a special suspension system and brush design. During the cleaning process (four or six times a year on a subscription basis), the robot is attached to clamps mounted on the building.

The robot is suitable for cleaning large buildings that pose a high risk to traditional window cleaners. It is aimed at building managers and cleaning companies. Window cleaners usually have to work at great heights in all kinds of weather, so their job is dangerous as well as physically demanding (one of the most dangerous jobs in the world, according to insurance companies). The KITE robot can clean buildings (glass as well as frames and many other materials) up to a height of around 80 meters.

WWW.KITEROBOTICS.COM

The KITE cleaning robot in action. (Photos: Gijs van Ouwerkerk/KITE Robotics)

This technology has a great potential for robot applications where acceleration and lightweight manipulators are important and where large workspaces are essential. Additionally, since a cable robot allows for the automation of many tasks that are currently being done by cranes, there is a wide field of further opportunities yet to be explored. ■

REFERENCES

[1] Landsberger, S.E. and Sheridan, T.B. (1985), "A new design for parallel link manipulators", *Proceedings of the 1985 IEEE International Conference of Systems, Man and Cybernetics*.
[2] Bruckmann, T., Mikelsons, L., Brandt, T., Hiller, M. and Schramm, D. (2008), "Wire Robots Part I - Kinematics, Analysis & Design", In: J.-H. Ryu (Ed.), *Parallel Manipulators, New Developments*, Vienna, Austria, I-Tech Education, pp. 109-132.
[3] Merlet, J.-P. (2015), "On the real-time calculation of the forward kinematics of suspended cable-driven parallel robots", *14th World Congress in Mechanism and Machine Science*, Taipei, Taiwan.
[4] Nguyen, D.Q., Gouttefarde, M., Company, O. and Pierrot, F. (2013), "On the Simplifications of Cable Model in Static Analysis of Large-Dimension Cable-Driven Parallel Robots", *2013 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, Tokyo, Japan.
[5] Reichert, C. and Bruckmann, T. (2015), "Unified Contact Force Control Approach for Cable-driven Parallel Robots using an Impedance/Admittance Control Strategy", *Proceedings of the 14th World Congress in Mechanism and Machine Science*, Taipei, Taiwan.
[6] Gouttefarde, M., Krut, S., Company, O., Pierrot, F. and Ramdani, N. (2008), "On the Design of Fully Constrained Parallel Cable-Driven Robots", In J. Lenarčič and P. Wenger, *Advances in Robot Kinematics: Analysis and Design*, Springer Netherlands.
[7] Berti, A., Merlet, J.-P. and Carricato, M. (2014), "Workspace Analysis of Redundant Cable-Suspended Parallel Robots", In Pott, A. and Bruckmann, T., *Second International Conference on Cable-Driven Parallel Robots (CableCon2014)*, Springer Verlag.
[8] Merlet, J.-P. (2014), "The Forward Kinematics of Cable-Driven Parallel Robots with Sagging Cables", In Pott, A. and Bruckmann, T., *Second International Conference on Cable-Driven Parallel Robots (CableCon2014)*, Springer Verlag.
[9] www.cablebot.eu

Helping elderly people

At Inria, the French National Institute for computer science and applied mathematics, a low-cost cable-driven parallel robot is being used to help move elderly people. In this case, four cables are used to help elderly people weighing up to 200 kg to get up, stand and walk independently, wherever they are in the room. At the same time, the robot platform is instructed to monitor the walking pattern of the elderly people as required by the medical community for functional and cognitive assessment. Furthermore, this robot is non-intrusive: when not in use it can completely disappear into the ceiling.

WWW.INRIA.FR/EN/CENTRE/SOPHIA

A patient being transported by a low-cost cable-driven parallel robot that was developed at the Sophia Antipolis (France) location of Inria.

WORLD'S FIRST MULTI-METAL PRINTER

High-end technology supplier Demcon has developed a multi-metal printer for additive manufacturing based on metal-jetting technology from Océ - A Canon Company. This printer is now available to explore the possibilities and applications of this unique technology. The first version was recently delivered to Professor Richard Hague's research group in Nottingham and will be used to carry out pioneering application research.

AUTHOR'S NOTE

Hans van Eerden is a freelance text writer in Winterswijk, the Netherlands. He is also the editor of Mikroniek.

HANS VAN EERDEN

Based on its knowledge and years of experience in the field of inkjet technology, Océ has developed a 'drop-on-demand' printhead that can 'jet' various metals with melting temperatures up to 1,800 degrees Celsius. Océ's research is focussed primarily on the jetting process: how can the printhead generate metal droplets reproducibly and stably, what parameters play a role and which metals lend themselves best for this process?

The process is now suitable for various metals, including tin, copper and silver. Océ has identified a wide range of applications, from ultra-thin connectors for the current and future-generation chips to microstructures on machine parts. Océ's metal-jetting technology is suitable for printing three-dimensional structures of multiple metals, but printing metal traces on flexible electronics or customised jewellery from precious metals are also interesting applications.

1 *The multi-metal printer developed by Demcon.*

British interest

One of the people interested in the development at Océ was Richard Hague, professor of Innovative Manufacturing and head of the Additive Manufacturing and 3D Printing research group at the University of Nottingham, UK. Hague, who is also director of the British EPSRC Centre for Additive Manufacturing, is recognised as an authority in the field of design, processing and materials for additive manufacturing and is focussing increasingly on technologies for jetting materials. This led to an agreement for the delivery of the first multi-metal printer using the metaljet technology. Océ delivered the printheads and the University of Nottingham tasked DEMCON with the design and construction of a metal-jetting system in which these printheads are integrated.

Mechatronics

DEMCON is a specialist in mechatronics, which combines disciplines like mechanics, electronics and software for the development and construction of advanced equipment. In the developed 3D printer (Figure 1), the printheads have a fixed position, because of the necessary 'infrastructure' to keep the metals at a high temperature. The substrate moves with high accuracy under these heads. The timing of the print pulses is crucial to dispense the next metal droplet on top of the already printed object on the moving substrate.

Continue on page 47

TSPE: A NEW PRECISION ENGINEERING SOCIETY

The Taiwan Society for Precision Engineering (TSPE) was founded as a non-profit members' association in 2014 at Chutung, Taiwan. TSPE is dedicated to promoting the research and application of precision engineering technology in order to assist academic development as well as industrial upgrading and transformation.

Within TSPE, the precision engineering field includes electrical and electronic systems, information technology, machinery, materials, chemistry, optics and measurement analysis, etc. TSPE has been actively cultivating the most important industrial and fundamental technology in precision engineering. It is aiming to master the technology of critical manufacturing equipment, components, raw materials and processes. TSPE is committed to enhancing Taiwan's industrial competitiveness.

Missions

1. Advance the research of precision engineering technology and promote its industrial application as well as development by integrating manpower and resources in relevant disciplines.
2. Organise and conduct precision engineering workshops, training courses, discussions, demonstrations, exhibitions and related activities.
3. Collect state-of-the-art information on precision engineering for the reference of academic and industrial research.
4. Entrusted by the government and enterprises to conduct research or solve problems related to precision engineering and provide a professional evaluation and assessment service.
5. Help schools to implement precision engineering education and research.
6. Networking with domestic and overseas agencies, academic institutions and industrial organisations to promote academic and technological interaction.
7. Engage in activities in line with the missions of TSPE.

History

The first president and honorary founder of TSPE is Dr Chia-Tung Lee, who is a senior advisor to Taiwan's president as well as an honorary professor of National Tsing Hua University. He is known as a prestigious scholar and researcher in fundamental science and engineering. Dr Lee has been concerned about the lack of consistent standard and common language on precision engineering development in Taiwan. He has reminded those in power that they should realise the important role of the 'engineer' when setting up national strategies for industrial upgrading.

With this vision in mind, the first preparatory meeting of TSPE was held on 22 October 2014 and then it was officially founded on 30 January 2015, when the first General Assembly Meeting and Board of Directors Election were held. Since then, TSPE has been actively sharing common R&D outcomes and trying to eliminate lots of duplicate errors from industrial development processes.

Activities

TSPE has actively participated in several global events, such as the 6th ASPEN (Asian Society for Precision Engineering and Nanotechnology) conference held in Harbin, China, on 15-19 August 2015, and the 14th IFToMM World Congress (of the International Federation for the Promotion of Mechanism and Machine Science) held in Taipei, Taiwan, on 25-30 October 2015. TSPE was the co-organiser of the Industry 4.0 Conference held in ITRI, Taiwan, on 30 September 2015. Also, TSPE is planning to hold an annual event, the Precision Engineering Symposium and Exhibition, which in 2016 will take place at National Tsing Hua University.

EDITORIAL NOTE

This news item was contributed by Larry Chang, Director of Strategic Planning and Promotion Division ITRI/MSL, and Shuo-Hung Chang, member of the TSPE Board of Directors / Executive vice president, ITRI.

