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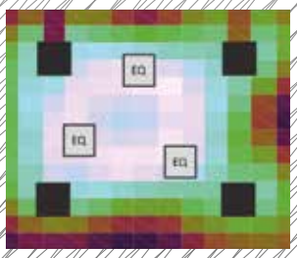
- THEME: **PRECISION IN AGRO**
- **DSPE OPTICS WEEK 2017** REPORT
- **2017 PRECISION FAIR** IMPRESSIONS
- ACTIVE **VIBRATION** CANCELLATION



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The main cover photo (representing the Trimbot counter-rotating cutter blades) is courtesy of WUR. Read the article on page 5 ff.

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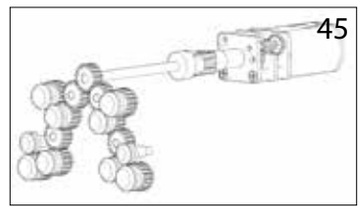

FEATURES

GROWING HIGH-TECH PARTNERSHIPS

The long-term perspective of the high-tech industry demands continuous innovation, hence cooperation between industry and knowledge institutes. Creating a network where high-tech companies, either large or small, and institutes can find technology partners is the main goal for High Tech NL, established in 2013, which now incorporates some 160 members and 30 partners (non-high-tech members, regional development agencies, sector organisations and clusters both in the Netherlands and beyond). It cover 'traditional' high-tech domains such as micro/nano electronics, but also 'emerging' fields like robotics. Besides these fields of attention, High Tech NL executes the Human Capital Agenda for the top sector High Tech Systems & Materials.

Up until now, many people who are active in high-tech started their careers in industrial conglomerates such as Philips or Stork; easy collaboration in an open atmosphere is still part of their DNA. But these companies no longer cover a broad range of activities and all of their people are gradually retiring. My ambition is for High Tech NL to cater for such an ecosystem as a 'virtual conglomerate', where people and companies can easily engage with one another as if they were working within one big company.

For this high-tech ecosystem, our country is famous and unique. However, it is not enough to be just part of this ecosystem; for successful innovation you have to maintain solid, long-lasting partnerships. This even holds for financial partnerships. Whereas investors in start-ups in, for example, software have an exit horizon of, say, two years, for high-tech (hardware) start-ups this may well have to be seven or even ten years. Alignment with financial partners that share this vision on a longer financial horizon for the high-tech industry is one of our aims.

The same applies to technological partnerships. That's why at the beginning of this year High Tech NL took the initiative to bring together industrial companies and scientific institutions in Holland Robotics, the successor to the earlier, stranded initiative of RoboNed. Our aim is to take national collaboration between science, industry and robotics entities to a higher level by enabling industry-driven roadmap development. We have identified business opportunities in agrifood, medical, logistics and inspection/maintenance applications, combined with a technological focus on the underlying domains, such as mechatronics, artificial intelligence (machine learning) and vision technology. We are currently working on a position paper addressed to the Dutch government.

In a similar vein, I have discussed the need for collaboration with DSPE president, Hans Krikhaar. DSPE focuses on deepening promotion of precision engineering, while High Tech NL takes a broad perspective on high-tech. At the crossroads of the two approaches we can strengthen each other. This editorial kicks off our collaboration and knowledge exchange, and the next step can be, for instance, a DSPE representative giving an in-depth presentation of precision engineering topics at a High Tech NL meeting. This could include a discussion of robotics in the cross-over of high-tech with the agrifood sector.

Food producers face the challenge of feeding nearly nine billion mouths in 2030. Here, the Dutch agrifood sector can play a crucial role, in collaboration with our high-tech industry for developing innovative machines and processes, helping the agrifood sector to achieve significant cost reductions, reduce the time-to-market and promote sustainability. But it takes time for both sectors to understand each other's language and way of working. We are now involved in a European research project where the application of collaborative robotics (cobotics) in food processing is being investigated. DSPE members, seize the opportunity...

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CROSS-OVER BETWEEN HIGH-TECH AND AGRI- & HORTICULTURE

Food producers face the challenge of feeding nearly nine billion mouths in 2030. Here, the Dutch agrifood sector can play a crucial role, in collaboration with the high-tech industry for developing innovative machines and processes, helping the agrifood sector to achieve significant cost reductions, reduce the time-to-market and promote sustainability. Wageningen University & Research is a key player in this field, making, for example, the cross-over to high-tech for developing robots in agricultural and horticultural applications.

EDITORIAL NOTE

Input for this article was provided by Wageningen University & Research professor Eldert van Henten and staff members Jochen Hemming, Bart van Tuijl, Joris IJsselmuiden and Rick van der Zedde. Their support is acknowledged.

The agenda has been set by the Technology Roadmap High Tech to Feed the World (HT2FtW) [1] (Figure 1). By applying high-tech systems and materials along with new ICT applications, the agricultural and food sectors will be better able to handle the major societal challenges which they face. In addition, this will improve the competitiveness of these sectors in the Netherlands and create opportunities to export the new systems and applications. Conversely, the high-tech sectors are challenged to find solutions to problems that so far have obstructed the application of these systems, such as the non-uniformity of products, the sometimes harsh operating conditions and the limited innovation budget (ultimately as a consequence of low food prices in the supermarket).

HT2FtW has been developed to stimulate cooperation between all sectors concerned through cross-overs. The application fields breeding, horticulture, agriculture, animal production, ingredients, food products and machinery for food processing are intertwined with technological developments in the field of materials, data acquisition, data analysis and usage, automation and control, and system architecture and integration. This calls for fundamental and applied research in interdisciplinary programmes.

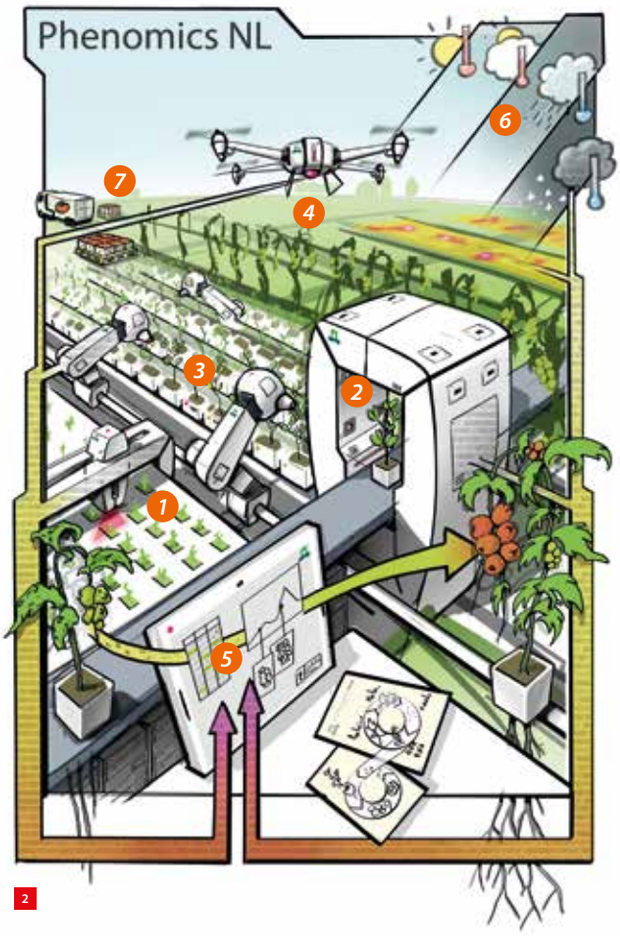
1 *The HT2FtW roadmap was published in 2015 and has been integrated in the innovation calendars of four Dutch top sectors: High Tech Systems & Materials, Agri & Food, Horticulture & Starting materials, and ICT.*

The HT2FtW roadmap (2015) was compiled by a consortium of high-tech companies, knowledge institutions and government to strengthen the cross-over collaboration and innovation. One of the key players is the 4TU federation, which comprises the three traditional Dutch universities of technology (Delft, Eindhoven and Twente) and Wageningen University & Research (WUR).

Wageningen

WUR's mission is to explore the potential of nature to improve the quality of life. Given the global challenges of population growth, agricultural area decrease and climate change (floods, droughts, new plant diseases), it is important to grow crops that can be cultivated efficiently and have high yields. WUR research groups, combined in the Phenomics NL platform [2] (Figure 2), are currently studying the behaviour of plants at different levels: from model and individual plants to the growth of crops in greenhouses and on the field.

One of the tools used are robots, for which WUR runs the Agro Food Robotics initiative [3], with four research institutes participating: Food & Biobased Research, Plant Research, Environmental Research, and Livestock Research. This covers the application of robots in the complete agrifood chain, from quality inspection of seeds, plants, crops and food products in the lab, greenhouse, field or factory, using computer vision, analytical techniques and handling systems; precision farming; processing and packaging; logistics and big data analysis.



2 *The Phenomics NL platform covers seven steps in the plant production chain:*
1 *Insights into plants' stress responses*
2 *Measurements on individual plants*
3 *Quality inspection in the greenhouse*
4 *Measurements in the field (field phenotyping)*
5 *Data analysis of plants*
6 *Research into climate influence*
7 *Post-harvest quality preservation*

Harvesting sweet pepper

An interesting project is Sweeper [4], concerned with the development of a sweet pepper harvesting robot in an ICT Robotic Use Cases project within the European Union's Horizon 2020 programme. Sweeper's main objective is to put the first generation greenhouse harvesting robots onto the market. In modern greenhouses there is considerable demand to automate labour. The availability of a skilled workforce that accepts repetitive tasks in the harsh climate conditions of a greenhouse is decreasing rapidly. In the EU Seventh Framework Programme project Crops [5] extensive research has been performed into agricultural robotics. One of the applications was a sweet pepper harvesting robot (Figure 3).

The Sweeper project involves five partners from four countries, including WUR and sweet pepper grower De Tuindershoek from the Netherlands (system integrator Irmato Industrial Solutions abandoned the project when after bankruptcy it moved over to FMI – for this reason, more technical details cannot be published yet). The consortium integrates a wide-range of disciplines: horticulture, horticultural engineering, machine vision, sensing, robotics, control, intelligent systems, software architecture, system integration and greenhouse crop management. The project will finish in the second half of 2018. First results of constructing and testing the system have been reported [6].

The robot is an assembly of several subsystems, such as a mobile autonomous platform, a robotic arm holding an end-effector for fruit harvesting, and post-harvest logistics. Software modules are based on the Robot Operating System (ROS). The end-effector (gripper) contains sensing tools for detecting sweet pepper and obstacles, and grasping the fruit without the need of an accurate measurement of its position and orientation. A time-of-flight sensor is used to record colour and 3D information simultaneously. To improve the level of robotic cognitive abilities, crop models are applied to approximate the location of sweet peppers. This 'model-based vision' will increase and speed up fruit detection, localisation and maturity rating; a special challenge is occlusion (e.g., peppers 'hidden' behind leaves). It was concluded that robot arm control does not require the initially designed nine degrees of freedom (DoFs). In the current project an off-the-shelf 6-DoF industrial robot arm (Fanuc LR-mate 201iD) is employed; this greatly reduces costs.

Trimming bushes, hedges and roses

Another 'green' Horizon 2020 project [7], TrimBot2020, does not concern a food application but is very interesting from a mechatronical perspective. The aim of this project is to investigate the underlying robotics and vision technologies and prototype the next generation of intelligent gardening consumer robots. The project is focused on the development of intelligent outdoor hedge, rose and bush trimming capabilities, allowing a robot to navigate over varying garden terrain, including typical garden obstacles, approaching hedges to restore them to their ideal tidy state, topiary-styled bushes to restore them to their ideal shape, and rose bushes to cut their flowers.

The project partners are the universities of Edinburgh (UK, coordinator), Wageningen, Amsterdam and Groningen

3 *The Horizon 2020 project Sweeper uses the technology developed in the EU FP7 project Crops to introduce, test and validate a robotic harvesting solution for sweet pepper in real-world conditions.*

4 *The TrimBot Garden test field in Wageningen. On the right, a Bosch Indego robot lawn mower, on which after modification a robot arm will be mounted.*

from the Netherlands), Freiburg (Germany) and Zurich (ETH, Switzerland), and German company Bosch. In Wageningen gripper design, software development (ROS control) and system integration was taken up and a test field was laid out (Figure 4). The project aims for a technology readiness level of 5-6 for the total trimming robot concept. Bosch already markets the autonomous lawn mower that will be used for the vehicle base, and is expecting to undertake further development and engineering following the project towards a new generation of gardening robots.

Objective

The system has to be capable of navigating by means of a rough user-defined garden map to approach hedges and bushes, and then, with a novel electric hedge cutter in conjunction with the 3D scene data, trimming flat surface hedges and shaped box-wood bushes. 3D computer vision research is aimed at sensing semi-regular surfaces with physical texture (overgrown formerly 'smooth' plant surfaces); coping with outdoor lighting variations; self-localising and navigating (using motion planning) over slightly rough and uneven terrain (grass, wood chips, gravel, tiles, etc.) and around obstacles; visual servoing to align a vehicle near to slightly moving target plants; and visual servoing to align leaf and branch cutters with a compliant surface.

Platform

A robot arm from Kinova will be mounted on a modified Bosch Indego robot lawn mower; Kinova is a Canadian manufacturer of wheelchair-mounted robot arms for disabled persons. The arm is partly made of carbon fibre for compact and lightweight construction. Another perk is that the controller is incorporated in the robot arm mount.

For the estimates of orientation and position of the robot a Visual SLAM (simultaneous localisation and mapping) algorithm is used. This algorithm basically uses the images from five stereo cameras; however, it additionally integrates measurements from an inertial measurement unit (IMU) and from an odometer (measuring the covered distance) to improve the solution with regard to accuracy and robustness.

The five stereo camera pairs are mounted on the platform to obtain a 360° view of the garden enabling correction for encoder inaccuracy and slip. As a starting point a rough sketch of the scenery is downloaded to provide the control system with a map of the garden. Using input of the stereo cameras and other sensors this map is continuously being refined to improve the accuracy of navigation and trimming. This is essential because, not only during the processing of a complete hedge but also when trimming a single bush, the robot platform has to move its position several times, as the range of the robot arm is too small to cover the whole surface in one pass.

Trimming control

As input for the trimming operation a model is made up comprising a polygonal mesh consisting of little triangles, derived from a scan of the actual bush or hedge. This model is used to define the surface to be trimmed. As the trimming tool works omnidirectionally (see below), it is only a matter of aligning the axis of the tool with the perpendicular of the local surface triangle and determining the depth of trimming (how many centimeters of material have to be removed). Therefore, effectively only five DoFs (three for the position in space of the tool centre point, and two to define the direction in space of the tool axis) have to be controlled, whereas the system nominally provides eight DoFs (six from the robot arm, two from horizontal platform motion). In general, this 8-DoF motion control is mathematically rather tricky, so effective 5-DoF control significantly reduces the computing power required on board the platform.

The path planning has been modelled as a traveling salesman problem to minimise the aggregated path length. During operation other stereo cameras mounted near the trimming tools are used for exact localisation and depth estimation of the surface to be trimmed and to provide feedback for improving the trimming result.

End-effectors

The end-effectors for trimming as well as rose cutting could not be obtained off-the-shelf but had to be custom-made (Figure 5). The design of the trimmer was inspired by commercially available counter-rotating saw blades; the toothed gear was derived from such a hand tool from the US. The star-like cutter was specially designed, with the arrow point shapes added for retaining thicker branches when trimming (this concept is used in commercial bush trimmers). The cutter blades were made by Tebra Machine Blades and Industrial Knives, specialised in manufacturing, grinding and hardening. A new housing was designed and maxon drives were integrated because of previous experience and their easy ROS control

For the rose-cutting end-effector a commercial rose-cutter was modified: the cutter and planetary gear were used and

5 *End-effectors; see text for further explanation.*
(a) For trimming; on the left, part of the robot arm.
(b) For rose cutting; the yellow feature is the 3D-printed flexible coupling between drive (on the left) and cutter.

6 *The trimming test system in action in the Trimbot Garden at Wageningen Research.*
(a) Overview showing a provisional test platform (not yet the Bosch Indego lawn mower).
(b) Close-up showing the counter-rotating cutter blades.

again a maxon drive was integrated. A 3D-printed flexible plastic coupling was inserted between drive and cutter to allow for some freedom of movement of the cutter head against the sturdy rose bush; this prevents excessive forces on the manipulator when it collides with rose branches.

Accuracy

The error margin for trimming of simple geometrical shapes was set to 2 cm over the complete bush or hedge surface. Before and after trimming a 3D reconstruction of the surface can be made and the two resulting point clouds can be compared to determine the actual error. A next step in the project will be to analyse error sources, such as the tool, the trimming algorithm and the robot platform.

As the current robot arm is not very stiff, it will be quite a challenge to meet the 2 cm accuracy requirement. The demanding and varying conditions (sunlight, temperature, humidity, fouling) add to this. For example, because of sunlight intensity, LED flash light is used for imaging with extremely short shutter times and a small diaphragm.

Given the TRL 5-6 objective, safety was not part of the project scope. In a subsequent project, aimed at designing a market-ready system, detection and avoidance of obstacles such as humans and animals will have to be considered and safety measures for the trimming operation need to be integrated, providing a neatly and securely trimmed exterior of the trimming robot.

Figure 6 shows the trimming test system in action. ■

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PRECISION FARMING SOLUTION

Precision farming is a farm management approach that uses a wide range of enabling technologies, not only filling the gap vacated by human workers but also significantly increasing productivity through effective and efficient use of available resources. One of these technologies is an aerial robot. A proof-of-concept of an aerial Agrobot and a corresponding docking station technology has been developed and its full functionality has been successfully demonstrated.

ABEJE Y. MERSHA

Introduction

According to a recent report by the world food and agriculture organisation (FAO), the population of the world is expected to grow by 30% in 2050. This increase, together with the continuing mass migration to urban centres, will have a significant socio-economic impact. One of the sectors that is affected by this demographic change and urbanisation is the agricultural sector, which accounts for one-third of the world's GDP.

The population growth, the urban migration as well as the fact that 70% of the world's arable land has already been used, essentially leaves the agricultural sector extremely stretched. The need to feed the ever-increasing population with less manpower and less arable land has necessitated new approaches, such as precision farming. Loosely speaking, precision farming is a farm management approach that uses a wide range of enabling technologies not only filling the gap vacated by human workers, but also significantly increasing productivity through effective and efficient use of available resources. One such advanced technology is an aerial robot. Figure 1 shows the technological evolution of farming.

The use of aerial robots in the agricultural sector has the potential to enable intercropping (combined cultivation) and reduce soil compaction, which greatly contribute to high productivity and environment-friendliness. Considering the growing world population, the use of such new technologies leading to optimal use of resources in an efficient and effective manner is paramount to the perpetuation of life.

In the Twente region of the Netherlands, Machinefabriek Boessenkool and Drone4Agro are two innovative companies that have been striving to develop new technologies for more automated and efficient farming. Machinefabriek Boessenkool has developed an electric tractor, which is distinctly lightweight and has a very small wheel footprint. This leads to a significant reduction in soil compaction, and thus a more effective farming. While such innovations have led to more automated farming processes, these tractors are not fully autonomous (they are still manned). Drone4Agro is currently working towards developing the first fully autonomous aerial Agrobot, which will be employed in precision farming, while completely preventing soil compaction. However, to render the aerial Agrobot fully functional, several new technologies still need to be developed.

One of the most important features of the aerial Agrobot is autonomy. The Agrobot needs to be fully autonomous to

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1 *Evolution of farming: from using animals to tractor deployment to futuristic use of (mega) drones.*

function with little or no human intervention and to carry out specific tasks successfully. This type of autonomy makes the Agrobot appealing for use by ordinary farmers as it needs no expert pilot to fly it or manually replenish its resources (battery and liquid sprays).

This article presents the results obtained in a collaborative project that is aimed at developing a proof-of-concept for an autonomous Agrobot that can tirelessly and reliably operate 24/7. The project consortium members are Research Group Mechatronics at Saxion University of Applied Sciences, Machinefabriek Boessenkoel and Drone4Agro. The project has been partly funded by TechForFuture and RAAK-KIEM Smart Industry.

Goals

The main goal of the project is to develop a proof-of-concept for an aerial Agrobot and a corresponding docking station technology, more specifically:

- an autonomous aerial Agrobot that is capable of carrying out a crop spraying mission, and is able to precisely and robustly land on a docking station;
- a docking station technology that can autonomously replenish energy sources and payloads of the aerial Agrobot.

Within the scope of this project, a small-scale and low-cost multi-rotorcraft aerial robot with vertical take-off and landing (VTOL) capability has been used to develop and demonstrate the desired functionalities.

Approach

For development of the desired technologies, the systems engineering approach using the V-model has been adopted [1]. The V-model is one of the linear methods for methodological design and development of complex systems. Although it is linear, this methodological approach allows iteration.

Various aspects of the aerial Agrobot and the corresponding docking station technology have been developed within a span of one year by groups consisting of students and researchers with various technical backgrounds within Saxion University of Applied Sciences. The design phase of this project consisted of functional and technical designs using the user and system requirements as inputs. Various concepts that partially or fully fulfil the requirements have been first drafted and compared based on the relevant metric. Once a final concept had been chosen, technical designs of the chosen concept were elaborated and realised.

The aerial robot platform used in this project is the Parrot AR Drone 2.0 Power Edition [2], see Figure 2. Parrot AR drone is a commercially available quadrotor platform,

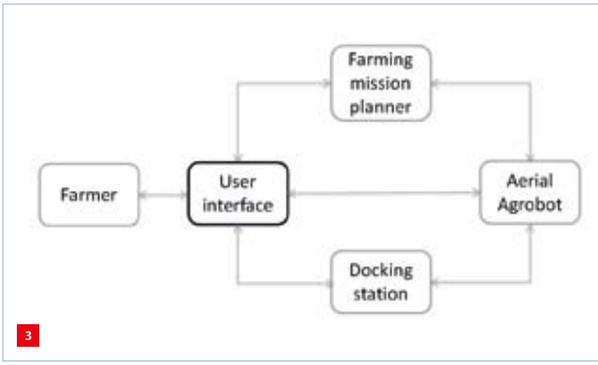
2 *Parrot AR drone.*

which is equipped with a 9-DoF (degree of freedom) inertial measurement unit (IMU), pressure sensor, ultrasonic altimeter sensor and frontal and bottom cameras. It has a 1 GHz 32-bit ARM context A8 processor, which runs the onboard controller. This platform has been chosen for its low-cost, robustness and relative safety when flying it in a confined environment close to people. The remainder of the mechanical parts for this project have mainly been 3D printed in the research group's lab.

During the course of this project the open source Robot Operating System (ROS) has been used as the main software development framework [3]. Besides other merits, ROS naturally allows modularity, facilitates the reuse of code with little or no adaptation, and permits the concurrent reuse of resources and the distribution of computational loads. Moreover, it is widely supported by a large and growing community.

Overall system architecture

The proposed farming technology using aerial robots is composed of the farmer, the aerial Agrobot, the docking station, the farming mission planner and the user interface, see Figure 3. The farmer is the user of the technology who is ultimately responsible for the farming mission and has the ability to start/abort the mission. The farmer is primarily supposed to be a specialist in farming, not in piloting the Agrobot. The farming mission planner can be a specific farming-related software program and/or hardware tool that may need to be mounted on the Agrobot for a specific mission.
The aerial Agrobot is the robot which carries out the actual mission. It is equipped with the appropriate sensors, actuators, processing unit, intelligence and autonomy to carry out the mission without the need for human intervention. The docking station, on the other hand, is an easily transportable station which is equipped with the necessary infrastructure to replenish the energy source and the mission-specific payload of the Agrobot. The farmer plans the mission, monitors the mission's status, the states of the Agrobot and the docking station using an intuitive user interface. The farmer can also control the Agrobot and the docking station using the user



interface. Although all subsystems in the overall architecture are crucial, the focus in this project lies on the aerial Agrobot and the docking station technology.

Turning Parrot AR drone to Agrobot

The most important requirement of the aerial Agrobot is its ability to autonomously carry out a crop spraying mission. This mission entails fundamental modification of the hardware and software of the original Parrot AR drone. For the spraying mission, the Parrot needs to be equipped with a liquid reservoir to transport the liquid payload and a pump to spray crops. Moreover, liquid level sensors, communication module and microcontroller are needed.

Since the maximum payload capacity of the Parrot is very low, experimentally determined to be 205 g without the protection hull, it is essential to reduce the weight of the additional onboard infrastructure. Figure 4a shows the 3D-printed liquid reservoir. The cover of the filling point has a hinge system that prevents any spilling of the fluid when the Agrobot is in operation. During refilling the hinge is pushed down and after refilling it will return to a closed position by means of a torsional spring placed inside the reservoir. The spacer on the bottom is a part created to make room for the battery and other additional hardware components.
The additional electrical components include a 5 V PWM-driven pump, a fluid level sensor based on fluid conductivity, and a bluetooth module to communicate with the ground station. A Genuino microcontroller is used to control the pump, read sensory data and monitor the battery level, see Figure 4b. In addition to their desired functionalities, the motivation for choosing these components is their low power consumption and low mass. The total mass of all the printed parts is 110 g, and the combined mass of the Genuino, the bluetooth module and the pump is 38 g. As a result, the maximum weight of the fluid payload cannot be more than 57 g.

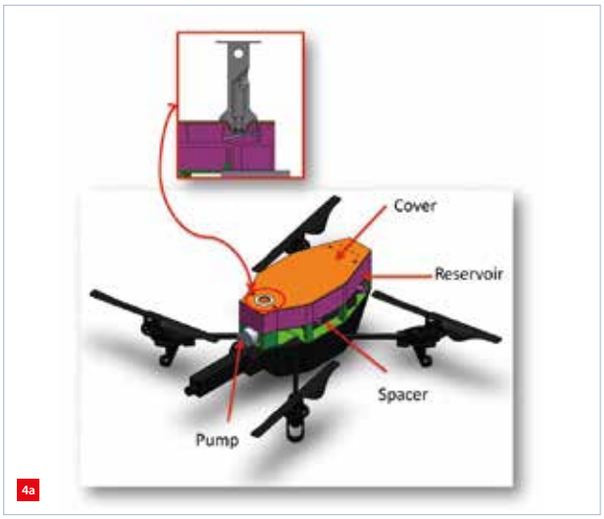
For autonomous flight to accomplish the spraying task, the AR drone ROS driver [4] as well as a modified version of the TUM_ARDrone [5] ROS packages have been used. The TUM_ARDrone package is capable of monocular simultaneous localisation and mapping (SLAM). The visual odometery is fused with the IMU and the ultrasonic sensor to obtain a more accurate estimation of the pose of the Agrobot in the environment. These estimates are in turn used as input to the cascaded PID controller realised to control the position and the yaw of the robot [6]. For robust landing, vision-based tag detection algorithms have been developed to more accurately estimate the pose of the landing area on the docking station. Figure 5 shows the aerial Agrobot during a spraying mission.

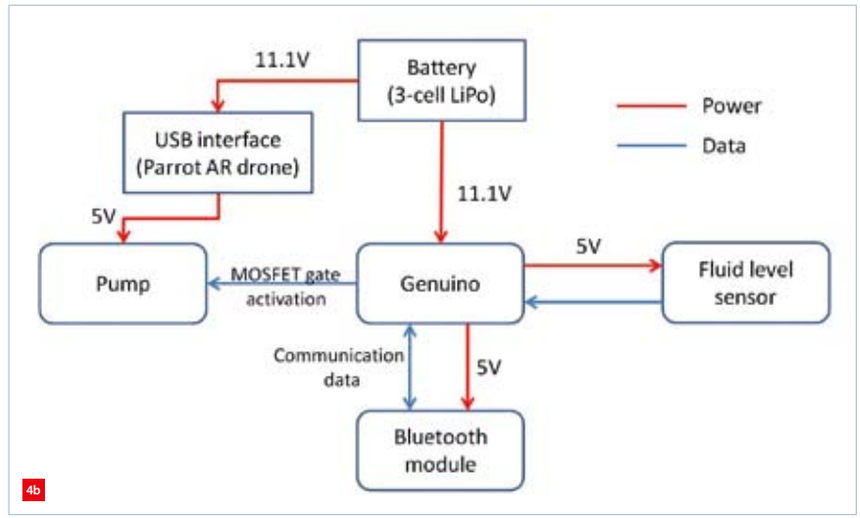
The lifeline for energy and payload replenishing

The primary use of the docking station is to provide a lifeline to the Agrobot by replenishing its energy and payload supply so that it can continuously perform its mission. In this project, the two main functional requirements of the docking station are its ability to recharge the battery and refill the liquid payload of the Agrobot. The main technical requirement is its ability to tolerate a landing accuracy of 2 cm and 10°, i.e., the station should be able to refill and recharge as long as the Agrobot lands within the aforementioned tolerance. In the first

3 *Overall system architecture.*

4 *Modifications to the Parrot AR drone.*
(a) Mechanical.
(b) Electrical.





version, two separate docking stations have been developed for refilling and recharging purposes. The details of these stations are provided in the following sections.

Refilling station
The refilling station is composed of a refilling manipulator, a webcam, a drone dock, liquid reservoir and a processor, see Figure 6. The refilling manipulator is a 3D-printed 4-DoF manipulator, of which only three DoFs are actuated by Dynamixel motors. The end-effector is the liquid refilling nozzle and is designed to be very light. The manipulator has a reach of 600 mm radius on the front side of the docking station, allowing a large tolerance to landing inaccuracy. In order to identify the refilling point on the Agrobot, vision-based tag identification and pose estimation algorithms have been developed. The webcam is optimally mounted in order to maximise the field of view while obtaining an accurate estimation of the Agrobot after it lands on the docking station.

In normal operation, the tag on the topside of the Agrobot is detected once the Agrobot has landed on the docking station. The pose of the robot, thereby the refilling point, is subsequently determined, and the manipulator moves the nozzle to the refilling point. The inverse kinematics and the path planning are realised using MoveIt [7], see Figure 7. After sucessfully refilling the tank, the station transmits a signal to the Agrobot to continue its mission.

Recharging station
The recharging docking station is mainly composed of a drone dock for the Agrobot, recharging electrical connectors, magnetic connectors for reliable connection and LED status indicators, see Figure 8. The connecting plate is mounted on the Agrobot using Velcro fabric hook as it allows an easy movement underneath, when needed. The four connecting plates on the connector plate are connected

5 *The aerial Agrobot in action.*

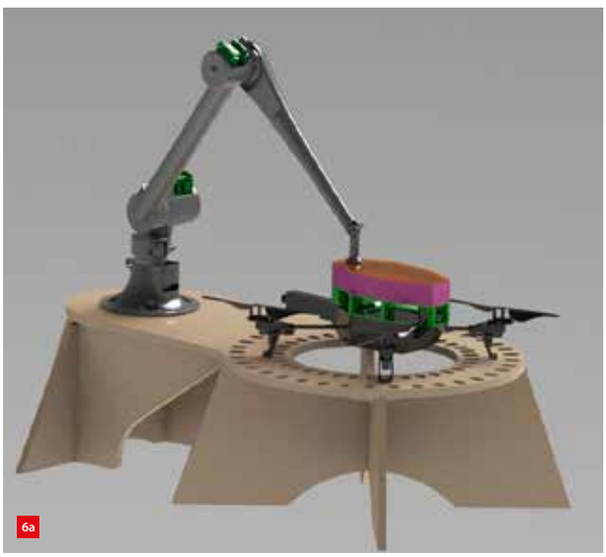
6 *The refilling docking station.*
(a) Model.
(b) Realisation.

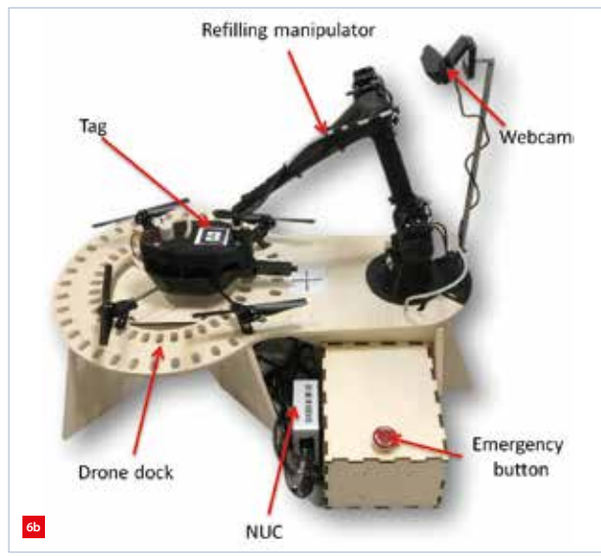
to the charging and the balancing pins of the battery. The iron disk at the centre connects to the electromagnet. The magnetic plug on the recharging station also consists of four copper wires, which deliberately stick out to ensure a good electrical connection.