1 *The second meeting of the first-term TSPE Board of Directors was held on 3 August 2015.*

TSPE Board of Directors
- *President and member, Chia-Tung Lee (Senior advisor to the president of Taiwan / Honorary professor, Nat'l Tsing Hua Univ.)*
- *Director and member, Executive Committee (EC), Cheng-Wen Wu (Senior vice president of academic affairs, Nat'l Tsing Hua Univ.)*
- *Director and member, EC, Shuo-Hung Chang (Executive vice president, Industrial Technology Research Institute (ITRI))*
- *Director and member, EC, Cheng-Kuo Sung (Professor, Dept. of Power Mechanical Engineering, Nat'l Tsing Hua Univ.)*
- *Director and member, EC, Chan-Hua Feng (Chief, Dept. of Engineering and Technologies, Ministry of Science and Technology / Professor, Dept. of Mechanical Engineering, Nat'l Chung Cheng Univ.)*
- *Supervisor and Chair, Supervisory Board, Ping-Hui Su (Former advisor, Dept. of Industrial Technology, Ministry of Economic Affairs / Professor, Dept. of Vehicle Engineering, Nat'l Taipei Univ. of Technology)*

Membership recruitment

TSPE forms a unique community and platform for sharing professional knowledge & technology in the field of precision engineering. Currently, it has more than 100 group and individual members. The members represent a variety of organisations from enterprises, academia and national labs. Many TSPE members are driving forces of Taiwan industry, such as HIWIN, Hermes Microvision, Shuz Tung Machinery, AST, Patech Fine Chemicals, FiberLogic, aePlasma 41, Avision, AccuteX, ITRI, National Taiwan University, National Tsing Hua University, Ministry of Science and Technology, etc. TSPE members are expected to join the annual assembly meeting held each spring. ■

INFORMATION
WWW.TSPE.ORG.TW (IN CHINESE)

Continuation from page 45

Metal droplets are formed by pushing molten metal through a small opening in the printhead using the Lorentz force.

Precise droplets

As is usual in 3D printing, the jetting is carried out in layers. Each droplet must land in exactly the right position within a layer and each following layer must be positioned accurately on top of the previous layer (this is called overlay). Various metals can be printed in each layer, originating from the different printheads. The overlay between printed droplets from various heads in a single layer is precise to 5 μm, as is the overlay from layer to layer. The jetting process is analysed using an ImageXpert droplet analysis system. A high-speed camera measures the speed, diameter and angle of the metal droplets. This system can also be used during printing to monitor the stability of the jetting process.

Eindhoven

Within DEMCON, the project for the metal-jetting system was carried out in Eindhoven. Toon Hermans, Managing Director of DEMCON Eindhoven, says, "We have not only the hardware and software developers required for this, but also the infrastructure to build the prototype. The construction of this printer was a complex integration task involving numerous disciplines. We have gone from a lab set-up that simply fires metal droplets to a 4-head printer. Such an upscaling is often underestimated."

New market

The cooperation with Océ goes beyond the construction of one metal-jetting system. Director Dennis Schipper from DEMCON explains, "When other parties see the ground-breaking applications the researchers at Nottingham are working on, they can start to look for their own applications. In the long term, production machines can also be created. Together with Océ, we can serve these customers with a customised machine. We are also cooperating with Nottingham on the technology development for their feedback on the metal-jetting system and further research into applications for the Océ metal-jetting technology." ■

INFORMATION
WWW.DEMCON.NL
GLOBAL.OCE.COM
WWW.EPSRC.AC.UK/RESEARCH/CENTRES/
INNOVATIVEMANUFACTURING/IMRCADDITIVE

NO PARTICLE LARGER THAN 1 µM

Technological advances in the field of microstructures and the need to process larger substrates called for the installation of a new final cleaning system at POG Präzisionsoptik Gera. The equipment solution proposed by UCM makes it possible to clean untreated wafers as well as structured and coated substrates. The cleanliness specification stipulating "no particle larger than 1 µm" can be reliably fulfilled.

AUTHOR'S NOTE

Doris Schulz is a journalist. Her agency, based in Korntal, Germany, specialises in PR solutions for technical products and services.
This article was commissioned by UCM.

www.schulzpressetext.de

DORIS SCHULZ

When the Zeiss Works in Gera, Germany, were closed down in 1991, the long tradition of optical manufacturing was preserved in POG Präzisionsoptik Gera. Today, the company has 140 employees. It develops and produces, on the one hand, custom optical precision parts, components and devices for the entire optical range of the spectrum, to be used.

On the other hand, the company has become a renowned manufacturer of both standardised and custom optical microstructures, e.g., net grid and scale graticules, USAF resolution targets, pinhole apertures and calibration targets. Recently, POG expanded the fabrication of microstructures in terms of both the range of technological options and the size of substrates that can be handled. Consequently, a new final cleaning system was needed (Figure 1).

1 For cleaning microstructures, such as this test target for testing lens systems, POG invested in a new ultrasonic ultra-fine cleaning system. (Photos: POG Präzisionsoptik Gera)

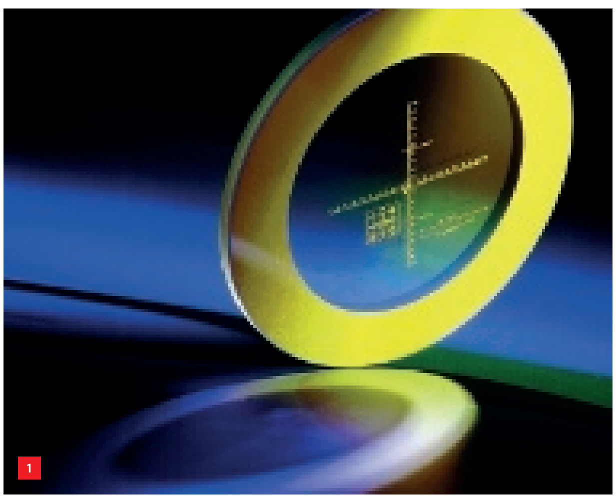
2 The patterns on the microstructured substrates measure as little as 2 µm in some cases, hence the cleanliness specification requires a maximum particle size of 1 µm. This USAF test target (originally defined in 1951 by the U.S. Air Force) is used for checking the resolution of optical imaging systems.

Maximum cleanliness

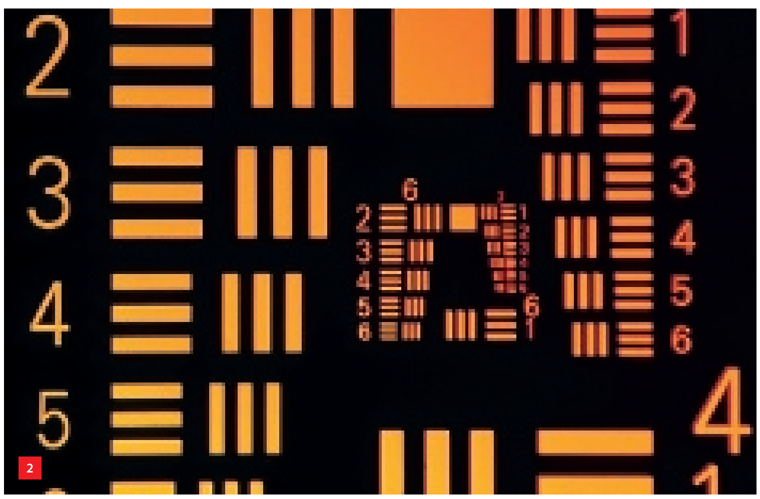
POG's optical microstructures are made chiefly from B 270 glass and quartz glass, as well as from ceramic and glass-ceramic substrates. A final cleaning step designed to remove dust, ultra-fine residue of polishing products and fingerprints is mandatory both with untreated substrates and after adding the structure and coating. Since the structures applied to the substrates measure only 2 µm in some cases, the cleanliness specification requires that no particle should be larger than 1 µm (Figure 2). POG developed a solution for these very exacting cleaning tasks jointly with an external consultant while discussing its technology with various equipment makers.

One versatile system

Various cleaning concepts for special uses such as cleaning masks or a specific substrate configuration for the



1



2

3 *The versatile cleaning system is set up in a cleanroom.*
(a) It is used to clean substrates both untreated and following application of the structure and coating.
(b) It comprises a total of eleven stations, including seven immersion tanks for cleaning and rinsing operations which can be flexibly selected.

semiconductor industry were considered. It appeared that POG would have needed three different systems to meet its cleaning needs, so it sought the assistance of Swiss-based UCM, a member of the Dürr Ecoclean Group. The expert in the manufacture of cleaning systems for optical products revised and adapted the equipment concept together with POG and an external consultant.

The new ultrasonic cleaning line is integrated in a cleanroom and comprises a total of eleven stations, including seven immersion tanks (Figure 3). These are designed for the following process steps: wet loading, cleaning with multi-frequency ultrasound (40 and 80 kHz), megasonic cleaning, rinsing, fine-rinsing, infrared drying over an indexing belt conveyor, and unloading.

The wet loading operation and all cleaning and rinsing processes are performed with demin. (fully demineralised) water. Depending on the cleaning program, the rinse water is used in a cascade loop, discarded, or passed to a separate drain. This method contributes to the high cleaning quality, as does the four-sided overflow feature developed by UCM which is used on all tanks.

The cleaning or rinsing fluid enters the tanks from below, moves upwards and then exits by overflow on all sides. As a result, foreign matter removed from the product will be discharged from the tanks straight away. This avoids re-contamination during unloading of parts while also preventing the formation of dirt pockets in the tanks. In addition, the substrates are treated very thoroughly and uniformly.

The rinse tanks come with another special design feature. Water is pumped into these tanks at high pressure so as to cause turbulence. This suffices, in conjunction with the product movement, to rinse the substrates without ultrasonic assistance at present. However, the mechanical equipment and control system are both prepared to support a future integration of ultrasound so that the user will be able to respond quickly and flexibly should more exacting demands arise.

Flexible control

The substrates to be treated, measuring up to 10 inches in size, are placed manually in the system's handling racks in special cassettes. The operator then selects the appropriate part-specific cleaning program. This is stored in the system's controller and determines which stations will be used in each case and which treatment parameters – e.g., ultrasonic power and frequency, dwell time – should be set for each tank. In order to ensure accurate compliance with the defined treatment duration at each station, the flexible control system supports an input of 'priority times'.
The cleaning system has been operating smoothly since its handover in March 2015. ■

INFORMATION
WWW.UCM-AG.COM
WWW.DURR-ECOCLEAN.COM
WWW.POG.EU

POSTGRADUATE PRECISION ENGINEERING EDUCATION GOES EUROPEAN

A joint DSPE-euspen symposium on postgraduate education in precision engineering was held on the second day of the Precision Fair in Veldhoven, the Netherlands. Inspired by the success of DSPE's Certified Precision Engineer program, euspen decided to take certification to a European level and the well-balanced symposium on 19 November marked the launch of the ECP² program.

DSPE developed a certification program in 2008 for commercially available training courses. These DSPE-certified courses were formally included in the development program for the title of certified precision engineer (CPE). Speaking during the symposium's first presentation, euspen Executive Director David Billington said that his association approached DSPE about its scheme about a year ago. Billington: "With the growing success of the DSPE scheme a collaboration has been agreed in order to extend the certification program from the national level to a European level. Our aim is to promote post-academic technical education by standardising certification of precision engineers across Europe."

CPE to ECP²

The result is the European Certified Precision Engineering Course Program (ECP²), which reflects the demand for multidisciplinary system thinking, excellent cooperative skills and an in-depth knowledge of the relevant disciplines. The ECP² program is based on the DSPE program, which means that all Dutch CPE-certified courses (see page 56) have been incorporated into the ECP² scheme, that all CPE points (credits a student can earn for each course; 25 points is a bronze level, while 45 points is a gold level, recognised with the title of CPE) have been transferred to the corresponding ECP² scheme. New courses, including those from other countries, will be added to the program after assessment and approval by the euspen Education and Scientific Committee.

Answers in Eindhoven

Following this first presentation, Nikola Vasiljević from the the Wind Energy department of Technical University of Denmark (DTU Wind Energy) talked about his research on the sensing of wind with light, i.e. with lidar (light detection and ranging). He vividly explained how he decided to go to Eindhoven, the pars pro toto of the Dutch high-tech (education) ecosystem, to get answers on the many high-level technical questions that arose in the course of his work. He did various CPE-certified courses and was the first to reach the bronze CPE level. Vasiljević's presentation clearly showed how the CPE program has helped him pursue his dream of designing a cheaper, more precise accurate and more robust scanning lidar that anyone with basic training can install and run.

Soft skills

To underline that there is more to a life of precision engineering than just having a technical education, Maarten van Herk, a freelancer working with Nu écht, talked about the importance of striking the right balance of hard and soft skills to increase one's impact in engineering. Complex engineering and innovation require collaboration, which involves communication, building relationships, personal and team leadership, and the awareness that success is always the result of a joint effort and that it needs to be celebrated. For an engineer to really have an impact in their job, they have to have technical skills and leadership qualities, but they also have to take into account the specific context of their job, Maarten van Herk concluded.

The ASML context

The next presentation saw Jelm Franse, Senior Director Mechanical Development at ASML, outline ASML's efforts in education and training. Franse came up with the idea for the ASML Academy, which Maarten van Herk helped set up. Franse discussed the need for continuous learning at ASML and the type of knowledge required for technical leaders, such as system architects, to have an impact: technical knowledge, personal effectiveness and – in the case of his company – the ASML Way of Working. Not surprisingly, the way knowledge management is organised at ASML reflects the complexity of its lithography machines and their development process.

■ *David Billington, Executive Director of euspen, (left) and Jan Willem Martens, chairman of the DSPE Certification Program, sign the agreement that officially marks the DSPE-euspen collaboration and the start of the ECP² program. (Photo: Jan Pasman/Mikrocentrum)*

'Employeneurs'

As the final speaker, Edwin de Zeeuw, Director Mechatronics of Dutch staffing & consultancy company TMC Group, argued that investing in the education of employees is not only about increasing their technical and leadership skills but also about boosting their morale, increasing staff retention, driving staff loyalty and boosting the employer's reputation. To conclude, he outlined TMC's practice of investing in coaching and encouraging the entrepreneurial spirit of its employees, called 'employeneurs', with a masterclass called *High Tech System Creation*, pizza sessions and an *Entrepreneurial Lab*.

Europe

If there was just one thing to take away from the symposium, then it was seeing how DSPE and euspen taking postgraduate education in precision engineering to a higher level in Europe boosted the symposium audience's morale. Similar kick-offs are planned in Germany, Belgium and the UK for early 2016, with other European countries set to follow in the next two years. Future issues of *Mikroniek* will share more on ECP². ■

WWW.EUSPEN.EU

WWW.DSPE.NL/EDUCATION

Precision in Business day at VDL ETG

On 8 October 2015, VDL Enabling Technologies Group (ETG) in Eindhoven, the Netherlands, hosted a well-attended Precision in Business (PiB) event organised by DSPE. A few times each year, a company opens its doors to allow the DSPE network to have a look and learn about each other's activities. This peek in each other's kitchen is instrumental in keeping our precision network alive and healthy to support our joint objective of staying world class by sharing experiences.

Following a general introduction on the history of the company and its current activities, CTO Guustaaf Savenije spent time to discuss the implications of a major transition that ETG is currently in the midst of: a move from offering build-to-print services as a contract manufacturing company, to also providing design services and even lifecycle management as a tier-1 supplier to its customers. This transition will allow ETG to increase its value proposition in a changing marketplace.

Taking the semiconductor equipment market as an example, equipment suppliers (the OEMs) have consolidated extensively and in semiconductor manufacturing 50% of capital expenditures is now done by the top-three: Samsung, Intel and TSMC. OEMs need to focus on cost of ownership for their customers and take responsibility for the functionality of their equipment – they move up towards their customers. In turn, contract manufacturers like VDL ETG need to climb up as well, and take function ownership for some of the modules for the OEMs. This poses challenges in terms of longer horizons for the total lifecycle of a module, as well as a responsibility to be pro-actively involved in the development of new technologies.

■ *Cleanroom assembly and qualification of a mechatronic module.*

After Guustaaf Savenije's presentation, the group was divided up in four smaller groups for the factory tour. Four dedicated topics were prepared.
At the first stop, visitors were shown some of the ongoing developments in the ETG parts production department: new, fully automated equipment, equipment with integrated functionality like cutting and turning, and a large new machining centre.
The second stop showed the cleanroom assembly and integration activities. A large vacuum system for a plasma source was highlighted as an example of the activities in the large cleanroom.
The third stop was in the development department and focussed on robotics for handlers, including robot control and new materials for end-effectors.
The fourth and last stop was in the thermal lab, where experiments are conducted to develop solutions for temperature control down to mK level non-uniformity.

After the tours, there were three, more detailed presentations:

- Technology roadmapping, connecting design and manufacturing technologies, by Ton Peijnenburg.
- The use of carbon fibre material for grippers, by Hans Steijaert.
- High-Voltage technology, by Paul Blom.

In the good PiB tradition, drinks were then served, over which people could reflect on the program and impressions, and share updates on other topics. The precision network in the Netherlands is (still) strong and by organising events like PiB, we can keep it like that! ■

WWW.VDLETG.COM

(report by Ton Peijnenburg, Manager Systems Engineering at VDL ETG)

THERE'S MUSIC IN PRECISION ENGINEERING

The 30th ASPE Annual Meeting was held in Austin, Texas, "the live music capital of the world" on 1-6 November 2015. The event was a great mixture of technical presentations, tutorials, exhibition and local adventures, with ample input from Dutch and Belgian participants.

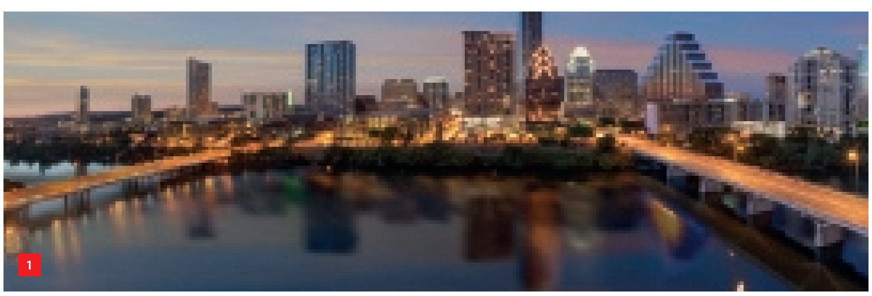
DANNIS BROUWER AND RAYMOND KNAAPEN

The annual meetings of the American Society for Precision Engineering (ASPE, aspe.net) are aimed at introducing new concepts, processes, equipment, and products while highlighting recent advances in precision measurement, design, control, and fabrication.