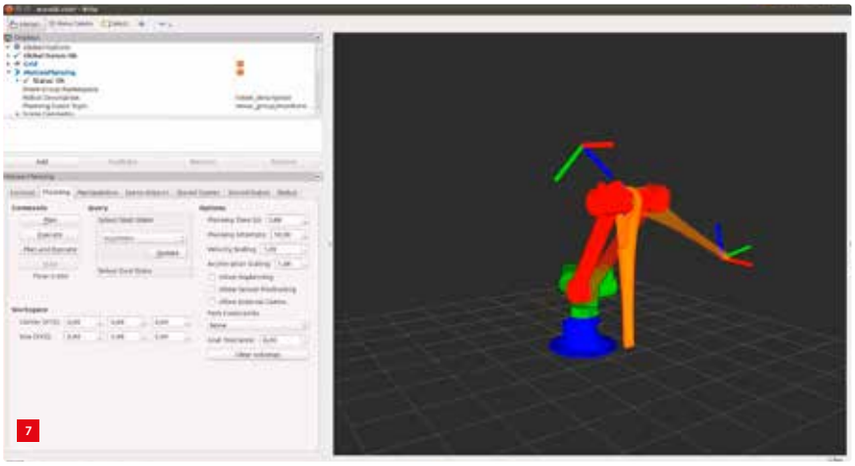
As can be seen in Figure 9, the design of the drone dock allows mechanical centring without hindering the propellers of the Agrobot. This centring mechanism always slides the Agrobot to the same position in order to allow a good connection with the charging plate. Moreover, the drone dock sticks out from the ground in order to minimise the ground effect, see Figure 10. Extensive experiments demonstrated that the drone dock has a total landing tolerance of approximately 2.5 cm, and 15°, and it centres the Agrobot correctly 95% of the time, making the electrical connection for recharging easier. Experiments also showed that it takes 90 minutes to fully charge the Agrobot's 3-cell LiPO high-density battery at 1 A.

The improved version

After evaluating the developed aerial Agrobot and its corresponding recharging and refilling stations, a second version has been developed that retains the best parts of the







7 *Path planning using MoveIt.*

8 *The main parts of the recharging station*

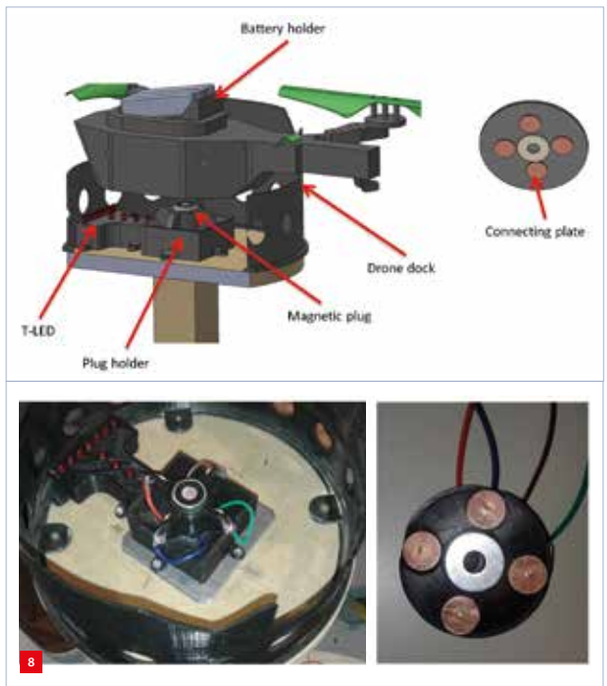
9 *Mechanical centring drone dock.*

10 *The front view of the recharging docking station.*

previous design and includes improvements and additional features. The main distinguishing features of this version are:

- the incorporation of the refilling and recharging station into one docking station, and corresponding new redesigns of the aerial Agrobot;
- the ease of transportability of the docking station;
- the shortening of the energy replenishing process.

With respect to the Agrobot shown in Figure 5, the changes in the improved version include the placement of the liquid reservoir on the bottom side. As can be seen in Figure 11, the new liquid reservoir has compartments that prevent sloshing, which minimises the dynamic disturbance from the liquid payload during lateral and longitudinal movements of the Agrobot. In addition, the original frontal camera of the Parrot AR drone has also been remounted on the bottom side in order to improve the accuracy of the vision-based precise landing since the frontal camera has a



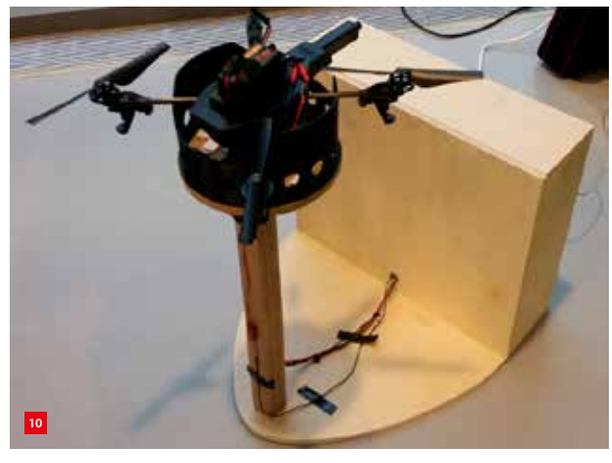
better resolution. Moreover, electrical contact points have been included to keep the Agrobot powered up. The overall control algorithm of the Agrobot has been adjusted to accommodate the aforementioned modifications.

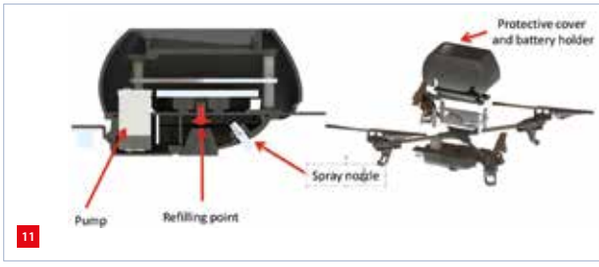
The improved docking station shown in Figure 12 is mainly composed of a battery recharging/changing subsystem and liquid refilling subsystem. Unlike the first version, the manipulator in the improved docking station is used to change the battery. For applications that need a rapid mission resumption, changing the battery in less than 2 min is far better than fast recharging at 2 A that takes around 45 min for the Parrot AR drone's high-density power battery.

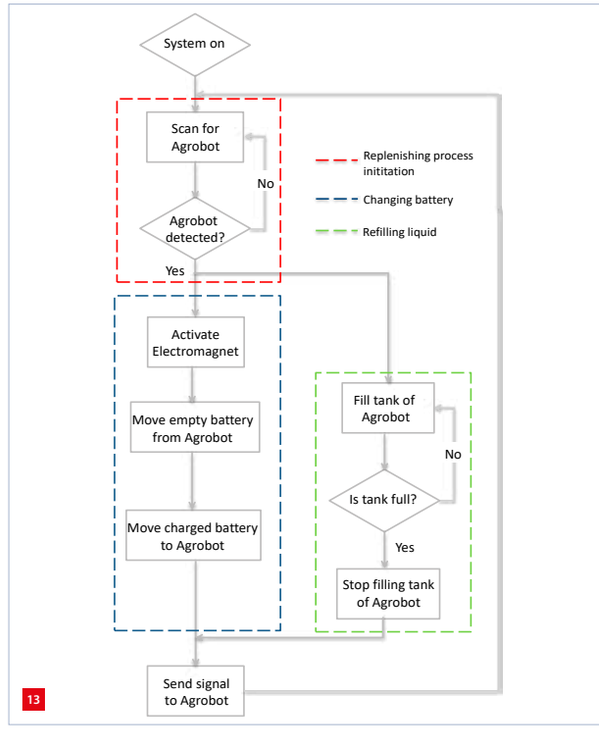
Moreover, the docking station has an electrical power supply interface that keeps the robot alive even while changing the battery. While changing batteries, an electromagnetic connection at the bottom of the Agrobot and the docking station keeps the electrical connection stable and the fluid refilling nozzle tight. The flowchart shown in Figure 13 provides an overview of the normal operation of the docking station.
One of the many appealing features of this docking station is its transportability. The drone dock and the manipulator can easily be folded for transport. The docking station measures 550 x 350 x 250 mm^3 and its mass is 13 kg, which makes it easy to transport by just one person (Figure 12). Various experiments have also shown that it takes less than 2 min to set up the docking station for operation.

Conclusion

Within this project, a proof-of-concept of an aerial Agrobot







11 *Exploded view of the improved version of the aerial Agrobot.*

12 *Improved foldable docking station.*

13 *Workflow of the normal operation of the foldable docking station.*

and a corresponding docking station technology has been developed. The docking station technology enables the Agrobot to carry out its mission reliably and tirelessly 24/7 by replenishing its energy and payload resources quickly. Changing the battery pack of the Agrobot takes less than 2 min. In addition, the docking station can be made ready for operation in less than 2 min. Moreover, the ease with which the foldable docking can be transported by just one person proved to be a very appealing feature. Although the very limited payload capacity of the original Parrot AR drone has been a limiting factor in certain choices, the full functionality of the proof-of-concept has been successfully demonstrated.

Future perspective

Although the proof-of-concept in this project has been developed in the context of precision farming, the developed technologies can be used for a wider range of other applications, such as fire-fighting, inspection and maintenance. Besides an effort to scale up the developed technologies a number of projects have been started in order to continue the development in this field within the scope of the Unmanned Robotic Systems Research line of the Research Group Mechatronics at Saxion University of Applied Sciences [8]. These projects include the Next Level, Buffalo and Mavric projects, which are collaborative projects with partner companies and governmental agencies. The research group is still interested in new (inter)national partners that would like to take part in joint innovative technological ventures in this field.

Acknowledgment

The author would like to thank the Saxion students (from the Robotics and Vision minor, the Industrial Automation minor and the Living Technology Project), the researchers involved, as well as Winfried Rijssenbeek (CEO/owner Drone4Agro) and Eelco Osse (CEO/owner Machinefabriek Boessenkool) for taking part in this project. ■

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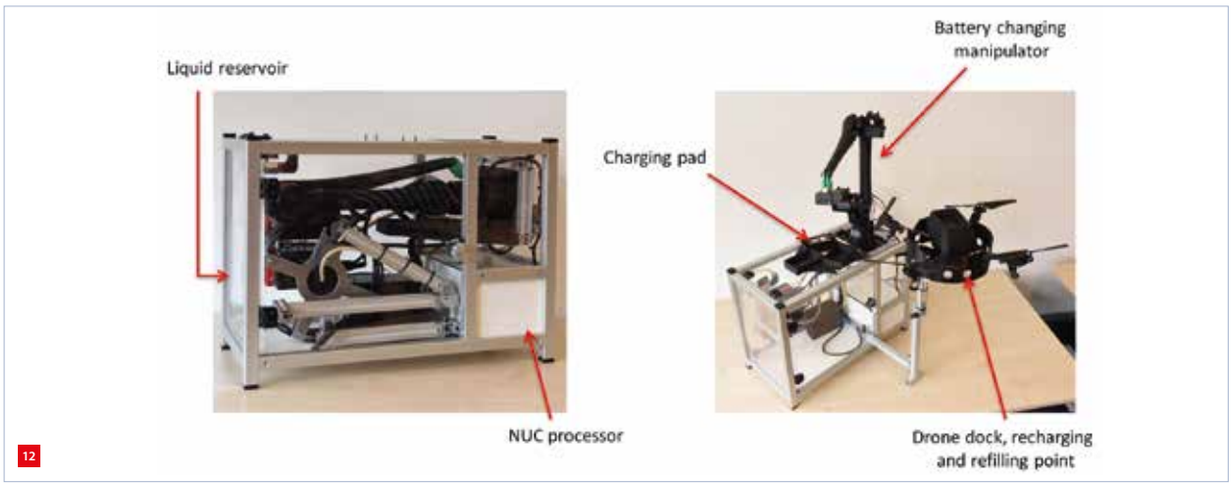

DRONES FOR DEMOS

Closing the loop in open-field agriculture is hard because there are so many factors that influence the crop yield at the end of the season. Variety in soil, the weather and input variables such as fertiliser and crop protection are only a few of those factors. For researchers and technology companies in the agricultural domain, there is an opportunity ahead to gain more control over the farming process by using unmanned systems. Avular provides the tools to facilitate this R&D field.

RAMON HAKEN

AUTHOR'S NOTE

Ramon Haken is co-founder and CFO of Avular, which started in 2014 in Eindhoven, the Netherlands, as a manufacturer of unmanned products. After participating in the Startupbootcamp HighTechXL accelerator in 2015, Avular raised seed funding to develop the safest industrial drone. To achieve this, an open robotics platform will be introduced to make drone research and development easier.

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Unmanned systems are everywhere in the news today: Domino's Pizza recently announced a partnership with Starship Technologies to use a delivery robot that rolls down the footpath to deliver pizza. For now a marketing gimmick, but soon reality. In industries such as land surveying, unmanned systems have already proved their economic value. Being one of the least digitalised industries, the agricultural market still has a long way to go before widespread adoption. Avular is paving the way with its Curiosity platform (Figure 1).

The idea

The manufacturing of hardware has gained momentum in recent years, with an increasing number of start-ups jumping into the hardware space. 3D printers and, open-source, hardware development systems like Arduino are making hardware accessible. Yet, while they are great as Internet of Things solutions, these platforms are not suitable for more complex systems.

Making unmanned systems is still a comprehensive, costly and error-sensitive process. Typical time-consuming tasks related to getting the device to work include reading out sensors, solving interference, setting up communications and writing device drivers. This process holds researchers back from doing the actual research and developers from adding value.

Inspired by the maker movement and the power of communities, Avular provides a solution by offering a 'brain for mobile robots' (Figure 2). The basic idea is that through integration of all relevant sensors and hardware in one device, the development process is accelerated. Avular's Curiosity platform contains real-time processors, IMU (inertial measurement unit), RTK-GPS navigation (RTK stands for real time kinematic), UWB (Ultra-Wideband wireless communication protocol), Xbee radio, and software for easy programming. It works with MATLAB®/Simulink® modelling and simulation software and ROS (Robot Operating System) to deploy error-free code and exploit off-the-shelf software

1 *Avular's Curiosity platform*

2 *Curiosity's brain, the control board.*

packages. The Curiosity platform can be used for unmanned aerial, ground and surface vehicles. It is delivered as a box or optionally with a drone chassis. Both the hardware and accompanying on-board software have been designed in-house by Avular.

Navigation

The ability to navigate its environment is important for every mobile device. As each environment is different, various types of sensors are needed. For navigation, the most important on-board modules are the IMU, RTK-GPS and UWB. With this combination of sensors, both indoor and outdoor navigation are possible. Because a standard GPS module does not achieve the accuracies needed for applications such as land surveying with drones, a base station is used on a fixed location. While the rover is constantly moving, the base station sends a correction signal, making it possible to determine the position of the mobile robots with an absolute precision down to 2 cm. The positions of the base station and the rover are constantly compared and the robot's position is determined using complex algorithms.

For agricultural research with drones, the precise GPS position is useful for two reasons. First of all the flight path is more accurate, so one can be sure post-flight that the part of the field which was to be covered has actually been covered. The second reason is that the position can be matched with the imagery. With some transformations, one can calculate how the images correspond to real-world co-ordinates. The result is that conclusions can be drawn at plant level.

For indoor applications, UWB can be used. The principle of triangulation is similar to the technique used for GPS. Instead of using satellites, beacons can be installed in the space where the robot moves. UWB has been specifically designed for positioning, making accuracies down to 10 cm possible. Its disadvantages include the relatively long interval needed to obtain a good position determination; in dynamic situations, it is not very fast. Along with the GPS and UWB, the IMU with accelerometers and gyroscopes to detect linear acceleration can be used, or a camera for vision-based positioning. Ideally, a combination of sensors is used.