Tutorials

The meeting in Austin (Figure 1) started on Sunday with tutorials, with Dutch and Belgian input coming from Gerrit Oosterhuis and Martijn Vanloffelt and their tutorial *Applications of Additive Manufacturing to Precision*. Selected case studies were presented to illustrate specifics aspects of additive manufacturing (AM) and their impact on part performance within the context of precision-engineered systems. Part design, process settings for the AM process and post-processing of the parts were discussed at length.

Piet van Rens and Dannis Brouwer had over 40 participants for their full-day tutorial *Design Principles for Precision Engineering*. This tutorial covered the conceptual approach to designing precision mechanisms like manipulators, scientific instruments, precision equipment, etc. It focussed on the mechanical aspects of precision in the context of a mechatronic system.



1 *ASPE Annual Meeting 2015 host city Austin by night. (Photos courtesy of ASPE)*

Other interesting tutorials included *Introduction to System Identification*, *Practical Aspects of Thermal Control*, and *Introduction to Surface Finish Metrology*.

Student competition

A student competition & mentoring event was held at the same time on the Sunday evening and the Monday afternoon. The competition included mentoring from various precision engineering experts who made themselves available for one-on-one sessions. Companies donated their time and equipment to provide support and tutorials.

Fifteen students arranged in three teams (Figure 2) were challenged with the task of designing and building an XY-stage for a height scanner with 2 x 4 mm travel. The teams had to draw on their precision engineering skills to solve a multidisciplinary challenge covering mechanical, electrical, metrology and control aspects. It was very interesting to see all the different approaches they took and the sophisticated improvements they came up with.

Keynote address

Prof. S.V. Sreenivasan of the University of Texas delivered his keynote speech, *The Role of Precision Systems in Scalable Nanofabrication Based on UV Imprint Lithography,* on the Monday evening. Nanoimprint lithography techniques are known to have remarkable replication capabilities down to a sub-5 nm resolution. Translating this nano-scale resolution to commercially viable manufacturing processes requires carefully designed precision systems that can achieve a variety of process performance, cost and reliability targets.

Prof. Sreenivasan presented a specific form of UV imprint lithography known as Jet and Flash Imprint Lithography (J-FIL). J-FIL technology has been implemented in a stepper format with precision overlay to complement photolithography at sub-20 nm half-pitch nodes for semiconductor ICs.

Presentations and posters

The annual meeting featured a variety of presentation sessions. For instance, Prof. Paul Shore from Cranfield University in the UK gave a very good introduction to the need for precision engineering in solving many of the challenges in the roll-to-roll manufacturing, coating and registration of multi-meter flexible substrates.

The following sessions included some of the Dutch contributions:

- Precision Metrology, with Arjo Bos (Eindhoven University of Technology) presenting *Design of a Nanometer-Accurate Form Measurement Machine for Segmented Large Telescope Mirrors*.
- Control of Precision Mechatronic Systems, with Gijs van der Veen (Delft University of Technology) presenting *Topology Optimization for the Conceptual Design of Precision Mechatronic Systems* and Pieter Wullms (MI-Partners) with *Polymer Damper Technology for Improved System Dynamics*,
- Precision Roll-to-Roll Machine Design and Controls, with Raymond Knaapen of VDL ETG presenting *Equipment for Atmospheric Atomic Layer Deposition in Roll-to-Roll Processes.*
- Precision Mechanical Design, with Dannis Brouwer (University of Twente) presenting *System Behaviour of a Multiple Overconstrained Compliant Four-Bar Mechanism.*

Belgian and Dutch posters were featured in the following sessions:

- Control of Precision Mechatronics Systems, with a poster titled *Interferometric Active Inertial Isolation for Extended Structures* from Université Libre de Bruxelles, CERN and MIT.
- Interferometry and Optics, with a poster titled *Modular Versatile Imaging, Focusing & Illumination for Vision with High Stability and Accuracy* from Settels Savenije van Amelsvoort.
- Micro and Nanometrology and Measurement Uncertainty, with a poster titled *Self-Calibration of the Non-Linear Length Deviation of a Linear Encoder by Using Two Reading Heads* from KU Leuven and a poster titled *Modelling the Effects of Detector Misalignments on the Measurement of a Cylindrical Array of Aluminum Spheres by X-ray Computed Tomography* from NPL and KU Leuven.

2 *Teamwork during the student competition.*

Exhibition

The sold-out exhibition hall had all the areas you could expect to encourage our precision engineers to get the main components they need to build a precision system, including the controlled environment. Over forty participants exhibited their latest and greatest developments and products in the field of precision engineering. In the commercial session, each exhibitor had two and a half minutes to present their products and services.

Tours

On the Tuesday evening, all the participants went to the Circuit of the Americas, a recent addition to the Formula 1 championship in the US. While there, participants were given the opportunity to visit the pits where vintage car racing drivers were getting their cars ready to race on the following days.
On the final day of the conference, there were three technical tours, one of which took in the University of Austin NASCENT (Nanomanufacturing Systems for mobile Computing and Energy Technologies) Center where innovative wafer-scale and R2R manufacturing tools and processes are being developed for scalable fabrication of advanced nanoelectronics, photonics and flexible electronics. One of the NASCENT Center's specific aims is to enable future generations of mobile computing and mobile energy devices.

To conclude

The annual meeting was again a worthwhile interactive knowledge-exchange opportunity for devoted precision professionals. ■

AUTHORS' NOTE

Dannis Brouwer is an associate professor in the Mechanical Automation and Mechatronics group at the University of Twente in the Netherlands. Raymond Knaapen is Senior System Engineer at VDL ETG in Eindhoven, the Netherlands.
The authors acknowledge the input of Luis Aguirre, chair of the 2015 ASPE Annual Meeting and Senior Systems Engineering Specialist at 3M in Austin, Texas.
d.m.brouwer@utwente.nl

PATENT OR SECRET?

AUTHOR'S NOTE

Teun van Berkel is European Patent Attorney at AOMB IP Consultants, based in Eindhoven, the Netherlands. He is a specialist in acquiring and enforcing IP rights and guiding companies through the field of IP information.

www.aomb.nl/en

When a product stands out from the crowd due to the implemented software, it is advised to carefully consider protecting the product including the software. Companies may choose to keep their software developments a secret. However, this is not always possible. In particular when the software involved represents a significant commercial value, a third party might go to great lengths to reverse engineer the software. In that case, protecting software with a patent is often a worthwhile investment and is also quite common.

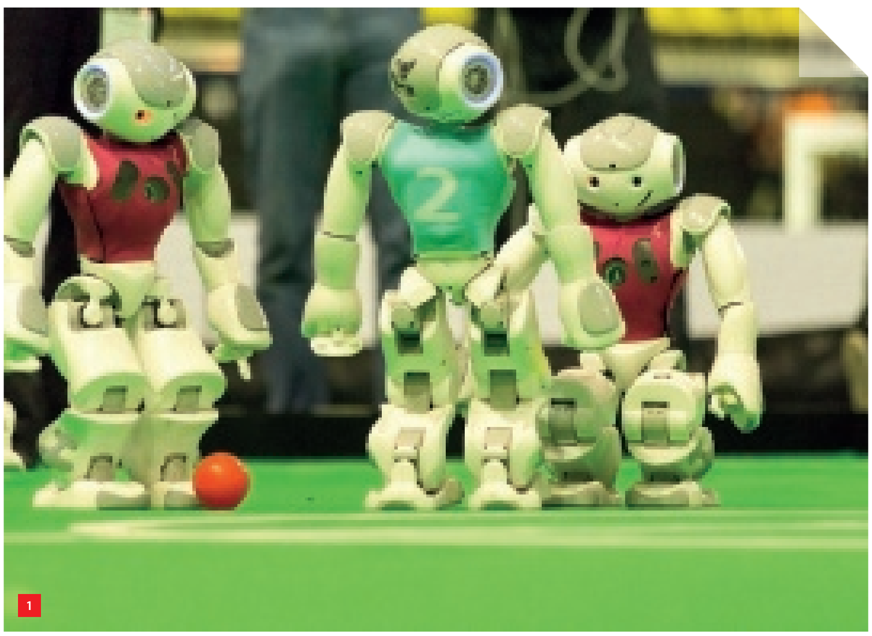
TEUN VAN BERKEL

Computer programs are an essential part of every robot. Even a mechanically and electrically well constructed robot will have a poor performance or may not perform at all if the computer program is poorly constructed. For example, in the RoboCup Standard Platform League all competing teams use standard robots like NAO by Aldebaran Robotics (see Figure 1). The difference between a victory or a defeat in this league depends on the software development.

Clearly, software can make a difference not only in a RoboCup League, but also for companies striving for a competitive advantage over their competitors. Companies increasingly rely on information technology, whether as a part of the product itself, in the making of the product, or as an aid in the business process, to achieve competitive advantage. But how about defending and maintaining a software-based competitive advantage? In the RoboCup example, the software used during the competition is publicly available after the competition. This is not necessarily a good approach for companies looking to increase their return on investments.

In particular, when the software functionality can not be obtained by third parties, through for instance reverse engineering, companies may choose to keep their software developments a secret. To this end, typically a method is applied wherein encrypted software code is decrypted by a computer processor only just before executing the code, thereby preventing reverse engineering tools from reading the decrypted code.