Specifications

Navigation and positioning

• GNSS	Neo-M8P
• IMU	Dual 9-DoF IMU and barometer
• UWB	Ultra-wideband localisation module

Communication

• Wireless link	2.4 Ghz Xbee
• I/O ports	I2C, SPI, UART, CAN or USB

Programmable modules

- 3 processors on board:
  - Real-time processor dedicated for low-level control (Cortex M4F)
  - Real-time processor dedicated for high-level control (Cortex M4F)
  - High-performance computing module for advanced algorithms (Raspberry Pi 3 compute module, 1.2 GHz 64-bit quad core)

Power

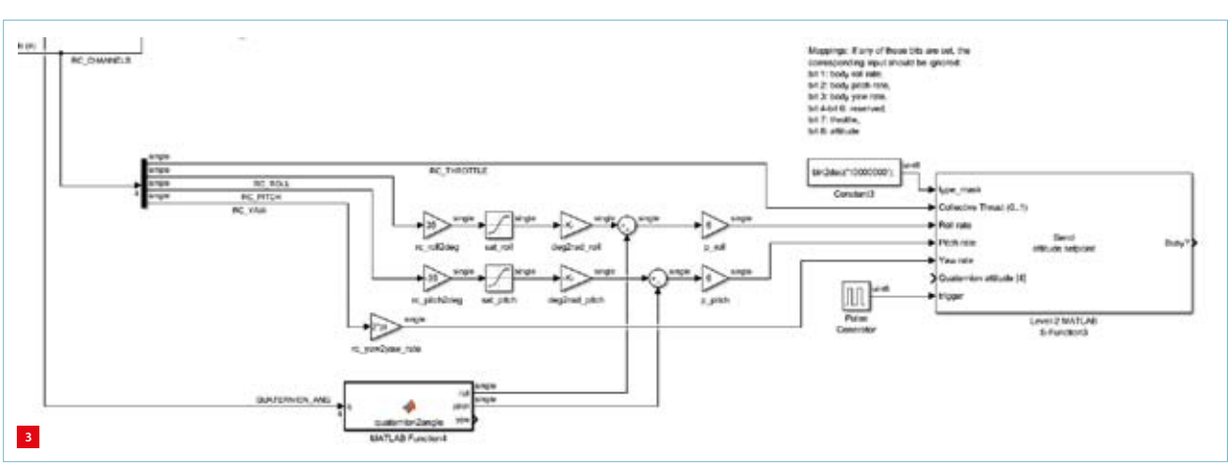
- Quick-connect battery: 4s(14.8v), 2,500 mAh

Integrations

- PX4 Open Source Autopilot
- ROS
- MATLAB®/ Simulink® Real-Time™

Hardware

Due to its low weight, the Curiosity drone requires no formal technical airworthiness assessment or certification. Still, many good engineering practices have been applied, including no wire-to-wire soldering, secure connections to prevent loosening during vibrations, and



3 *A Matlab/Simulink model of orientation control for the Curiosity platform.*

adequate fastening methods. Engineering challenges for drones are often related to correct positioning of sensors in the system, to avoid interference by the high current and voltage or by the magnetic properties of materials. In the coming years, more regulations for drones will be introduced, making the safety requirements for systems more proportionate to the type of mission they execute. This is good news for agricultural applications, as the risks involved are much lower than with the use of drones near airports or urban areas. One development that will influence all types of drones is the design of an unmanned traffic management system to allow for safe integration of drones in the airspace. This will require new on-board systems, such as a transponder that sends out information about the owner of the drone and flight status information. Testing these type of systems is another application for the Curiosity platform.

Control systems

Most of the founders at Avular have a background in control systems, so managing and controlling the behaviour of unmanned (sub)systems is one of the key activities at Avular. The Curiosity platform has been designed with that goal in mind. The platform can be used to design and test the user's own controllers. In a world with very complex machines, a model-based design process is the key to ensuring the integrity of the code generated.
As most unmanned systems are complex machines, Avular has made an integration with MATLAB and Simulink Real-Time. Figure 3 shows a Matlab/Simulink model of orientation control for the Curiosity platform. At Eindhoven University of Technology, this integration is used to create a new type of controllers for drones. Instead of a 'standard PID controller', a model-predictive controller will be used. For users who do not intend to make their own controller, the open source PX4 stack provides an alternative. With control in place, Curiosity is ready for take-off (Figure 4). ■

4 *Curiosity ready for take-off; on the right, the base station.*

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DIFFERENT PRECISION, OVERLAPPING TECHNOLOGIES

The 'precision' in Precision Livestock Farming is not the same as that of precision engineering in high-tech industry. It's not about micro- and nanometers, but about the precise control of farming management with the aid of sensing and data processing. However, there is overlap in the technological domain, for instance regarding sensors and robots. So, both worlds can learn from each other. That's why in Den Bosch, mechanical engineering students pursuing a minor in 'Machines in Motion' are working on a farming application. Mikroniek offers a sneak preview.

HAS University of Applied Sciences in Den Bosch, profiling itself as 'the education and expertise centre of the southern Netherlands for the agro, food and living environment sectors', has established a Precision Livestock Farming research group. Its objective is to conduct research into smart farming: the efficient and precise management of daily farming operations using technology and (big) data.

Robots and sensors

High-tech equipment such as robots is already known in livestock farming. Think of the milking robot: a mechatronic achievement that operates under 'rough' conditions, it allows cows to give more milk while at the same time offering them more comfort, because they can determine themselves when they wish to be milked. Feeding robots can already navigate autonomously through a barn.

The latest technological development is the use of various kinds of sensor technology to monitor individual cows. For example, there are pedometers that give an indication of a cow's activity and thus its well-being, and accelerometers that help detect fertility, when cows show increased activity. The trend is now towards smartwatches for cows. The most advanced sensor today is a probe placed in a cow's stomach that measures its temperature (fever, sufficient (cold) water?) and pH (diet), and when required sends alerts to the farmer via his farm management system.

"Sound, movement, growth, production, milk composition; these are all signals that sensors can absorb. Within the research group, the question is how we can use such sensor data to optimise farming", says Lenny van Erp, Professor of Precision Livestock Farming in Den Bosch for the last year and a half (Figure 1).

1 *Professor Lenny van Erp's inaugural speech: "Animals, Data and Daredevils", 2016.*

Co-operation

Livestock farming is, however, a small world, and therefore co-operation with external technology partners is necessary for the transfer of knowledge and experience, as well as cross-pollination (Figure 2). "With parties such as Eindhoven University of Technology and the province of Brabant, I look for the connection between technology and the agro-food sector. For example, I spoke with Maarten Steinbuch, a professor of control system technology, active in robotics and automotive. Among other things, his group is known for their work on soccer robots that are able to observe each other and work together." This could be

similar to a swarm of robots that monitor the condition of chickens in a barn, by measuring their temperature and activity and so on. "Examples of issues include how to use vision, which cameras to use, how to construct a world view, what software to develop, etc."

Machines in Motion

Recently, a collaboration began with the Mechanical Engineering department at Avans University of Applied Sciences, also based in Den Bosch, within their minor 'Machines in Motion'. This six-month specialisation covers the design of fast and precise machines for the so-called 'high-tech, low-volume' market. In terms of mechanics, the design and tolerances are subject to stringent requirements, and motion control – or motors in servo systems – is just as important. Students learn to work together with other disciplines and gain insight into the relationship between the design of a machine and the processes in which it will operate.

2 *Professor Lenny van Erp: "With parties such as Eindhoven University of Technology and the province of Brabant, I look for the connection between technology and the agro-food sector."*

The minor includes a project, generally suggested by a company (in this case the Precision Livestock Farming research group), which covers the whole process from initiation right through to manufacturing a prototype, from drafting a list of requirements and wishes, to preparing and overseeing manufacture and testing. Here, the objective is to design a robot platform equipped with sensors that can operate in modern broiler farms under demanding conditions, regarding temperature, humidity, manure, obstacles (other animals), etc. The first results will be published next year. ■

INFORMATION
WWW.HAS.NL/NL/KENNISCENTRUM/LECTORATEN

ONE 2 THREE

Last month, the Dutch high-tech start-up Cerescon presented the world's first 3-row asparagus harvesting robot at Expo-SE 2017, Europe's leading exhibition for asparagus and berry production. After a successful test period with a 1-row version over the past season, Cerescon displayed the prototype of the definitive machine to the asparagus industry during the 'Spargelmesse'. Cerescon received the Innovation prize during the expo, awarded annually for the product most likely to deliver the greatest benefits for its users.

Cerescon is a young and rapidly-developing high-tech start-up, based in Heeze, the Netherlands. Its machine is selective, as it only cuts harvest-ripe asparagus, with a better quality than that obtained by means of manual cutting, and it solves the problem of high labour costs in Western Europe. To prevent violet discolouring due to sunlight, the machine detects and harvests the asparagus underground. Little ultra-thin bars that gently 'plough' through the sand bed and are fitted with a touch probe, can automatically determine the location of an asparagus, after which the coordinates are sent to an automatic cutting unit.

Tests

Under the watchful eye of growers from the Netherlands, Germany, Italy, France and Peru, and of the international media, this spring Cerescon presented the 1-row version of the machine. It was tested successfully during the 2017 harvesting season, and in the 2018 season the first asparagus will be harvested commercially with a Cerescon asparagus harvesting robot. New and extensive application tests are also underway, part of a three-year study being conducted in conjunction with Wageningen University and Research, the LimGroup and several large growers in the Netherlands. The application tests are intended to compare the machine harvesting with manual harvesting; exact figures for the increased yields and higher quality from machine harvesting can be shown this way.

Benefits

The 3-row version of the machine:
- halves the cost price for harvesting;
- detects subsoils, resulting in better quality and more asparagus;
- can maintain ± 50 hectares per season;
- replaces ± 70 manual harvesters;
- is pulled by a tractor.

As Cerescon is in the middle of patent applications, no technical details can be published yet. ■

INFORMATION
WWW.CERESCON.COM

1 *Prototype of Cerescon's 3-row asparagus harvesting robot.*

DeltaPatents – providing high-tech patents and high-calibre training

DeltaPatents is a patent attorney private practice based in the centre of Eindhoven, the Netherlands, with a second office at the Bioscience Park in Leiden, the Netherlands. DeltaPatents provides professional IP services to innovative high-tech companies; clients range from start-up companies and knowledge centres to large multinationals. It specialises in providing high-quality patent services in complex technical fields, such as mechatronics and precision engineering, and is also renowned for its patent-related courses, in particular those aimed at passing the European Qualifying Examination and the Certified Formalities Officer examination.

Time-to-market

As you drive your innovation from idea to reality, there are many hurdles: solving technical problems, arranging financing, agreeing terms with business partners, sourcing manufacturers, and planning marketing campaigns. Intellectual Property (IP) discussions are frequently postponed until success is guaranteed, or until a conflict arises. By then it may be too late to protect your own IP.

1 *Protect the IP rights on your 'golden egg' idea.*

IP helps from the outset

IP rights transform ideas into tangible assets belonging to your company. They add value and prevent the loss of valuable ideas, increasing your chance of investment & subsidy. They can be traded or licensed as part of conflict resolution or joint-development agreements. They are used to register ideas before meeting potential collaborators. Their use in promotion helps build a brand, and increases your innovative reputation. If necessary, they can be asserted to stop a competitor or an ex-employee gaining an unfair advantage.

Choose the rights that you need

Patents protect inventions made when technical problems are solved in fields such as software, mechanics, electronics, chemistry or bio-technology. Trademarks ensure that clients associate products & services with your business as brand owner. Industrial designs protect the aesthetics of products, providing additional brand recognition. Some innovative processes are trade secrets, but they should be documented using confidential registration. Copyright on software, manuals & product appearance is also strengthened by such registration. ■

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DAZZLING OPTICS

"A dazzling optics week in Aachen with a lot of knowledge sharing and interaction, with special thanks to the Fraunhofer institutes ILT and IPT for their hospitality." That's how DSPE president Hans Krikhaar describes the successful third edition of the DSPE Optics Week, which was held in Aachen, Germany, in late October. The four-day event included a symposium and fair, a demonstration day and two high-level optics courses. This report presents highlights of the symposium and the demonstration day.

The DSPE Optics Week 2017 was a unique collaboration between Dutch, German and international organisations. The third edition of the biennial event was held on 23-26 October at the RWTH Aachen University in Germany. The four-day event brought together outstanding international speakers and lecturers from a variety of backgrounds, ranging from semiconductors and medicine to the optical and machine building industries. Some 100 representatives from German and Dutch industry and academia attended the symposium, which included a fair with nearly 20 exhibitors, from ASML to Zeiss...

ASML

Jos Benschop, senior vice president Technology at ASML in Veldhoven, the Netherlands, and professor of Industrial Physics at the University of Twente, acted as chairman for the day at the DSPE Optics and Optomechanics Symposium. In his informal and direct way he managed to adhere to the tight symposium schedule and generate ample discussion after each presentation. His contribution underlined the relevance of the DSPE Optics Week for the Dutch high-tech ecosystem, as did the large delegation from the world-market leader in lithography ASML that attended the demonstrations at the Fraunhofer institutes the next day.

Dutch Optics Centre

Paul Urbach, professor in Optics at Delft University of Technology (TU Delft) in the Netherlands and president of the European Optical Society, used the occasion of the opening presentation to introduce the Dutch Optics Centre (DOC) [1], an initiative by TU Delft and TNO established in 2016, of which Urbach is the academic director. DOC's mission is to conduct research (in imaging, spectroscopy and metrology) from low to high TRL (Technology Readiness Level), share facilities, educate students in optics and optomechatronics, and provide training for industry workers. A master's programme in optomechatronics began this year, while a joint master in optics with the Friedrich-Schiller-Universität Jena is under development.

In addition, Urbach presented examples of new results from research projects. These included computationally assisted imaging for incoherent optical imaging systems, lensless imaging, hyperbolic materials (anisotropic stacks of very thin alternating dielectric and metallic layers, which exhibit strongly enhanced transmission of P-polarised evanescent waves), molecular spectroscopy of human breath, topology optimisation for designing complex optical structures with minimum weight and volume, and position metrology with resonant nanostructures excited by specially focused fields.

Urbach concluded his presentation by inviting his audience to attend the European Optical Society Biennial Meeting (EOSAM) 2018, which will be held in Delft, from 8 to 12 October 2018 [2].

Self-optimising optics assembly

Oliver Pütsch, group leader Optical Systems at RWTH Aachen University [3], talked about self-optimising assembly strategies for tomorrow's optical systems production. He stated that the assembly of laser systems for a strongly growing global market is still dominated by manual work, but that cost-price pressure from low-wage countries requires automation. This could mean full automation, for mass production with limited flexibility, but an alternative is emerging in the form of self-optimising assembly, which offers advantages in terms of flexibility (high diversity of products) and consistent quality.

Model-based approaches for the assembly of optical systems offer a high degree of automation and high throughput, while maintaining high optical performance even for small and medium lot sizes. Quality factors such as assembly, component and alignment tolerances, as well as thermo-optical effects, are taken into account holistically to achieve optimal optical functionality.

Two self-optimising assembly strategies were discussed: dynamic optical modelling and wavefront-based alignment. The dynamic optical model approach is based on the

EDITORIAL NOTE

This report was based on the presentations at the symposium and a demonstration day impression by Reik Krappig, manager business unit Optics, Fraunhofer IPT.

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interplay between the virtual domain (the optical, Zemax model yielding target positions for optical component placement) and the physical domain (the assembly set-up yielding measurement data for current optical performance, Figure 1). Wavefront-based alignment starts with the prior characterisation of the optical system concerning the influence of each degree of freedom on the wavefront. Corrective actions for component alignment are then derived by inverse calculations using a single measured wavefront.

Of course, there are always issues, such as – with the dynamic optical model – the investigation of the influence of the assembly order on the overall optical performance, and the multi-sensor approach for realising a so-called 'digital optical twin', and – for wavefront-based alignment – the interdependencies of the wavefront parameterisation and achieving higher precision (lower noise) as well as a larger sensor area in wavefront measurement. But Pütsch concluded that self-optimising strategies are a key technology for the assembly of high-quality optical systems, combining low production cost and flexibility to close the gap between fully automated mass-production techniques and flexible manual production.

Metrology for laser-based machining

Léon Woldering, group leader optical and vision engineering at Demcon Focal in Enschede, the Netherlands, talked about adaptive optics in industrial applications, in particular about the European Adalam project [5]. This Horizon 2020 project is being coordinated by Unimetrik, a Spanish metrologic service company and calibration laboratory, and participants for the work packages to which this work belongs include Fraunhofer IPT, Sill Optics, Demcon Focal and the Dutch company Lightmotif, which develops ultrashort-pulse laser micromachining systems.

Adalam is aimed at developing a sensor-based adaptive micromachining system for zero-failure manufacturing, based on ultrashort-pulse laser ablation and a novel depth measurement sensor, together with advanced data analysis software and automated system calibration routines. The technology developed will generate new solutions for the manufacturing of high-quality and innovative products, based on the principle of 'measuring where you are milling'.

Woldering focussed his presentation on the development of the high-speed, low-coherence interferometry-based topography sensor. Part of this project is the development of a proof-of-concept set-up in which adaptive optics is used for providing an optimal measurement spot through the f-theta lens, which is used in the machining/measurement set-up. The spot quality is improved by means of a membrane-based deformable mirror, which works in conjunction with a spot re-imaging system and a Shack-Hartmann wavefront sensor. This work aims at the improvement of the lateral measurement resolution.

3D printing

Professor Andreas Heinrich, head of the Centre of Optical Technologies (Zentrum für Optische Technologien, ZOT) [4] at Aalen University, Germany, delivered an enthusiastic presentation on his 'hobby', the 3D printing of optics. He presented additive manufacturing (AM), commonly known as 3D printing, as a new way to realise complex-shaped optical components. After a brief introduction of AM for polymer and metallic optics, he discussed the work at the ZOT in the fields of illumination, optical metrology and components. The ZOT includes a spin-off activity for commercialising the 3D printing of optics.

Heinrich gave an overview of the available AM infrastructure and the post-processing required: polishing (Figure 2), coating and UV/thermal treatment. A key factor is material screening for optimising optical performance, such as transmission, of 3D-printed optics. He also showed the AM platform developed at the ZOT, comprising a robot arm guiding the print head and a hexapod for accurately positioning the substrate on which an optic component is being printed.

As application examples are the proof of the pudding, Heinrich gave a generous overview that included individualised optical metrology for complex-shaped

1 *Laboratory set-up for the self-optimising assembly of optical systems. (© Fraunhofer Institute for Laser Technology ILT, Aachen, Germany)*

2 *3D-printed optics often require post-processing, such as polishing.*

products, imaging optics using liquid lenses with membranes in which 3D-printend structures are integrated, and 3D-printed light pipes. New developments include the use of 3D printing for the functionalisation of surfaces in, e.g., OLEDs and microlenses, and for active optics, for example in an array of printed active components that can be excited by UV radiation at various wavelengths for the imaging of biological samples.

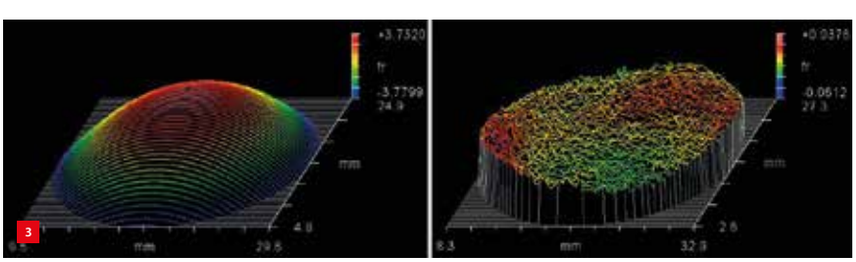
Thin-film stress in coatings

The subject of Martin Bischoff, director of the Advanced Coating & Components group of Qioptiq [8] in Göttingen, Germany, was optical coatings: "mysterious things that change the properties of surfaces". He focused on the thin-film stress of complex optical coatings: impact and compensation mechanisms. The design complexity for UV-VIS-NIR coatings increases with growing demands regarding reflection, blocking, edge steepness and spectral bandwidth. Usually, ion beam or magnetron sputtering techniques are used to fabricate high-precision coatings.

However, the main drawback of sputtering technology is the high compressive thin-film stress of the deposited coatings. This can have an enormous impact on the shape of the deposited surface leading to reflected wavefront deformations when using these components in optical systems. The result can be a negative impact on the imaging quality of the optical system. Therefore, thin-film stress control is essential for the performance of highly complex optical components. The undesirable deformation of the substrate surface has to be compensated for in order to achieve the required surface flatness.

The simplest compensation mechanism is a backside coating. However, using backside coatings just for stress compensation is inefficient due to double process time and in some cases it is not even possible to realise a suitable backside coating because of complex substrate geometry. Therefore, alternative methods for stress reduction after the deposition have to be discussed.

An alternative and intriguing method is the post-deposition treatment of optical coatings for stress compensation. Though this method is well-known for reduction of absorption losses, it also directly allows adjusting the final thin-film stress by optimising the annealing temperature (Figure 3). However, this method is also limited to certain substrate materials as well as coating materials. Therefore, further options are available such as adjustment of the coating process and coating design parameters; so-called pre-compensation using uncoated structures; and lens adjustment for spherical error compensation. However, no universal method is available for different applications, Bischoff concluded. "Weighing the (dis)advantages of each method will remain necessary."



3 *Surface mapping of a HfO_2/SiO_2 multilayer coating on fused silica after deposition (as-deposited; left) and after post-deposition treatment with optimised process parameters (right).*

Thermal effects

Bernd Granzin, head of Optical Design at Fisba [6] in St. Gallen, Switzerland, discussed thermal effects and their compensation in optical systems. A variation of temperature inside an optical system, due to environmental conditions and/or the luminous flux, will most likely change its optical performance due to the thermal expansion of the materials (characterised by the CTE coefficient) and a change in the refractive index $n(T)$. The prime thermal effect is mostly a shift of the focal plane, but other (higher-order) effects also occur.

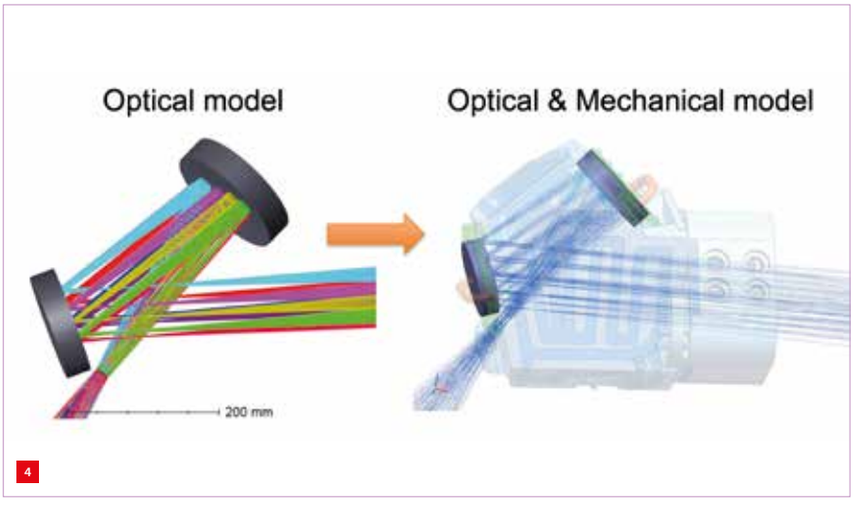
Thermal lensing was described as an example: absorption in the lens elements or in the coatings generates spatial temperature distributions, leading to local optical path differences that in turn generate wavefront distortions. To study the effect, finite-element modelling is required. Granzin discussed the thermal and chromatic power of a lens, describing the temperature- and wavelength-dependence of a single lens element. Both coefficients are helpful in selecting appropriate materials for lens elements in optical systems. The term 'athermal glass', used for optical glasses that are insensitive to spatial temperature gradients, was briefly discussed as well.

The second part of the presentation was a short introduction to the athermalisation of optical systems: the principle of stabilising the optical performance with respect to temperature, either by designing the optical elements and mounts to be mutually compensating or by including movable corrective mechanisms. In the latter case, active athermalisation that uses sensors and actuators to control the motion of the compensating elements is a viable option. Active compensation can deal with difficult conditions, but it is an expensive solution and in itself creates additional problems, as actuators generate heat.

Passive athermalisation can be achieved either in a mechanical or an optical fashion. The mechanical option is based on the use of materials for spacers, springs, etc., in optical (lens) assemblies with different CTE values, combined in such a way that their assembly 'automatically' corrects the positions of lens elements. Complex mechanical

assemblies can be part of such a solution. As an example the athermalisation with a so-called reciprocating mount was discussed. Optical athermalisation can be achieved by choosing appropriate optical glasses and optimising the optical design to compensate the focus shift.

The exact modelling of the mechanics is complex and prone to errors, partly because of the limited accuracy of the 'thermal' data (CTE, d*n*/d*t*). Moreover, the measurement of the real thermal behaviour can be a challenging task on its own, as Granzin said in conclusion to his interesting talk. Chairman Jos Benschop appreciated the way in which Granzin provoked the attention of his audience by pointing out a few errors in the designs he showed. This sparked off an animated discussion.



4 *The direct coupling of optical raytrace software with thermomechanical CAD packages makes the assessment of systems faster and less prone to error. Here, the ITER case is shown.*

Nanometrology

Professor Stefanie Kroker, head of the research group Metrology for Functional Nanosystems in the Lab. for Emerging Nanometrology [7] at the Technical University and the Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig, Germany, discussed optomechanical material properties for high-precision experiments. Increasing the signal-to-noise ratio in these optics-based experiments can be achieved by either increasing the signal level, involving higher mechanical and/or optical quality factors, or by reducing the noise level. Both 'routes' depend on the material properties, such as mechanical loss, Young's modulus, Poisson's ratio and refractive index.

Optomechanical light-matter interaction influences the sensitivity of, e.g. frequency-stabilised laser systems or gravitational wave detectors. The coupling of optical and mechanical modes may enhance the measurand, but may also lead to detrimental fluctuations (i.e., noise) limiting the sensitivity of the experiment. The optomechanical material properties are key parameters for the coupling strength. Kroker discussed methods to investigate important material properties and their relevance for high-precision experiments.

To illustrate her point, she addressed the sensitivity of gravitational wave detectors, which currently can detect a relative length change of 10^{-21}, i.e. 0.1 nanometer of the Earth-Sun distance! In order to enhance this sensitivity by another factor of ten, thermal noise has to be reduced. Kroker presented highly reflective metasurfaces (for mirrors in the interferometric set-up) with which the Brownian thermal noise was studied. She also showed that crystalline materials such as the silicon (111) surface can be an alternative to the conventional amorphous materials, like fused silica, which exhibit an increasing mechanical loss with decreasing temperature. However, there still is a lack of material parameters for micro- and nanoscale systems.

Beyond tolerancing

The title of the presentation by James Day, optical designer at TNO [9] in Delft, was "Beyond tolerancing – Structural Thermal Optical Performance (STOP) Analysis". Chairman Jos Benschop was intrigued: "I am fond of analysis, so why stop?" Day introduced STOP analysis as a powerful tool to evaluate designs for their as-built performance. The direct coupling of optical raytrace software with thermo-mechanical CAD packages makes the assessment of systems faster and less prone to error.

Conventional optical tolerance analysis includes decentres, tilts, surface form errors, uniform material imperfections and thermal loads. Not included are stress gradients, due to, e.g., mounting or gravity release, or gradients in the temperature or refractive index. With STOP analysis, the impact of a load case on optical performance can be assessed, taking into account thermal effects, gravity release/orientation, mounting, (micro-)vibrations and stresses applied by actuators, using a combination of standard and custom optical/mechanical/thermal software.

Day presented two application cases: the wall and fusion diagnostics systems for the ITER Tokamak nuclear fusion reactor (Figure 4), and the TSBOA (Telescope, Scrambler and Beam-splitter Optical Assembly) of the Sentinel-5 Earth observation telescope. He concluded that STOP analysis in particular shows its value for optical systems under extreme conditions (e.g., a plasma temperature of $1.5 \cdot 10^8$ K in ITER), with using STOP optimisation to close the loop being the holy grail of optomechanical system analysis.

Subnanometer disturbances

Ralf Zweering, mechatronics architect for lithography optics at Carl Zeiss SMT [10] in Oberkochen, Germany, described the road from nano-world specifications to a real-world optics system, starting with the technical challenges. From the top-level specifications for (EUV) lithography, the sub-

specifications can be derived for the Zeiss optics, i.e., the projection optics box (Figure 5). Currently, specifications for resolution and overlay typically are 13 and 2 nm, respectively. "Two nm is not very much", Zweering commented dryly, considering it is the square root of the quadratic sum of some 50 contributions, each amounting to approx. 300 pm.

The disturbances on the subnanometer scale include heat loads and thermal expansion, floor vibrations and reaction forces of actuators, sensor noise, magnetic interactions, pressure and humidity (fluctuations), material drift and so on. As an example, Zweering calculated that the temperature stability of the optical structure during a 30 sec wafer exposure should be better that 0.030 mK.

But this is only half the story: the 'non-technical' issues (complexity, time-to-market, industrialisation, economics) are just as challenging. Complexity calls for systems engineering to manage the hundreds of requirements successfully and structure the product creation process. Time-to-market can be reduced by employing concurrent engineering. Industrialisation depends on the available workforce, production layout, design for manufacturing and assembly, serviceability, etc. In the end it comes down to economics, so design-to-cost is paramount.

Connecting one of the previous subjects, gravitational wave detectors, and Zweering's list of potential disturbances, the question was raised whether the collision of two black holes would be a potential disturbance. Zweering could not guarantee that his list was 100% complete, but he discarded this particular suggestion. However, he added a note: "We are not concerned about the moon's gravity… but it's only a question of time!"

Serendipity

The symposium concluded with a highly interesting talk about a spin-off from the optical R&D at ASML. Patrick de Jager, senior director New Business at ASML, presented LightHouse [11]: the production of radio-isotopes for medical diagnosis with a superconducting electron-optical accelerator. The advantage of LightHouse is that radio-isotopes can be produced without nuclear waste or the use of enriched uranium.

LightHouse was described by De Jager as a case of serendipity: while watching a TV documentary about the problems associated with the current nuclear production method for these radio-isotopes, he suddenly thought of the free-electron laser that ASML had investigated (and later discarded) as an option for the EUV light source. This technology can be used in a set-up with a 60 m long RF accelerator assembly and an exposure cell where the electron beam hits a specially designed target for generating the required radio-isotopes.

5 *The EUV projection optics box. (Source: Carl Zeiss SMT)*

De Jager sketched out business development, including consortium formation, and technical issues, in particular the conflicting challenges in the exposure cell design regarding yield, specific activity of the material used and thermal issues. These issues demand either more or less beam power, either more or less target material and either longer or shorter exposure time. The current status of LightHouse is that the feasibility study has been concluded. Now the development and engineering can start.

To be continued. Just as the series of successful DSPE Optics symposia deserve to be continued with a fourth edition in two years.

Demonstration day

The next day, the Optics Week provided attendees with the chance to gain extensive insights into the optical activities of the Fraunhofer Institutes for Production Technology IPT [12] and Laser Technology ILT [13]. Some thirty attendees took the opportunity to connect with Fraunhofer scientists from the field of optics as they explained their research at a variety of laboratory set-ups and prototypes. Divided into small groups, the participants shifted through six demonstrations, each presented by one of the Fraunhofer institutes. Due to the effectively sized groups, participants were able to enjoy a hands-on experience and vivid discussions on the latest Fraunhofer technology.

The guided tour also posed a nice opportunity to catch up on the theoretical presentations given during the symposium by illustrating the real-life behaviour of a variety of technological approaches, ranging from a laboratory set-up to a production-oriented scale. Examples of the demonstrated technologies included the highly precise alignment of optical components using wavefront sensing technology and the laser-based production of optical components via ablation, polishing and form correction.

Furthermore, the tour also incorporated demonstrations on the issue of digitalisation and its possible impact on the precision and efficiency of the production of optical components. This was demonstrated, for instance, for a precision blank moulding process, in which data from the machine is used in order to generate a real-time simulation of the moulding behaviour. In this way, the operator is granted a precious view into the otherwise non-visible process, allowing them to detect any deviations early on and accordingly to perform parameter changes in a timely manner.

In addition to the Fraunhofer Institutes, the demonstration day also included a visit to the nearby research campus dedicated to Digital Photonic Production DPP [14]. Among other stations, the companies Innolite [15] and LightFab [16] impressed participants with their capabilities in the field of precision machine technology and 3D laser printing of optical, respectively glass components; see Figures 6 and 7. These examples of developing the numerous research activities of the Aachen region into leading-edge commercially available products for the optical industry formed an ideal conclusion to an exciting demonstration day. ■

6 *Innolite offers sophisticated solutions for optics production by advanced diamond machining technologies*

7 *LightFab builds subtractive 3D printers for the manufacture of optical components using the Selective Laser Etching process.*

INFORMATION

[1] WWW.DUTCHOPTICSCENTRE.COM
[2] WWW.MYEOS.ORG/EVENTS/EOSAM2018
[3] WWW.TOS.RWTH-AACHEN.DE
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[15] WWW.INNOLITE.DE
[16] WWW.LIGHTFAB.DE

EQUALIZER: REDUCING VIBRATIONS, PRESERVING STIFFNESS

A novel tool to reach low vibration levels in existing buildings has been developed. Active vibration cancellation can be applied on floors in existing buildings next to already installed equipment. A few sensors and actuators the size of a shoe box together with a control system can lower vibrations with a factor three to ten. The lower vibration levels do not come at the cost of lower stiffness as is the case with active or passive isolation solutions.