Keeping software a secret is, however, not always possible. In particular when the software involved represents a significant commercial value, a third party might go to great lengths to reverse engineer the software to arrive at software with similar functionality. In the latter case, protecting software with a patent is often a worthwhile investment and is also quite common. A query in the database of the European Patent Office returns over 100,000 hits for computer program-related patent applications filed by amongst others Philips, ASML, Océ and NXP. However, obtaining a patent on software requires special attention as outlined below.



1 *NAO robots at RoboCup 2013 in Eindhoven, the Netherlands. In the RoboCup Standard Platform League all competing teams use standard robots like NAO. The difference between a victory or a defeat in this league depends on the software development. (Photo: Bart van Overbeeke)*

In general, as with any exclusive national right, patentability of an invention is governed by national law. For software, the differences between the various laws are remarkably big, making the desired geographical scope of protection an important aspect when deciding to file a patent application. For instance, under U.S. law software has been refused patent protection in several cases since the U.S. law excludes 'abstract ideas' from patentability. In Europe, on the other hand, the European Patent Convention (EPC) has a specific provision for patents on software which excludes only 'computer programs as such'.

The foregoing implies the source code itself can not be patented in Europe, but a specific implementation of the software program, like a robot using the software might be patentable. Typically, such a patent application will be directed towards a robot which is able to perform the steps as construed by the source code. The basic notion behind this reasoning is that the software accomplishes a more technically advanced robot. Returning to the RoboCup example, the developed software might for instance improve the interaction between the various NAOs in a team, thereby leading to a sure victory in view of the competitors.

The source code itself, like the text of this article, is protected from unauthorised copying under copyright law. In general, copyright is obtained automatically and need not be registered. However, the protection derived from this law is limited since it is confined to mere copying of the source code. As such, copyright does not protect against a third party obtaining identical functionality by simply rewriting the original source code.

In particular when a product stands out from the crowd due to implemented software, it is advised to carefully consider protecting the product including the software. Even if the product is mechanically and electrically identical to a competitor's product, a patent on the implemented software might make the difference between a sound return on investment or a marginal bottom line contribution. ■

CPE COURSE CALENDAR

The DSPE Certification Program has been incorporated in ECP², the European Certified Precision Engineering Course Program. Read the report of the launch symposium on page 50.

COURSE (content partner)	CPE points	Provider	Starting date (location, if not Eindhoven)
BASIC			
Mechatronic System Design - part 1 (MA)	5	HTI	4 April 2016
Mechatronic System Design - part 2 (MA)	5	HTI	11 April 2016
Design Principles	3	MC	9 March 2016
System Architecting (Sioux)	5	HTI	7 March 2016
Design Principles Basic (SSvA)	5	HTI	to be planned
Motion Control Tuning (MA)	6	HTI	15 June 2016
DEEPENING			
Metrology and Calibration of Mechatronic Systems (MA)	3	HTI	to be planned
Actuation and Power Electronics (MA)	3	HTI	14 March 2016
Thermal Effects in Mechatronic Systems (MA)	3	HTI	21 March 2016
Summer school Opto-Mechatronics (DSPE/MA)	5	HTI	to be planned
Dynamics and Modelling (MA)	3	HTI	12 December 2016
Summer School Manufacturability	5	LiS	to be planned
SPECIFIC			
Applied Optics (T2Prof)	6.5	HTI	3 March 2016
Applied Optics	6.5	MC	3 March 2016
Machine Vision for Mechatronic Systems (MA)	2	HTI	23 June 2016
Electronics for Non-Electronic Engineers – Basics Electricity and Analog Electronics (T2Prof)	6	HTI	to be planned
Electronics for Non-Electronic Engineers – Basics Digital Electronics (T2Prof)	4	HTI	5 September 2016
Modern Optics for Optical Designers (T2Prof)	10	HTI	to be planned (2016)
Tribology	4	MC	5 April 2016 1 November 2016 (Utrecht)
Design Principles for Ultra Clean Vacuum Applications (SSvA)	4	HTI	to be planned
Experimental Techniques in Mechatronics (MA)	3	HTI	to be planned
Advanced Motion Control (MA)	5	HTI	7 November 2016
Advanced Feedforward Control (MA)	2	HTI	14 November 2016
Advanced Mechatronic System Design (MA)	6	HTI	to be planned
Finite Element Method	5	ENG	in-company only
Design Decision Method	3	SCHOUT	to be planned / in-company

DSPE Certification Program

Precision engineers with a Bachelor's or Master's degree and with 2-10 years of work experience can earn certification points by following selected courses. Once participants have earned a total of 45 points (one point per course day) within a period of five years, they will be certified. The CPE certificate (Certified Precision Engineer) is an industrial standard for professional recognition and acknowledgement of precision engineering-related knowledge and skills. The certificate holder's details will be entered into the international Register of Certified Precision Engineers.

WWW.DSPE.NL/EDUCATION/LIST-OF-CERTIFIED-COURSES

Course providers

- Engenia (ENG)
  WWW.ENGENIA.NL
- The High Tech Institute (HTI)
  WWW.HIGHTECHINSTITUTE.NL
- Mikrocentrum (MC)
  WWW.MIKROCENTRUM.NL
- LiS Academy (LiS)
  WWW.LISACADEMY.NL
- Schout DfM (SCHOUT)
  WWW.SCHOUT.EU

Content partners

- Dutch Society for Precision Engineering (DSPE)
  WWW.DSPE.NL
- Mechatronics Academy (MA)
  WWW.MECHATRONICS-ACADEMY.NL
- Settels Savenije van Amelsvoort (SSvA)
  WWW.STTLS.NL
- Sioux
  WWW.SIOUX.EU
- Technical Training for Professionals (T2Prof)
  WWW.T2PROF.NL

Saxion Research Group Mechatronics – Combining technologies to create innovative products

Mechatronics is about achieving the maximum synergy between technologies from different disciplines to create successful innovative products. The Saxion Research Group Mechatronics provides the knowledge, the structure and the methodology to achieve this.

The Research Group Mechatronics (RG-MT) of the Saxion University of Applied Sciences in Enschede, the Netherlands, bridges the gap between academia and industry. It holds a unique intermediary position between these two, especially focussing on SMEs. The group integrates existing modern technologies into smart and innovative systems and products. The use of Systems Engineering as a development method ensures that the chosen solutions fulfil all requirements of the application in an economically feasible way.

The Research Group Mechatronics team in the lab. On the right Rini Zwikker, professor of Mechatronics.

The RG-MT started in November 2012. It is growing in terms of manpower and knowledge base each year. At the moment, the group consists of 8 people (3.6 FTE) with a variety of expertise. A growing number of students (over 50 in the last year) from various engineering fields contribute to projects. The RG-MT participates in a range of regional, national and European projects. The main current project involves developing building blocks for medical (care) robotics.

Focus areas include:
- Localising, recognising and – compliant – gripping of objects.
- Safe autonomous navigation inside a building.
- Sensing and processing of mechatronic and environmental parameters.
- 'Soft robotics' for supporting muscular actions.

Universal Robots UR5 robot arm with 800 mm reach, equipped with a Lacquey gripper, used in various research projects, e.g. involving vision-based control.

Knowledge from these building blocks will be incorporated into two demonstrators:
- A mobile platform with modular hardware and software able to manipulate its environment using a robotic arm and a vision system.
- A portable arm support that is able to detect the intended movements of the user and can actively support that movement.

These building blocks and demonstrators are under development for care robotics and can be adapted for industrial use. They are essential components for flexible manufacturing systems, which are part of the national (Dutch) Smart Industry action programme.

The basis for developing successful innovative systems which combine different technologies is a structured development process. Therefore, Systems Engineering (SE) is an additional focus area of the research group. The SE methods used must combine process structure with design freedom. ■

Invitation

Companies (especially SMEs) are invited to contact the research group for cooperation on any innovative project in the field of mechatronics. This cooperation may be in the form of participation in a group project with other companies and research institutes, or individual advice on challenging mechatronics questions. The opportunities for partial funding from subsidies can be investigated in both cases.

J.M.ZWIKKER@SAXION.NL
(RINI ZWIKKER,
PROFESSOR OF
MECHATRONICS)
WWW.SAXION.NL/
DESIGNENTECHNOLOGIE/
SITE/OVER/LECTORATEN

FROM BAIE DE SOMME TO TAIPEI

Recently, I attended two conferences in the field of mechanisms and robotics. Their nature was virtually opposite. The first one was the French National Robotics Research Days, held in beautiful, remotely located Baie de Somme. This meeting was all in French, except my talk that opened the first day. Luckily I had picked up some technical French from patents. The second was the IFToMM World Congress that is held every four years, on alternating continents, this time in a four-million-people Taiwanese metropolis, Taipei. Both have their charms, and both are important in their own right.

JUST HERDER

AUTHOR'S NOTE

Just Herder is a professor at Delft University of Technology, the Netherlands, and at the University of Twente, the Netherlands, in the field of interactive mechanisms, mechatronics and robotics. He is also treasurer of IFToMM.