SERVAAS BANK

A quiet place

With the demand for ever smaller structures there is an increasing demand for a quiet place within precision machines, where accurate processes are not hindered by vibrations. In practice the precision machine has a vibration specification, the maximum vibration level at which it will achieve its intended performance. The user has a floor where he wants to put the machine. The vibration level of the floor is measured and if it exceeds the specification a solution must be found. An isolation pedestal, which isolates the precision machine from the vibrating floor may be considered as a solution (see the first box: Non-technical aspects).

Two possible downsides to this solution however exist. Firstly, vibration isolation often does not work well underneath precision machines with internal vibration isolation, as unwanted interaction may occur, leading to increased vibration levels or decreased stability. Secondly, if the machine exerts forces on the system, which is the case for most machines with fast moving parts, the machine will need a solid, stiff support. This contradicts with an isolation solution that tends to be rather soft, even the so-called 'hard-mount' systems (see the second box: Stiffness versus isolation).

1 *Equalizers in a cleanroom. The units each measure 350 x 150 x 160 mm³ and their mass is approx. 25 kg.*

2 *Typical situation of a factory floor with precision machine and disturbance sources.*

2 *Equalizer reducing vibrations on the floor field.*

AUTHOR'S NOTE

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Non-technical aspects

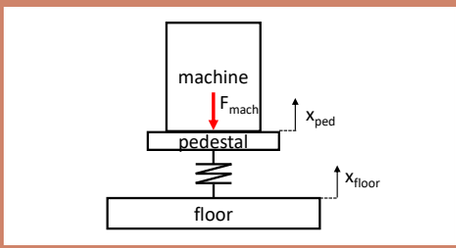
In case of problems, try to solve them at the source. This is a very broad and true recommendation. It holds perfectly for vibration problems. And yet, the question "we have a vibration problem – can you please solve this for me at the source?" seldom reaches the vibration expert. Most of the time the customer with the problem specifically asks for a solution at the machine.

Mecal's experience confirms the power of problem solving at the source. Sometimes a ten-minute walk through the servicing room with the proper measurement equipment and expertise can pinpoint the pumps which are causing the high vibration levels. Servicing these pumps will not only lower the vibration levels of the whole building but probably also extend the lifetime of the pumps.

Why then do customers ask for a solution at the machine? The answer lies in organisational and practical reasons. The person with the vibration problem is responsible for the precision machine, not for the building and not for the unbalanced pumps in the basement; this person wants a solution that is within his jurisdiction.

Stiffness versus isolation

Pedestal vibrations can originate from floor vibrations (x_{floor}) or from machine forces (F_{mach}). We can describe the pedestal as a simple spring mass system.



Vibrations due to machine forces

For forces of the machine applying Newton's laws leads to:

$$\text{Compliance} = x_{ped} / F_{mach} = (1/k) / (1 - f^2/f_0^2 + i{\cdot}2{\cdot}\beta{\cdot}f/f_0)$$

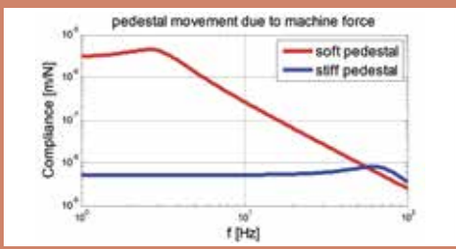
or:

$$\text{Stiffness} = F_{mach} / x_{ped} = k \cdot (1 - f^2/f_0^2 + i{\cdot}2{\cdot}\beta{\cdot}f/f_0)$$

Here:

k = spring constant [N/m]
f_0 = resonance frequency ($1/2\pi \cdot \sqrt{(k/m)}$ [Hz])
m = mass [kg]
β = damping constant
$i = \sqrt{-1}$

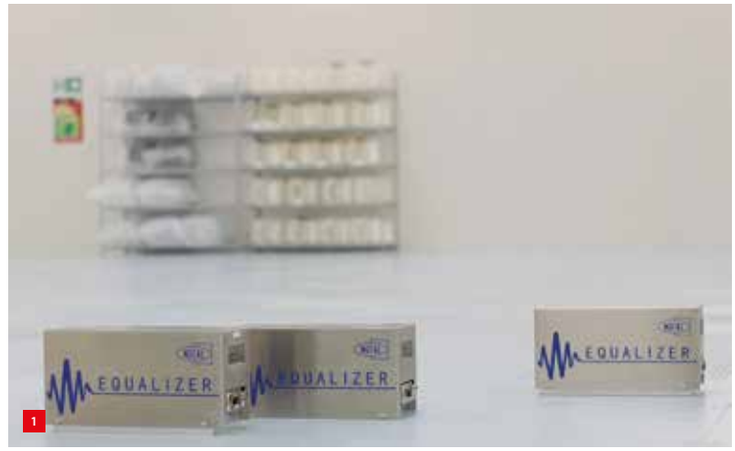
Now we can compare a 'soft' isolation pedestal with a stiff pedestal. The stiff (blue) pedestal moves much less than the isolation pedestal. Above the resonance frequency of the stiff pedestal the movement of both pedestals is governed by the mass only.



Vibrations due to floor movement

$$\text{Transmissibility} = x_{ped} / x_{floor}$$
$$= (1 + i{\cdot}2{\cdot}\beta{\cdot}f/f_0) / (1 - f^2/f_0^2 + i{\cdot}2{\cdot}\beta{\cdot}f/f_0)$$

We can plot this for the same soft and stiff pedestal. The soft (red) isolation pedestal moves less than the stiff pedestal. Active vibration cancellation with an Equalizer gives the opportunity to have the robustness and good performance for machine forces of a stiff pedestal and still have a significant reduction of floor vibrations.



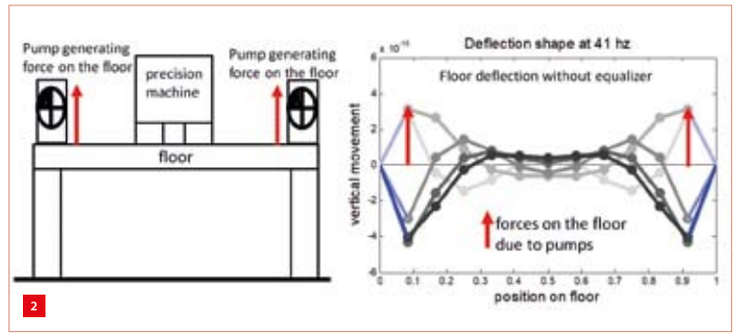
1

An alternative solution to lower vibration levels without lowering the stiffness beneath the machine and with little to no interaction with any active systems within the machine has been developed by Mecal. This is an active vibration cancellation system called Equalizer (Figure 1).

Working principle

Suppose a factory as in Figure 2. Disturbance sources (e.g., pumps) generate forces that lead to vibrations on the floor where the precision machine is located. In general, the floor is vertically much less stiff than horizontally and will typically have most movement in the vertical direction.

A vibration pattern with modal minima and maxima will be formed on the floor depending on the frequency of the disturbance and the modal characteristics of the



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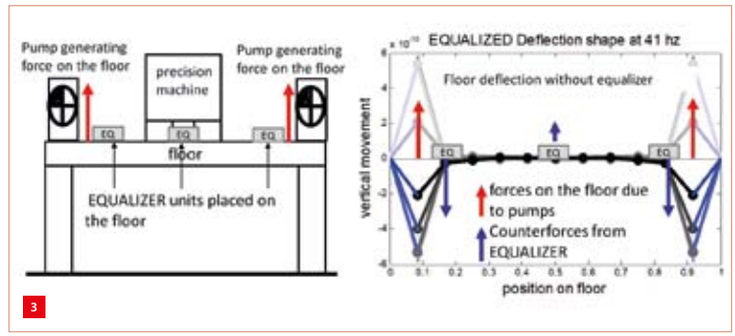

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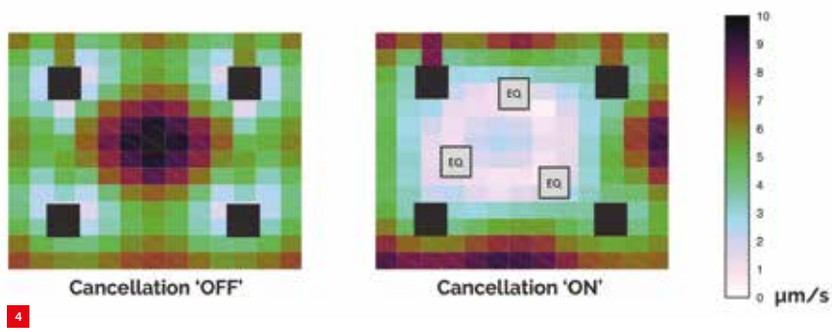

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4 *Vibration levels on a floor (left) and on the same floor with three Equalizer (EQ) units (right).*

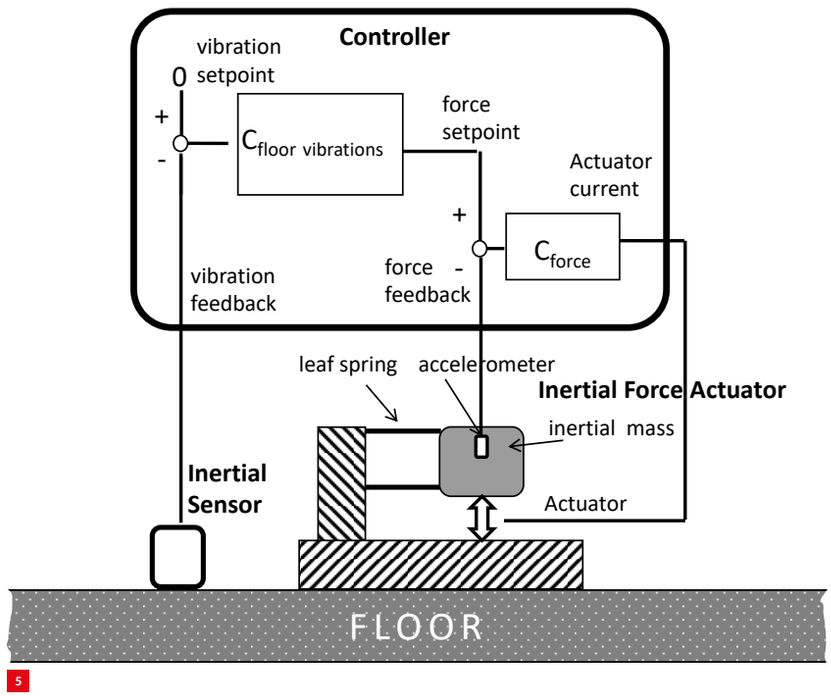
5 *Schematic of the Equalizer.*

6 *Controller and three Equalizer units.*

floor. This is indicated in the right graph of Figure 2. If the modal pattern for the disturbing frequency is known, points on the floor with a modal maximum can be selected to apply a counterforce. This counterforce will be controlled by a control system with feedback from the floor movement so that the local floor movement will be reduced with at least a factor ten. See Figure 3.

By reducing the floor movement with a factor ten at the places where an Equalizer is placed, the vibration level can be reduced over a large area with a factor three to four. An example can be seen in Figure 4, which shows a top view of a floor field. The black squares indicate the position of the supporting columns. Colour indicates the vibration levels at the disturbance frequency and the grey squares labelled EQ denote the Eequalizers.

The optimal placement of the Equalizers can be established by modal measurements of the floor and a simulation of the floor with and without the Equalizers.



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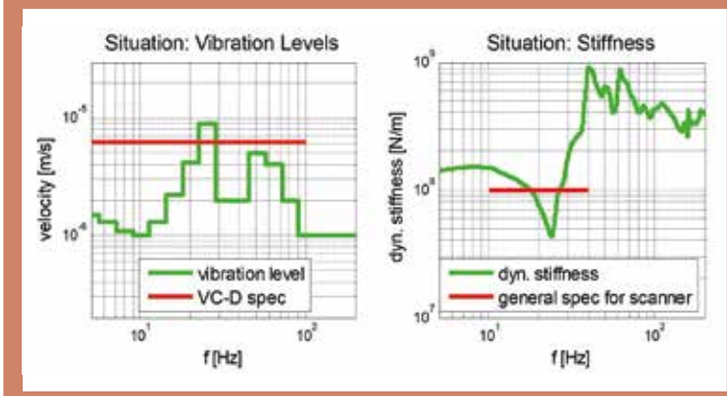
Inside the Equalizer

Each Equalizer unit consists of an inertial actuator, paired with an inertial sensor and a feedback control system (Figure 5). Based on the vibrations measured by the sensor, the control system precisely determines the force to be applied on the floor by the actuator. The feedback control loop continuously adapts the force to minimise the measured floor vibrations. It is intended to be used on the stiff fab floor or on a machine pedestal which is stiffly connected to that floor. For optimum results, usually a configuration of several Equalizer units and a controller has to be used (Figure 6).

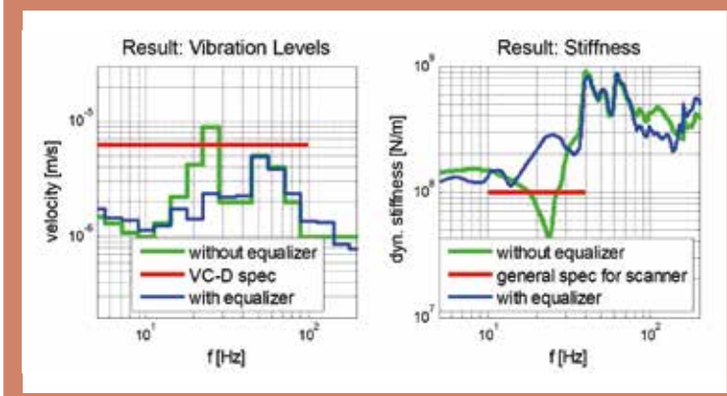
Inertial forces can be produced effectively at frequencies above the resonance frequency of the inertial mass. The lower noise limit of the system depends on the noise level of the sensor. Mecal developed an inertial sensor with noise levels well below $1 \cdot 10^{-8}$ m/s at 1 Hz (one-third octave velocity level). Subsequent internal modes of the actuator and sensor that are visible in the control loop are much higher than 500 Hz. This is necessary to achieve a controlled bandwidth up to 100 Hz.
In practice the Equalizer is most effective in cases where the vibration levels need to be lowered at one or two specific disturbance frequencies, e.g., 50 and 25 Hz, or at the frequency of a badly damped floor resonance (see the third box: Example – vibration reduction and active stiffening).

Example – vibration reduction and active stiffening

Normally, active vibration cancellation will be used to counteract vibrations with a specific frequency, e.g., 50 Hz from asynchronous motors. Because the system counteracts the forces working on the floor, it also works as an active stiffening device. This is illustrated in the graph below, which shows vibrations and stiffness measurements on a real factory floor. The vibration level exceeds the spec at 23 Hz. This is due to a floor resonance at 23 Hz indicated by a dip in stiffness where the stiffness is also below spec: the floor needs very little excitation force at this frequency to vibrate. In the graph, VC-D is a general vibration spec for demanding equipment; and $1 \cdot 10^8$ N/m is a general stiffness spec which is used for equipment with high-speed stages, like wafer scanners.



An Equalizer can be placed at this measurement point. The Equalizer control system can be tuned by a Mecal engineer at installation to be effective around 23 Hz. If the aim is a reduction of a factor 10 the results as shown in the graph below would be obtained.



The vibration peak at 23 Hz is lowered. Furthermore, the stiffness dip due to floor resonance has been effectively removed. This is not only active vibration cancellation but also active stiffening!

MECAL solving vibration problems

MECAL has extensive experience in solutions for vibration problems. This ranges from finding vibration sources, designing vibration isolation platforms and developing vibration cancellation technology, to the design-in of vibration isolation systems inside precision machines. For this, MECAL developed a wide range of technologies and competences such as Hummingbird vibration isolation technology, Equalizer vibration cancellation technology, optimised vibration sensors and model-based design and improvement of machines and buildings.