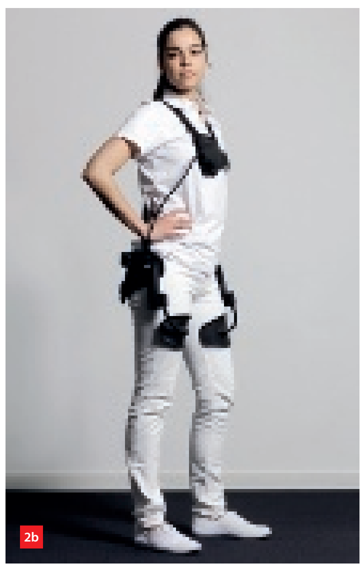
j.l.herder@tudelft.nl
www.pme.tudelft.nl
www.utwente.nl/ctw/wa

Retreat

The French Robotics days (Journées Nationales de la Recherche en Robotique, JNRR) are notorious for their remote locations, which are plentiful in France. The 2015 edition was held in the historical building of the Cap Hornu conference centre in the Baie de Somme area (Figure 1). Of course this selection of a remote location is done intentionally, to stimulate discussion and cross-fertilisation. This is reflected in the programme, which consists of invited talks, not on latest results per se but mainly allowing presenters to share their vision with the visitors – this time 180, including 40 students.

I presented some ideas on compliant robotics, a niche area between conventional rigid-link robots and the emerging field of soft robotics, in which we aim to create mechanisms based on compliance, i.e. distributed motion, in combination with distributed actuation and sensing. Ideally, this leads to what may be called mechatronic materials,

1 *A location that stimulates discussion and cross-fertilisation: the shore of Baie de Somme, breathtaking nature but not always the best weather.*



2 *Body support system based on non-linear spring mechanisms as a step towards shell-based mechanisms. (Courtesy of Laevo)*
(a) Rendering.
(b) Application.

integrating mechanism, actuator and sensor, as well as multiple functionalities in one part.

As a development example toward this goal I presented a shell-based body support for workers and care givers (Figure 2). Other presentations included an approach to increase precision in a multi-DoF manipulator (DoF = degree of freedom) by locking – after careful trajectory planning – certain DoFs once close to the target position, thereby reducing backlash considerably. Physical interaction between industrial robots and humans was also discussed, a topic that still bears many challenges. Also less immediate topics, such as robotic techniques in choreography, and robotic cartography in unstructured environments were treated. In line with the meeting objectives, several round table discussions were held and professionally directed to tangible results.

Exposure

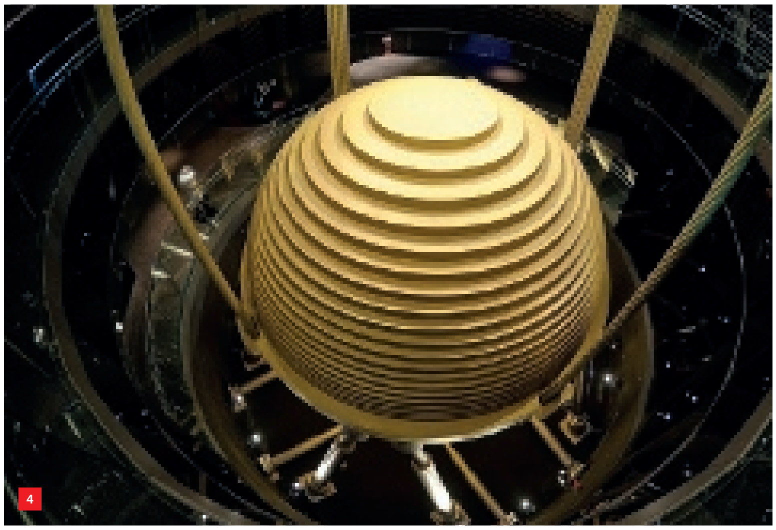
In Taipei, the official language was English, and it was a good event for those collecting different accents and pronunciations, as the International Federation for the Promotion of Mechanism and Machine Science (IFToMM) that organised the event aims to unite the mechanical sciences world in a way similar to the United Nations. Professor Yoshihiko Nakamura, president of IFToMM, joked that his organisation is probably the smallest professional society on Earth, with only 47 members. The thing is, these members are countries or territories.

The Netherlands are also a member, which implies that every Dutch citizen can enjoy the benefits of IFToMM events, such as discounts, travel grants, and financial support in conference organisation. A range of technical committees, such as Robotics and Mechatronics, Tribology, Vibrations, organised part of this World Congress, while they also organise their own conferences, such as the European Conference on Mechanism Science (EUCOMES).

I mainly visited the Computational Kinematics and Linkages, and Controls sessions, and was pleased to learn during the revolving-disk gala dinner that my student Teun Jelle Lassche received the Best Application Paper Award for a collaborative work between the University of Twente and Prof. G.K. Ananthasuresh of the Indian Institute of Science, Bengaluru.

With the General Assembly (Figure 3), various committee meetings, a presentation at a symposium organised by Dr. Chin-Hsing Kuo of Taiwan Tech, an editorial board meeting of the IFToMM journal Mechanism and Machine Theory, and meeting up with many conference friends, I had little opportunity to enjoy the city. Yet a visit to Taipei 101, the building that does not seem to end was deemed essential. And indeed, with a super smooth elevator, an impressive counter mass (Figure 4) against frequent earthquakes and typhoons, and a magnificent view over the hilly outskirts, it made a nice topping on a well-organised event, hosting around 750 delegates from all over the world. ■

3



4

3 *The General Assembly of the IFToMM that was held during the conference with all the flags of the member organisations. The insert shows Dr Volkert van der Wijk, currently at King's College, London, placing a vote on behalf of the Netherlands.*

4 *The 660-tonne counter mass in Taipei 101 in its cable suspension and hydraulic actuation system with parallel kinematic architecture. (Photo courtesy Armand du Plessis / Wikimedia Commons)*

INFORMATION

JNRR-15.SCIENCESCONF.ORG
WWW.IFTOMM2015.TW
WWW.IFTOMM.ORG

LiS Academy manufacturability course once again a success

To inspire young professional designers in particular about manufacturability, the LiS Academy (part of the LiS – Leidse instrumentmakers School) this year joined forces with a number of partners to host the third Summer School on Manufacturability, a DSPE, Hittech and LiS initiative. From 2-6 November, the 'late summer school' saw course participants visit a variety of companies and receive a range of lectures. Both the participants and the companies involved were positive about the programme.

The eleven participants were from the companies Baat Medical, cosine, Delmic, Elekta, Hittech, NTS-Group, Quooker, Tegema and VIRO. The following companies and institutes were also involved in the programme: Airbus Defence and Space, ECN, Hittech Gieterij Nunspeet, Hittech MPP, Hittech Multin, KO-AR, Mitutoyo, NLR, Suplacon, Ter Hoek Vonkerosie, Tetraëder FMT, TNO and, of course, the LiS. The initiative was supported by DSPE, Brainport Industries, DPT and FME.

Subjects discussed during the intensive week included spark erosion, micro laserjet cutting, 3D metal printing, sheet metal options, casting, the significance and measurement of roughness, anodising and surface treatments, machining and hard milling, polishing, value engineering and the CAD/CAM process. The programme culminated in a short course on turning. The programme also included a debate session which saw different groups of participants debate industry matters with experts.

A new course is being developed for 2016.

INFO@LISACADEMY.NL
WWW.LISACADEMY.NL

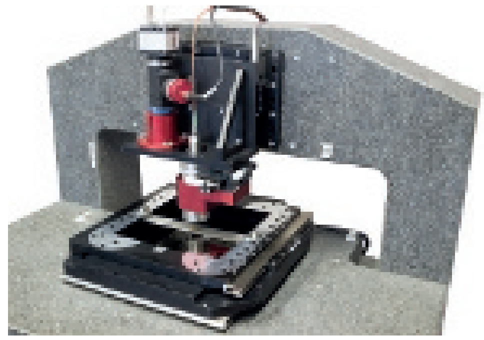
■ *Explanation of the casting process at Hittech Gieterij Nunspeet.*

The future of optics production

On November 12, the start of the joint study on "The Future of Optics Production" took place with a kick-off event at the Fraunhofer Institute for Production Technology IPT in Aachen, Germany. Combining well-known partners from industry and research, this one-year initiative aims to elaborate a detailed picture on the technologies for the efficient production of advanced optical components, in core areas such as freeform optics, materials, functionalisation and miniaturisation. Companies can still seize the opportunity to participate in the industrial consortium, introducing research questions and determining the topics of the study.

REIK.KRAPPIG@IPT.FRAUNHOFER.DE
WWW.IPT.FRAUNHOFER.DE

New multi-sensor 3D measuring system, Accuro



At the Precision Fair 2015, Irmato, a specialist in machine and device construction, presented a new multi-sensor 3D measuring system called the Accuro. The Accuro performs 3D shape/thickness measurements quickly and in a contactless manner, accurate to a submicron level, in both offline and inline applications. The Accuro contains one or two (white light) sensors and can accommodate additional sensors such as cameras and line and/or surface sensors. The lateral resolution is 0.5 µm (or even better, depending on the image processing software), and the vertical resolution is 0.1 µm.

WWW.IRMATO.COM/METROLOGY

Delta robot with scalable, open-architecture control

Aerotech introduces the RCP-DELTA robot, available in four models that support payloads up to 3 kg, with X/Y operating ranges of 500/800/1,100/1,300 mm, and an optional continuous rotation about the Z axis (yaw). Extensive use of carbon fiber and light-weight aluminum results in a robot that is capable of sustaining 200 pick-and-place operations per minute with peak acceleration in the order of 15 *g*. With absolute encoders on each motor the robot never has to be referenced, even after a loss of power.