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Conclusion

Active vibration cancellation is a tool which preserves the inherent stiffness of the floor. This makes the system suitable for machines with a stiffness specification. The Equalizer system can even be used to stiffen the floor at certain frequencies. Interaction with machine dynamics or internal isolation systems is minimal since the interaction depends mainly on the floor and not on the machine.

Active vibration cancellation is a new tool for lowering floor and pedestal vibrations. Compared with traditional vibration isolation systems, whether passive or active, it has the advantage of a high stiffness and effectiveness over a large area (possibly multiple machines will benefit). In existing situations, the relative small Equalizer units can be easily placed on a few well-chosen points on the floor. Compared to high-performance active isolation, as with the Mecal Hummingbird, the vibration reduction is limited. ■

THE FOURTH DIMENSION OF ADDITIVE MANUFACTURING

The 2017 Precision Fair in Veldhoven attracted over 4,000 visitors and nearly 300 exhibitors from the Netherlands and abroad. It gave attendees many opportunities to investigate the penetration of 3D-printing technology (additive manufacturing or AM) into machining practice. The speed at which AM is being accepted adds the dimension of time to this relatively new manufacturing technology. Thus, at this year's Precision Fair, we quasi entered into Albert Einstein's four-dimensional space-time continuum in trying to assess the rate of AM acceptance in the mechanical workshop.

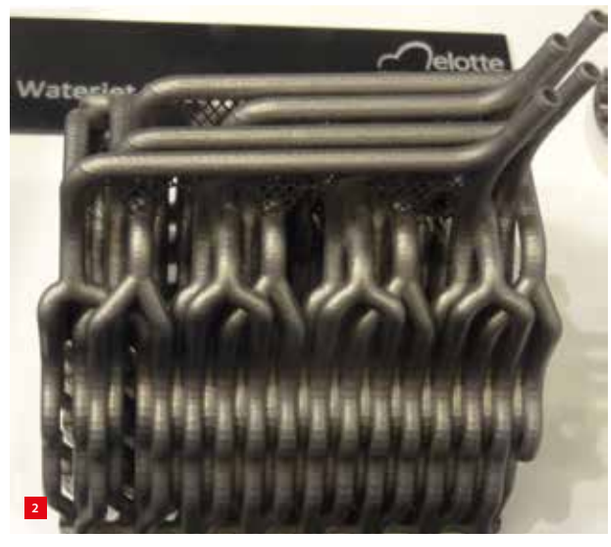
FRANS ZUURVEEN

Most people representing conventional cutting workshops state that they view 3D printing as an interesting technology, but they are not considering adopting it. They regard its current speed, surface finish and precision as inadequate. This is especially true for, as an example, vacuum chamber producers, who are not inclined to take up 3D printing because of some disadvantages, including insufficiently smooth surfaces and less than 100% homogeneity. Nevertheless, everyone follows developments in 3D printing with interest.

Co-operation

Some cutting specialists say that their company co-operates with AM firms for the production of difficult components with, for example, internal cavities or complicatedly bended tubes. An example of this is the partnership of mechanical-manufacturing specialist Wilting in Eindhoven with 3D Systems LayerWise in Leuven, Belgium, to manufacture completely finished 3D-printed products in titanium or other 'difficult' materials. Figure 1 shows a complicated product 3D printed by LayerWise.

The advantage of this partnership is that Wilting designs a component in such a way that it complies with 3D-printing rules. One example of this is the addition of material to the LayerWise product for planes that need extra mechanical finishing by Wilting to fulfil accuracy requirements.



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1 *A 3D-printed product by LayerWise, now part of 3D Systems.*

2 *A unit for the mixing of gases, 3D printed by Melotte.*

AUTHOR'S NOTE

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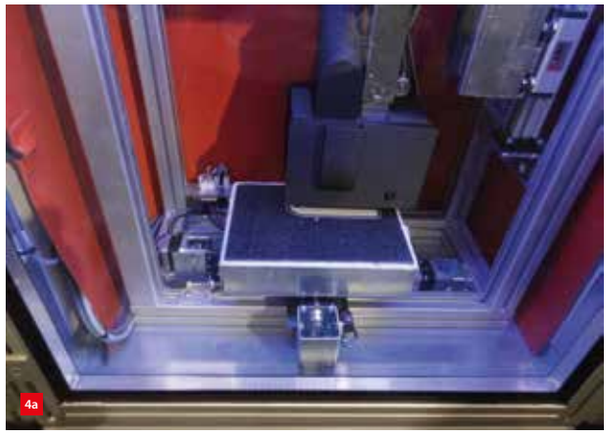
Designing 3D printers

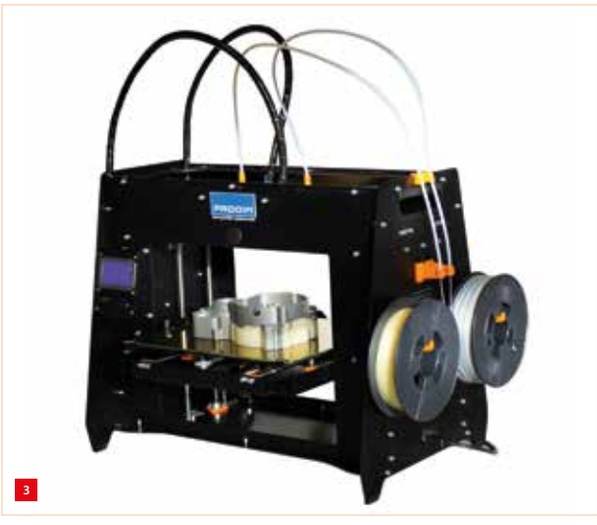
Notwithstanding the general, understandable reluctance of cutting specialists to adopt 3D printing, there were exhibitors that have both cutting and 3D printing experience in house, one of them being Melotte in Zonhoven, Belgium. It has designed and manufactured its own 3D printers and also has all metal-cutting equipment at its disposal: CNC milling, turning and grinding. It also applies sophisticated EDM wire and spark technology. Figure 2 shows a 3D-printed Melotte product, a unit for the mixing of four different gases. Such a unit cannot be fabricated by conventional manufacturing techniques, at least not as such a compact component.

Plastics

Printing plastics is an 'easier' technology than metal printing, of course. This explains why there were some plastic printers on show. Prodim International from Helmond exhibited its Orcabot XXL plastic printer (Figure 3). At a printing volume of 22.9 litres, Prodim claims a printing resolution of 0.05 mm for many thermoplastic materials like PLA, ABS and PET. The metallic printer heads successively lay interrupted lines 0.2 mm wide on the growing product, to a maximum length of 362 mm. The printer is very useful for the rapid production of professional prototypes.

Another designer of 3D printers is SDD (for Smart Dedicated Design) in Emst. They showed a 3D printer with a granite base delivered by surface plate specialist Mytri (Figure 4a). This is a small version of the larger production printer SDD 3DP1204, called 'Ghettoblaster' (Figure 4b), being marketed by SDD daughter AMR Europe. This in-house developed 3D printer aims to print plastics, for example ABS, with four printing heads in a building volume as large as 1,200 x 600 x 300 mm^3 with a minimal layer thickness of 0.1 mm.





SDD is also investigating the printing of metallic products. One possible metal-printing process is the application of plastic wire with integrated metallic particles. The printed product is heated, which burns the plastic away leaving a metallic-powder skeleton. Further heating causes sintering of the metallic grains, resulting in a metallic workpiece. A disadvantage here is that the product shrinks, but this volume decrease is predictable and can be compensated for in the original plastic printing dimensions.

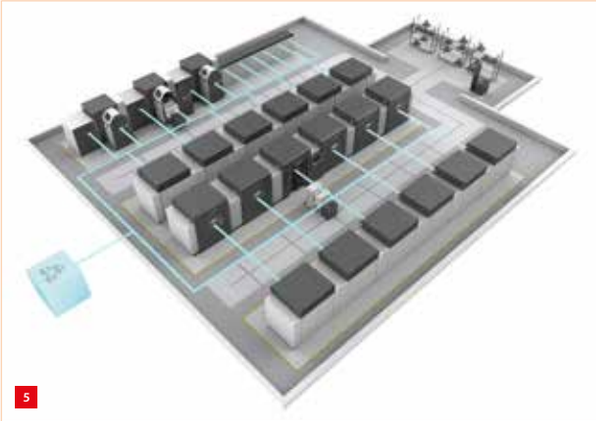
The future of 3D metal printing

LayerWise, referred to above, is a pioneer in metallic 3D-printing technology and recently became part of 3D Systems. In the 3D Systems stand, Raph Alink proudly showed 3D Systems LayerWise's prospects to deliver a fully automated 3D-printing system with integrated interchangeable units. This modular system is called DMP 8500 Factory Solutions and will be deliverable by the end of 2018 (Figure 5).

The heart of the system is the newly developed metallic printer DMP 8500, which comprises three printing lasers for the fast production of one workpiece or a lot of smaller ones within a large building volume of 500 x 500 x 500 mm^3. A special feature of this multi-laser printer is that the

3 *The Orcabot XXL 3D plastic printer with a maximum building length of 362 mm, produced by Prodim International.*

4 *3D printers by SDD.*
(a) A small version of the 3D printer SDD 3DP1204, called 'Ghettoblaster'.
(b) The real Ghettoblaster, marketed by AMR Europe, with a building volume of 1,200 x 600 x 300 mm^3 for the printing of displays.



printing process begins in an evacuated oxygen-free product space, which is thereafter filled with argon. This inert gas prevents corrosion of the product, as well as pollution of the laser light entrances. The modular units comprise various steps in the AM production process: sealed metallic powder supply, product printing, powder removal and product transport. Mechanical finishing should, in the author's opinion, also make up part of the production chain.
The LayerWise DMP 8500 3D printer is not the largest one in the world, however. At the Formnext fair (in Frankfurt, Germany, held in the same week as the Precision Fair), Concept Laser, part of GE Additive, showed its ATLAS project for the printing of huge aircraft components in a building volume of 1,100 x 1,100 x 300 mm³.

Miscellaneous

There was much more on show at the Precision Fair than 3D printing alone, of course. Several student teams demonstrated their enthusiasm for the study and application of mechanical engineering. Figure 6 shows two students from the Haagse Hogeschool department in Delft with their own development of a computer-controlled manipulator. They aim to add vision to the pick & place actions of their brain-child.

The fair also demonstrated that precision is not only a property of tiny objects. HiWin Motion Control Systems showed ball-circulating precision-screw units in various dimensions, while ball-bearing specialist Schaeffler exhibited the bearing assembly from the engines of the largest passenger aircraft, the Airbus A380 (Figure 7). This is real precision technology, because avoiding contact between fast-moving turbine blades and nearby stationary ones asks for high rotational stability and accuracy.

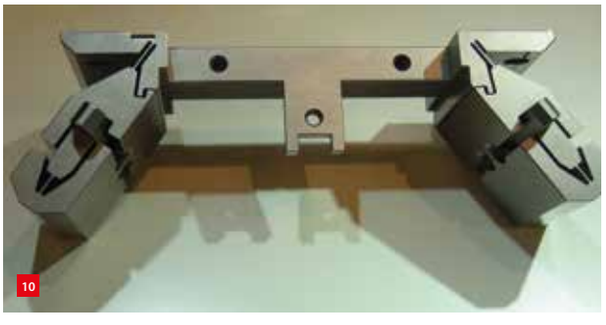
LAB Motion Systems in Leuven, Belgium, showed evidence of its expertise in the design of high-precision air bearings with a turntable for measuring machines (Figure 8). The radial and axial rotation errors are smaller than 100 nm. Another proof of air-bearing accuracy was shown by IBS

5 *Impression of the futuristic modular AM system with interchangeable units, called DMP 8500 Factory Solutions, developed by 3D Systems.*

6 *Students from the Haagse Hogeschool with their own development of a computer-controlled manipulator.*

7 *Examples of precision in large objects.*
(a) Ball-circulating precision-screw units shown by HiWin Motion Control Systems.
(b) The bearing assembly from the engines of a large passenger aircraft, exhibited by the Schaeffler Group.

8 *A turntable with high-precision air bearings shown by LAB Motion Systems.*



Precision Engineering from Eindhoven. While a thin web is easily transportable by means of a roller with bearings, IBS was able to demonstrate that a web can be better guided by a supporting pressurised-air film. IBS creates such a film by transporting air through a porous cylinder.

As is the tradition at the fair, many metal-cutting specialists, including spark eroders, demonstrated their precision engineering capabilities. Figure 9 depicts a gearwheel machined from titanium by Lucassen from Sittard. It has been finished by EDM with a radial tolerance of only 5 µm. The involute tooth flank form was integrated in the CAM software. The wire-eroded workpiece shown in Figure 10 is a monolithic product from Ter Hoek Vonkerosie in Rijssen. Such difficult-to-make leaf-spring hinges can only become a reality through using spark-erosion with an ultra-thin wire.

Co-ordinate measuring machines

There can be no precision without accurate measuring. As a rule of thumb, the precision of measuring equipment should be a factor ten better than the precision of the product to be measured. Once again, companies from three different countries showed CMMs (co-ordinate measuring machines) able to reach that precision. As well as the impressive CMMs from Japanese firm Mitutoyo and German firm Zeiss, Schut Geometrische Meettechniek from Groningen showed a DeMeet CMM 404, with a granite base plate and bridge. Its precision definitions are to a large extent attributable to the integrated Renishaw scales. For the largest CMM from the DeMeet series, with a range of 700 x 500 x 300 mm^3, Schut claims a precision of $4 + L/200$ µm (L in mm) with a resolution of 0.1 µm.

To conclude

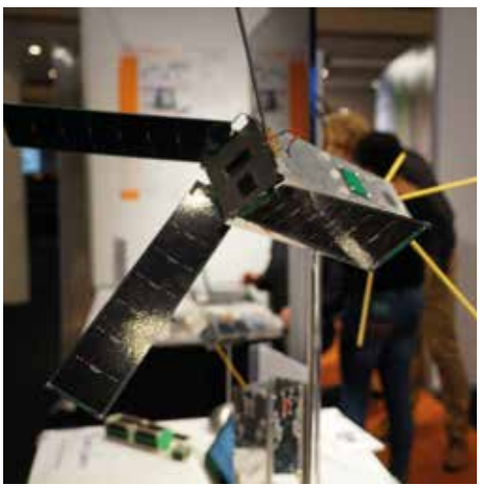
It was interesting to investigate the fourth dimension of 3D printing. Regarding the time dimension, rapid growth was sometimes observed, but more apparent were signs of reluctance mixed with careful observation of the progress in 3D printing. Anyhow, 3D printing is gaining a foothold. Meanwhile, a phenomenon called 4D printing is emerging, promising 'reprogrammable' products that after being printed can exhibit structures that transform in a pre-programmed way in response to a stimulus (e.g., pressure, heat).

There was much more besides AM to be seen in the exhibitions and to be heard in the lectures; see Figure 11 for impressions. Thus visiting the 2017 Precision Fair was again more than worthwhile, for its many technological aspects as well as for the networking.

9 *A gearwheel machined from solid titanium by Lucassen with a radial tolerance of 5 µm.*

10 *Monolithic product with leaf-spring hinges wire-eroded by Ter Hoek Vonkerosie.*

11 *Impressions from the 2017 Precision Fair. (Photos: Mikrocentrum)*



First Belgian winner of Dutch design engineering award

Sam Peerlinck has received the Wim van der Hoek Award 2017 certificate from DSPE board member Jos Gunsing. The inset shows the associated trophy, made by LiS. (Photos: Mikrocentrum)

At the 2017 Precision Fair, DSPE presented the Wim van der Hoek Award, also known as the Constructors Award, to Sam Peerlinck (KU Leuven, Belgium). Out of nine nominees, the jury selected Peerlinck as the winner of this design engineering award for his well-founded, very readable and wide-ranging model study of asymmetrically moving cilia (protuberances from biological cells) for fluid propulsion.

The second day of 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 Dutch doyen of design engineering principles, Wim van der Hoek. The Constructors Award is presented every year to the person with the best graduation project in the field of design in mechanical engineering at the Dutch (and Belgian) universities of technology and universities of applied sciences. This award includes a certificate, a trophy made by LiS (Leiden Instrument Makers School) and a sum of money (sponsored by the 4TU federation).