The RCP-DELTA control system is based on Aerotech's A3200 Machine Controller. The controller's networked, distributed architecture provides a scalable platform upon which additional robots, I/O, and positioning devices can be integrated easily. Additional delta robot specific functions are included for common robotic operations such as target queues, tracking moving material, and teaching tool/part locations.

WWW.AEROTECH.COM

Deburring, grinding and polishing with robotics

During the first DeburringEXPO, 13-15 October 2015 in Karlsruhe, Germany, robotics-based solutions were presented bij various exhibitors. Among them Heinz Berger Maschinenfabrik, based in Wuppertal, Germany, who presented a system for deburring, grinding and polishing with robotics. Precise and defined deburring is decisive e.g. for the machining of cylinder heads as die cast parts. The deburring edges should be 0.3 to 0.5 mm wide to guarantee a maximum size of the sealing surfaces. The applied robotic station is equipped with rotating power tools such as milling burrs and grinding pencils, grinding flap discs or brushes. An integrated 3D measuring sensor for the calibration of complete pieces or individual contour elements checks the position of the piece during processing.

WWW.BERGERGRUPPE.DE

The first industrial 3D metal printing system

Last month, Additive Industries presented the first truly industrial 3D metal printing system at the Formnext fair in Frankfurt, Germany. The MetalFAB1 system offers substantially improved performance over typical mid-range systems. The industrial-grade additive manufacturing machine and integrated Additive World software platform will deliver up to a tenfold reproducibility, productivity and flexibility.

The improved performance is achieved by robust and thermally optimised equipment design, smart feedback control and calibration strategies, elimination of waiting time and automation of build plate and product handling. The modular design of the MetalFAB1 system allows for customer- and application-specific process configuration. Multiple build chambers with individual integrated powder handling make this industrial 3D printer the first to combine up to four materials simultaneously in one single machine. The size of a single build envelope (420 x 420 x 400 mm^3) places the MetalFAB1 among the top-three largest 3D metal printers available.

WWW.ADDITIVEINDUSTRIES.COM

The MetalFab1 6-module version. (Photo: Bart van Overbeeke/Additive Industries)

The OpenBionics Prosthetic Hand concept

A prosthetic hand concept, created by the Greek open-source initiative OpenBionics, was appointed first-prize winner of the Robotdalen Innovation Award 2015, at a prize ceremony held in Västerås, Sweden, in September. Robotdalen is a Swedish robotics initiative with the mission to enable commercial success of new ideas and research within robotics and automation; focussing on solutions for the industry, service and healthcare sector.

An OpenBionics Prosthetic Hand in action.

The jury's motivation: "The dexterous and compliant OpenBionics Prosthetic Hand allows the user, as an amputee with hand loss, to experience a wide variety of grasping postures. Additionally, the prosthetic robot hand concept satisfies the needs of the main target users concerning the light-weight and the low price of the product. The concept benefits from the prospects of rapid prototyping using 3D printing as well as easy fabrication."

WWW.ROBOTDALEN.SE/EN

WWW.OPENBIONICS.ORG

NEWS

First professor of Biorobotics in the Netherlands

Delft University of Technology has appointed Martijn Wisse, co-founder of the TU Delft Robotics Institute, as professor of Biorobotics at the Faculty of Mechanical, Maritime and Materials Engineering, making him the first professor of Biorobotics in the Netherlands. His appointment will strengthen TU Delft's research and education on nature-inspired robot designs and cooperation between humans and robots.

Wisse: "In our field, we look for examples from the biology of humans and other organisms for the design of robots. There are plenty of excellent examples of 'intelligent' designs in nature. For example, we closely studied the way tendons are attached to bones in the human hand. We used this knowledge to develop sensitive robot grippers that are currently being used to select and sort fragile products in the horticulture sector." Biology is also important to his work in another way: the robots of the future will need to be able to cooperate with humans in a 'biological' environment.

According to Wisse, biorobots can be used in any industry, and in particularly in the SME sector. "The first applications were in the horticulture and metal industries. These are mostly small businesses that perform a lot of repetitive manual labour, such as packaging and sorting objects."

ROBOTICS.TUDELFT.NL

LEO Center for Service Robotics projects

Researchers at the University of Twente (UT), operating within the LEO Center for Service Robotics, and international academic and industrial partners will be working on three major European Horizon 2020 projects in the field of robotics. Two of these projects are coordinated by the UT: MURAB (MRI and Ultrasound Robotic Assisted Biopsy) and DE-ENIGMA (aimed at assisting children with an Autism Spectrum Disorder (ASD) using a robot in order to develop their social skills). The SoftPro project (Synergy-based Open-source Foundations and Technologies for Prosthetics and Rehabilitation) is coordinated by the Italian Institute of Technology (IIT)

WWW.LEOROBOTICS.NL

ADVERTISERS INDEX

Development

TNO
T + 31 (0)88-866 50 00
W www.tno.nl

TNO is an independent innovation organisation that connects people and knowledge in order to create the innovations that sustainably boosts the competitiveness of industry and wellbeing of society.

member DSPE

Development and Engineering

ACE ingenieurs- & adviesbureau
werktuigbouwkunde en elektrotechniek BV
Dr. Holtroplaan 46
Postbus 7030, 5605 JA Eindhoven
5652 XR Eindhoven
T +31 (0)40 - 2578300
F +31 (0)40 - 2578397
E info@ace.eu
W www.ace.eu

ACE has developed into a leading engineering and consultancy firm with a strong focus on mechanics and mechatronics. Services include conceptualization, development, engineering and prototyping.

member DSPE

Development and Engineering

Lencon Engineering
Hondsdijk 3,
2396 HG Koudekerk aan den Rijn
Postbus 28
2396 ZG Koudekerk aan den Rijn
T +31 (0)71 341 65 55
F +31 (0)71 341 65 58
E sales@lencon.nl
W www.lencon.nl

Lencon provides maximum flexibility in high-end mechanical engineering and product development. Turn-key projects and detachment of experienced productengineers and precisionengineers.

member DSPE

SEGULA Technologies Nederland BV develops advanced intelligent systems for the High Tech and Automotive industry. As a project organisation, we apply our (engineering) knowledge to non-linear systems. This knowledge is comprised of systems architecture and modelling, analysis, mechanics, mechatronics, electronics, software, system integration, calibration and validation.

SEGULA Technologies Nederland BV
High Tech Campus 5
5656 AE Eindhoven
T +31 (0)40 8517 500
W www.segula.nl

member DSPE

Education

Leiden school for Instrumentmakers (LiS)
Einsteinweg 61
2333 CC Leiden
The Netherlands
T +31 (0)71-5681168
F +31 (0)71-5681160
E info@lis.nl
W www.lis.nl, www.lisacademy.nl

The LiS is a modern level 4 MBO school, with a long history (founded in 1901). The school encourages establishing projects in close cooperation with industry and scientific institutes, allowing for high level "real life" work. Under the name LiS-Engineering and LiS-Academy the school accepts contract work and organizes education for others.

member DSPE

PAO Techniek
Stevinweg 1, 2628 CN Delft
Postbus 5048, 2600 GA Delft
T +31 (0)15 27 88 350
F +31 (0)15 27 84 619
E info@paotechniek.nl
W www.pao.tudelft.nl

Electrical Discharge Machining (EDM)

Ter Hoek Vonkerosie
Propaanstraat 1
7463 PN Rijssen
T +31 (0)548 540807
F +31 (0)548 540939
E info@terhoek.com
W www.terhoek.com

INNOVATION OF TOMORROW, INSPIRATION FOR TODAY
Staying ahead by always going the extra mile. Based on that philosophy, Ter Hoek produces precision components for the high-tech manufacturing industry.

We support customers in developing high-quality, custom solutions that can then be series-produced with unparalleled accuracy. That is what makes us one of a kind.
It is in that combination of innovative customization and repeated precision that we find our passion. Inspired by tomorrow's innovation, each and every day.

member DSPE

Lasers, Light and Nanomotion

Laser 2000 Benelux C.V.
Voorbancken 13a
3645 GV Vinkeveen
Postbus 20, 3645 ZJ Vinkeveen
T +31(0)297 266 191
F +31(0)297 266 134
E info@laser2000.nl
W www.laser2000.nl

Laser 2000 Benelux considers it her mission to offer customers the latest photonics technologies available.
Their areas of expertise are:

- Lasers and laser systems for industry and research
- Light metrology instruments for LED and luminaire industry
- Piezo- and stepper motion products for nano- and micro-positioning
- LED illumination and high speed inspection in machine vision applications

3D Measurement Services

Mitutoyo Nederland B.V.
Wiltonstraat 25
3905 KW Veenendaal
T +31 (0)318-534911
E info@mitutoyo.nl
W www.mitutoyo.nl

3D Measurement Services

Carl Zeiss
Industrial Metrology
Trapezium 300
3364 DL Sliedrecht
T +31 (0)184 433 551
F +31 (0)184 433 500
E m.trupia@zeiss.nl
W http://www.zeiss.nl

Carl Zeiss Industrial Metrology is the world's leader in CNC coordinate measuring machines and complete solutions for multidimensional metrology in the metrology lab and production environment. We also provide contract programming and contract measuring in our Measuring House near Eindhoven (NL).

Mechatronics Development

CCM Centre for Concepts in Mechatronics
De Pinckart 24
5674 CC Nuenen
T +31 (0)40 2635000
F +31 (0)40 2635555
E info@ccm.nl
W www.ccm.nl

CCM translates technology into technique.
Commitment, motivation, education and skills of our employees are the solid basis for our business approach.

member DSPE

Mechatronics Development

Manufacturing Technical Assemblies (MTA) b.v.
Waterbeemd 8
5705 DN Helmond
T +31 (0)492 474992
F +31 (0)492 474510
E info@m-t-a.nl
W www.m-t-a.nl

MTA is an high-tech system supplier specialized in the development and manufacturing of mechatronic machines and systems.
Our clients are OEM s in the Packaging, Food, Graphics and High-tech industries.

Metal Precision Parts

Etchform BV
Arendstraat 51
1223 RE Hilversum
T +31 (0)35 685 51 94
F info@etchform.com
W www.etchform.com

Etchform is a production and service company for etched and electroformed metal precision parts.

member DSPE

Micro Drive Systems

Maxon Motor Benelux

The Netherlands

Head Office
maxon motor benelux bv
Josink Kolkweg 38
7545 PR Enschede

South
High Tech Campus 9
5656 AE Eindhoven
T +31(053) 744 0 744
E info@maxonmotor.nl
W www.maxonmotor.nl

Belgium / Luxembourg

maxon motor benelux bv
Schaliënhoevedreef 20C
2800 Mechelen - Belgium
T +32 (15) 20 00 10
F +32 (15) 27 47 71
E info@maxonmotor.be
W www.maxonmotor.be

maxon motor is the worldwide leading supplier of high precision drives and systems. When it really matters! Try us.

member DSPE

Micro Drive Systems

FAULHABER Benelux B.V.
Drive Systems
High Tech Campus 9
5656 AE Eindhoven
The Netherlands
T +31 (0)40 85155-40
E info@faulhaber.be
E info@faulhaber.nl
W www.faulhaber.com

FAULHABER specializes in the development, production and deployment of high-precision small and miniaturized drive systems, servo components and drive electronics with output power of up to 200 watts. The product range includes brushless motors, DC micromotors, encoders and motion controllers. FAULHABER also provides customer-specific complete solutions for medical technology, automatic placement machines, precision optics, telecommunications, aerospace and robotics, among other things.

Physik Instrumente (PI)
Benelux BV
Hertog Hendrikstraat 7a
5492 BA Sint-Oedenrode
The Netherlands
T +31 (0)499-375375
F +31 (0)499 375373
E benelux@pi.ws
W www.pi.ws

PI is the world's leading provider of nanopositioning products and systems. All key technologies are developed, manufactured and qualified in-house by PI: Piezo components, actuators and motors, magnetic drives, guiding systems, nanometrology sensors, electronic amplifiers, digital controllers and software.

member DSPE

Micromachining

Reith Laser bv
Bijsterhuizen 24-29
6604 LK Wijchen
The Netherlands
T +31 (0)24 3787564
F +31 (0)24 3787586
E info@reithlaser.nl
W www.reithlaser.nl

For more than 22 years Reith Laser bv is the leading supplier of laser-processed products in Europe.
We can offer you a great diversity of lasermaterialprocessing activities:

- Laser- (micro-) cutting
- Laser drilling
- Laser welding
- Laser micromachining

Reith Laser is active in precision industry, medical industry, aerospace, semiconductor- and automotive industry.

Motion Control Systems

Aerotech United Kingdom
The Old Brick Kiln
Ramsdell, Tadley
Hampshire RG26 5PR
UK
T +44 (0)1256 855055
F +44 (0)1256 855649
W www.aerotech.co.uk

Motion Control Systems

Newport Spectra-Physics B.V.
Vechtensteinlaan 12 - 16
3555 XS Utrecht
T +31 (0)30 6592111
E netherlands@newport.com
W www.newport.com

Newport Spectra-Physics BV, a subsidiary of Newport Corp., is a worldwide leader in nano and micropositioning technologies.

member DSPE

Physik Instrumente (PI)
Benelux BV
Hertog Hendrikstraat 7a
5492 BA Sint-Oedenrode
The Netherlands
T +31 (0)499-375375
F +31 (0)499 375373
E benelux@pi.ws
W www.pi.ws

PI is the world's leading provider of nanopositioning products and systems. All key technologies are developed, manufactured and qualified in-house by PI: Piezo components, actuators and motors, magnetic drives, guiding systems, nanometrology sensors, electronic amplifiers, digital controllers and software.

member DSPE

Motion Control Systems

Reliance Precision Ltd
Florijnstraat 20
4879 AH Etten-Leur
T +31 (0)76-5040790
E sales@reliance.co.uk

- Positioning systems
- Drives
- Mechatronic Assemblies
- Intelligent Motion Control

Reliance Precision Ltd manufactures, assembles and tests precise motion control solutions for high-accuracy applications.

Rotero Holland bv
Pompmolenlaan 21
3447 GK Woerden
Postbus 126
3440 AC Woerden
T +31 (0)348 495150
F +31 (0)348 495171
E info@rotero.com
W www.rotero.com

Rotero is your partner and advisor in the field of high-precision components: stepper- and servomotors up to 1.5kW, ball screws, precision leadscrews and gear boxes.

Optical Components

Molenaar Optics
Gerolaan 63A
3707 SH Zeist
Postbus 2
3700 AA Zeist
T +31 (0)30 6951038
F +31 (0)30 6961348
E info@molenaar-optics.nl
W www.molenaar-optics.eu

member DSPE

Optics and Imaging

Focal Vision & Optics
Institutenweg 25A
7521 PH Enschede
T +31 (0)53 - 428 7880
E info@focal.nl
W www.focal.nl

Focal Vision & Optics provides services for optical system design and advanced image processing. We design and deliver custom made and high speed precision inspection systems to OEMs and industrial manufacturers.

member DSPE

Piezo Systems

HEINMADE BV
Heiberg 29C
NL - 5504 PA Veldhoven
T +31 (0)40 851 2180
E info@heinmade.com
W www.heinmade.com

HEINMADE develops and supplies piezo system solutions for mainly precise positioning. Check our standard amplified piezo actuators and nanostages. As distributor of Noliac a wide variety of piezo actuators are offered.

member DSPE

Piezo Systems

Physik Instrumente (PI) Benelux BV
Hertog Hendrikstraat 7a
5492 BA Sint-Oedenrode
The Netherlands
T +31 (0)499-375375
F +31 (0)499 375373
E benelux@pi.ws
W www.pi.ws

PI is the world's leading provider of nanopositioning products and systems. All key technologies are developed, manufactured and qualified in-house by PI: Piezo components, actuators and motors, magnetic drives, guiding systems, nanometrology sensors, electronic amplifiers, digital controllers and software.

member DSPE

Precision Cutting

Dutch Precision Technology (DPT)
Postbus 2600
3430 GA Nieuwegein
Einsteinbaan 1
3439 NJ Nieuwegein
T +31 (0)30 605 33 44
E dpt@metaalunie.nl
W www.dptech.nl.nl
Twitter:
www.twitter.com/verspaners

Dutch Precision Technology (DPT) is the principal association for precision cutting in the Netherlands. The companies affiliated with DPT guarantee expertise, quality, flexibility and effective cooperation. DPT has top specialists for all kinds of precision processes, combined with options for assembling parts into composites and/or complete systems or products.

Ultra-Precision Metrology & Engineering

IBS Precision Engineering
Esp 201
5633 AD Eindhoven
T +31 (0)40 2901270
F +31 (0)40 2901279
E info@ibspe.com
W www.ibspe.com

IBS Precision Engineering delivers world class measurement, positioning and motion systems where ultra-high precision is required. As a strategic engineering partner to the world's best manufacturing equipment and scientific instrument suppliers, IBS has a distinguished track record of proven and robust precision solutions. Leading edge metrology is at the core of all that IBS does. From complex carbon-fibre jet engine components to semiconductor chips accurate to tens of atoms; IBS has provided and engineered key enabling technologies.

member DSPE


SMART INDUSTRY
ROBOTICS
AGRO & FOOD
ADDITIVE MANUFACTURING
REGISTER NOW
ENTRANCE FREE OF CHARGE
HIGH-TECH SYSTEMS
24 MARCH 2016 EINDHOVEN
www.hightechsystems.eu
Partners
Brainport Industries
DSPE
TU/e


HEIDENHAIN
How do you measure the future?
Without vision there is no future. That's why HEIDENHAIN devotes itself to turning the technological impossibilities of today into the realities of the future. Time and again HEIDENHAIN has been the impetus for improvements in the accuracy and productivity of machine tools, and this will remain so in the future whenever it becomes time to transform ideas into industrial standards. That's why both machine manufacturers and industrial research institutes rely on HEIDENHAIN in matters of measuring and control technology. And we are constantly investing in new processes, methods and production facilities, so that you can put your visions into action.
HEIDENHAIN NEDERLAND B.V.
6710 BB Ede, Netherlands
Telephone: 0318-581800
www.heidenhain.nl
Angle Encoders + Linear Encoders + Contouring Controls + Subsequent Electronics + Length Gauges + Rotary Encoders