Criteria for the assessment of the graduation theses include quality of the design, substantiation and innovativeness, as well as the suitability for use as teaching materials. The jury, under the presidency of DSPE board member Jos Gunsing (MaromeTech), received nine nominations (by far the largest number in the award's history), each submitted by the graduation supervisor/professor of the student concerned. A total of two universities of applied sciences and three universities nominated candidates: Avans Hogeschool Breda, Fontys Hogescholen, KU Leuven (Belgium), TU Delft and TU Eindhoven.

Following a careful assessment, the jury selected Sam Peerlinck (KU Leuven) – the first winner from Belgium since the start of the award in 2006 – for his thesis "Asymmetrisch bewegende cilia voor vloeistofpropulsie bij lage Reynoldsgetallen: een fysisch model" (Asymmetrically moving cilia for fluid propulsion at low Reynolds numbers; a physical model). In his Master's project, Peerlinck was the first to create an artificial cilia surface that is capable of imitating all asymmetric characteristics of biological cilia (cilia are organelles found in eukaryotic cells; these are slender protuberances some tens of micrometers in length that can propel small volumes of fluid).

The jury praised Peerlinck's choice for this challenging subject and valued the wide scope of his project, ranging from ideation and theoretical foundation to the realisation of test equipment and performing actual tests. The physics of the subject was described thoroughly and overall the thesis was rated as very readable. The jury acknowledges that it still is a long way from a real application but sees the potential for lab-on-a-chip design and inkjet printing.

The jury of the Wim van der Hoek Award 2017, convening in the Professor Wim van der Hoek conference room at Janssen Precision Engineering (JPE) in Maastricht, the Netherlands, from left to right: Jos Gunsing (DSPE), Johan Vervoort (Vervos), Marc Vermeulen (ASML), Maurice Teuwen (JPE), Hans Steijart (VDL ETG) and Wouter Vogelesang.

UPCOMING **EVENTS**

7-8 March 2018, Veldhoven (NL)
RapidPro 2018
The annual event on prototyping, (low-volume) production and product development.
An important prototyping and production technology at RapidPro is 3D-printing. Also many other technologies will be comprehensively presented, "from design to manufacturing".

WWW.RAPIDPRO.NL

20-23 March 2018, Utrecht (NL)
ESEF 2018
The largest and most important exhibition in the Benelux area in the field of supply, subcontracting, product development and engineering, showcasing the latest innovations.

WWW.ESEF.NL

21-23 March 2018, Dresden (DE)
Conference on Thermal Issues in Machine Tools
This conference is organised by CRC/TR 96 and euspen (Special Interest Group Thermal Issues), which have been working to solve the conflict between reducing energy consumption and increasing accuracy and productivity in machining since 2011. See also News, page 50 ff.

WWW.EUSPEN.EU

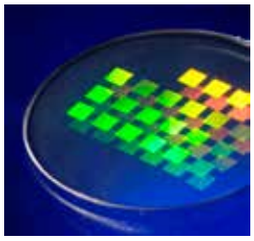
22 March 2018, Eindhoven (NL)
High-Tech Systems 2018
One-day conference and exhibition with the focus on high-end system engineering and disruptive mechatronics. The conference themes include industrial internet of things, cobotics and design for additive manufacturing.

WWW.HIGHTECHSYSTEMS.EU

29 March 2018, Eindhoven (NL)
Dynamics for Precision Engineering – From macro to micro
This workshop – organised by Mikrocentrum, with the support of TU Delft and DSPE – provides an overview of the challenges and solutions involving dynamics and control in precision engineering at all length scales. Contributions come from both industry and academia.

WWW.MIKROCENTRUM.NL

10-12 April 2018, Aachen (DE)
Aachen Optics Days 2018
Event combining two conferences. The Polymer Optics Days conference (10-11 April) is devoted to injection-moulded optics, line production of planar optics and sheets, new materials and applications for plastic optics, light sources and optical systems, and digitalisation of optics production. Organised by Fraunhofer IPT and ILT, and the Institute of Plastics Processing (IKV) in Industry and the Skilled Crafts at RWTH Aachen University.
The International Colloquium on Glass Optics, organised by Fraunhofer IPT and ILT, is a two-day congress (11-12 April) centred around glass optics and photonics featuring sessions on material, display, imaging, infrared, and digitalisation of optics production.



AACHEN.POLYMEROPTICS.DE
WWW.OPTIK-KOLLOQUIUM.DE

30-31 May 2018, Veldhoven (NL)
Materials 2018
Trade fair, with exhibition and lecture programme, targeted at product developers, constructors and engineers. The focus is on materials - analyses - surfaces - connections.

WWW.MATERIALS.NL

4-8 June 2018, Venice (IT)
Euspen's 18th 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 robotics and automation, Industry 4.0 for precision manufacturing and applications of precision engineering in biomedical sciences.
The deadline date to receive extended abstracts is 31 December 2017.

Conference venue is the Venezia Terminal Passeggeri.

WWW.EUSPEN.EU

7 June 2018, Eindhoven (NL)
Martin van den Brink Award
During the Dutch Technology Week, the Martin van den Brink Award, for the best system architect in precision engineering, will be handed out for the third time.

WWW.DSPE.NL

4-5 September 2018, Sint-Michielsgestel (NL)
DSPE Conference on Precision Mechatronics 2018
Fourth 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 "Precision Imagineering", inspired by the notion that every enterprise starts with a dream or 'imagination', but that it takes 'engineering' to actually transform the initial idea into a successful product, service or business. See also the DSPE page, 49.

WWW.DSPE-CONFERENCE.NL

MOVING NANO FROM LAB TO APP

Nanotechnology has been and still is a 'hot' research topic, and the Netherlands have a forefront position in the scientific field. The expectation is that nano will be fuelling new applications and functionalities. Time has come to exploit the potential and create real impact in industry and society. To this end, TU Delft has initiated the Nano Engineering Research Initiative (NERI), a collaborative research programme aimed at moving nano from lab to app. On 25 October 2017, NERI went public officially. An inspiration event was organised to mark the occasion.

MARCEL TICHEM AND GABY OFFERMANS

Opportunities and big challenges

In semiconductor manufacturing, working at nanometer scale is common practice. Ever smaller line-widths can be written in a lithography-based process. However, 'nano' as it is explored in fundamental science has more potential than semiconductor technology offers. New nanomaterials are investigated, including nanoparticles, carbon nanotubes or 2D nanomaterials like graphene. Surface structuring and functionalisation on the very small length scale affects properties like wettability or fouling, or can be used to create surface-integrated sensors. Also, multi-material 3D structuring of materials from nano to micro to macro is expected to result in entirely new classes of materials with new behaviour.

The big challenge is to open up this potential for the design and manufacturing of materials, components and devices that will enter real markets, and thus impact our daily life. Although selected examples are entering markets already, e.g. in point-of-care medical diagnostics, the general observation is that a lot of potential of the field has still to be tapped into.

NERI

The Nano Engineering Research Initiative attempts to address precisely this challenge. What industry-compatible manufacturing methods are needed to produce nano-enabled materials and components? What functionalities,

1 *Impression of the nano engineering inspiration event in Delft.*

AUTHOR'S NOTE

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2 On the right Just Herder, professor of Mechatronic System Design, explaining the concept of engineered material structures to Cor Heijwegen, CEO of Hittech Group.

3 On the right Jo Spronck, associate professor of Mechatronic System Design, demonstrating an in-line nanometrology set-up to Gijs van der Veen, senior dynamics and control developer at Nexperia. This set-up is a result of the aim4np (Automated in-line Metrology for Nanoscale Production) EU project.

robust against real-life use scenarios can be proposed? How can this knowledge be made available to designers?

The initiative was started from the Department of Precision and Microsystems Engineering (PME), which focuses on functions that derive performance from the small scale, 'nano-enabled', and on the machines and instruments that allow operating at the small scale, 'enabling nano'. NERI is a collaborative research programme, where research institutions and industrial partners engage with each other to address the relevant challenges, and set out to work towards breakthrough innovations based on 'nano'. Moving nano from lab to app requires alignment and cooperation with potential industrial end-users. They learn what the impact of the small scale might be for their products. The ambition for NERI is to grow into an international initiative; the first steps in these directions have already been taken.

Inspiration event

To celebrate the official start of NERI, a nano engineering inspiration event was organised on 25 October 2017 (Figure 1). In an afternoon programme, research was put on display in an exhibition-like setting to illustrate the overall NERI vision and to inspire the attendants. Around sixty company representatives joined the event, mostly R&D project leaders and decision makers. The event was organised in collaboration with Holland Instrumentation, the high-tech platform for the Western parts of the Netherlands.

In an interview with NERI partners Krohne Altometer and Nexperia it became clear why they team up in NERI: "The fundamental knowledge we gain from the projects can be further developed within our own field of application", Andre Boer, general manager of Krohne Altometer, said. "We find in PME a multidisciplinary team that operates with the same values 'Passion', 'Professionalism', 'Perseverance' and 'Performance' as our own company Nexperia", Marcel Vugts, general manager of Nexperia-ITEC, added.

In one of the sections the opportunities of engineered smart materials were explained (Figure 2). 3D structuring of materials across length scales leads to properties that are uncommon to the material's bulk form. Even more interesting is the question how such materials may be designed in order to have a certain, prescribed and unique property. Industrial partners Nexperia and Krohne Altometer collaborate with PME researchers on the development of such smart materials for advanced sensing applications.

Polymers can be structured and functionalised in many ways. The combination with topology optimisation, a computer-based design method to find topographies, provides new opportunities to make smart micro-fluidic functions. Volume-compatible manufacturing is needed to bring applications to markets. NERI collaborates with the Technical University of Trondheim (NTNU), Norway, and the Norwegian company Conpart to explore the use of micro- and nanoparticles for new functionalities in flexible and wearable electronics.

Nanostructures fabricated by CVD diamond topographies, graphene, and nanocantilevers were displayed to show that entirely new ranges of sensors may be obtained. The integration of an AFM with a standard industrial robot showed that nanoscale metrology in a real-life production environment is possible (Figure 3). Together with the Dutch Metrology Institute, VSL, new activities will be started on 3D AFM.

PME staff members demonstrated NERI research topics at the inspiration event (Figures 2 and 3). ■

BETWEEN PRECISION ENGINEERING AND NASCAR RACING

The 32nd edition of ASPE's Annual Meeting was hosted during the last week of October at the Westin hotel in Charlotte, North Carolina. Charlotte is the third-fastest growing city in the US, and is home to the Center for Precision Metrology (CPM) at the University of North Carolina at Charlotte (UNCC), one of the premier centres for precision engineering research and education. It is also the home of NASCAR racing and hosts several facilities related to this sport. Highlights of the meeting included the keynote address delivered by ASML, the seventeen (!) half-day tutorials, and the visit to the UNCC CPM.

RICK BAADE

About ASPE

The American Society for Precision Engineering (ASPE), the American equivalent of DSPE, hosts several meetings a year, one annual meeting where the broad field of precision engineering is covered and several topical meetings where a specific topic is considered in more detail. The annual meetings are aimed at sharing advances in the field of precision engineering and the attendees represent a good balance between academia, national laboratories and industry.

The ASPE organisation has identified six key technical areas within the broad field of precision engineering which are represented by technical leadership committees (TLCs) for each of these areas within the Society.
The committees are each chaired by members of the Board of Directors and help to set the technical direction of the Society. The technical areas under the purview of the TLCs are:

- Precision manufacturing
- Metrology systems
- Characterisation
- Precision design
- Micro- and nanotechnologies
- Controls and mechatronics

WWW.ASPE.NET

AUTHOR'S NOTE

Rick Baade is a Ph.D. student in Control Systems Technology at Eindhoven University of Technology, the Netherlands. He acknowledges the input of Vivek Badami (conference chair, Zygo Corporation) and Ton Peijnenburg (VDL ETG).

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Tutorials

The meeting started on Sunday morning with a set of tutorials. Both Sunday and Monday were divided into half-day tutorial sessions, with a selection of 17 different tutorials on topics varying from machining dynamics to precision metrology. Part of the tutorials were accommodated at the Center for Precision Metrology on the UNCC campus and included hands-on sessions and demonstrations in the UNCC laboratories.

Three tutorials were presented by Dutch participants: Henny Spaan (IBS Precision Engineering) and Eric Marsh (Pennsylvania State University) provided a tutorial on "Precision Metrology – Spindles and Tables". The tutorial, "Introduction to Controls" was presented by Stephen Ludwick (Aerotech) and Theo Ruijl (MI-Partners), while Gerrit Oosterhuis and Ton Peijnenburg (both VDL ETG), who replaced Raph Alink (3D Systems), delivered a tutorial on additive manufacturing.

Keynote address

Traditionally, the conference opens with a keynote address on a topic relevant to precision engineering. This year's keynote was delivered by Jelm Franse and Ken Bogursky from ASML, titled: "Precision Mechanics and Mechatronics in ASML Lithography Equipment – Key Drivers for the Continuation of Moore's Law for Semiconductor Devices".

After a brief introduction to ASML, Moore's law and the lithography process, the main mechanical and mechatronic challenges in the development of the Twinscan lithography

machines were discussed. The system architecture consisting of a dual-stage design, with each stage containing a long-stroke and short-stroke actuator, combined with a balance mass, was explained in detail. The talk ended with a view to the future, discussing the EUV systems and the corresponding design challenges.

The talk was well received and most of the attendees were both impressed by the extreme performance requirements and capabilities of the machine, such as the acceleration levels and accuracy requirements of the system, and surprised by the level of technical detail provided during the keynote.

Student Challenge

The Student Challenge is a recurring annual event at the ASPE Annual meeting (Figure 1). This year's challenge was to design an active vibration isolation system to stabilise a laser pointed at a fixed target over a distance of six meters. The first requirement was to demonstrate the ability to maintain the laser spot on the target in the absence of environmental vibrations. The teams were then judged on the ability of the system to maintain the laser spot on target while a disturbance vibration was imposed on the system by a motor spinning an unbalanced mass.

Each team was provided with a Mechblock kit containing structural elements, a triple-axis accelerometer, three displacement sensors and three voice-coil actuators. A National Instruments myRio was supplied for controlling the isolation stage. The assignment was provided to the students a few weeks in advance of the conference to prepare a mechanical and controller design. They were given only 24 hours of time to construct and test their systems during the conference.

Oral presentations

The oral presentations [1] were divided into eight sessions over the course of three days, with four to six presentations per session. One session was devoted to each TLC topic (see the box) where the first talk of each session was presented by the chair of the corresponding TLC. This opening talk was aimed at providing an overview of the state-of the art, and to highlight current developments and identify the 'hot topics' in each field. Two additional sessions were on Applications of Precision Design and Manufacturing to Telescopes and Synchrotron Optics, and Precision Engineering Potpourri.

Tours

Tuesday's lunch featured a talk by Jim Cuttino, president of Camber Ridge LLC, about the technological advances of NASCAR. He elaborated on the extensive wind tunnel and tire testing done at request of the NASCAR teams. He also shared several funny anecdotes on the history of NASCAR and the battle between the teams and the regulatory body to creatively circumvent the technical regulations. The competition ethics can be summarised as follows: "Win if you can, loose if you must but cheat at all cost". His entertaining lecture raised interest for NASCAR among the conference participants and served as a good preparation for the conference dinner, which was hosted at the NASCAR Hall of Fame (Figure 2). This is an interactive museum and exhibition on the drivers and technology in NASCAR.

On the Friday after the conference, three technical tours were organised. The first tour started at the Siemens Charlotte Energy Hub where gas turbines, steam turbines and generators are assembled. The tour participants were able to view the full assembly chain for all three products. After lunch at Siemens, the tour continued to Okuma America where all US sold CNC lathes and machining centres are modified, tested and repaired. In parallel, a second group joined a tour of the facilities of 3D Systems, while a third group visited the Carl Zeiss Technology Center where participants attended short presentations followed by a demonstration or hands-on activity.

Visit of UNC Charlotte

At the end of the last conference day, all participants went to the UNCC campus for a tour through the Center for Precision Metrology [2] (director: Chris Evans) followed by

1 *Prize ceremony for the Student Challenge; on the left Jelm Franse, ASML. (Photos: Vivek Badami)*

2 *A glimpse of the NASCAR Hall of Fame.*

3 *John Ziegert explaining about advanced manufacturing at the UNCC Center for Precision Metrology.*

the closing reception. Arriving at UNCC, we were all impressed by the size and prestigious appearance of the campus in combination with the university football field of the Charlotte 49ers. During the tour we visited several laboratories. Again, it was remarkable to see the quality and broad range of facilities and equipment available in the laboratories.

Another notable observation is the amount of research done on manufacturing technology and its integration into the curriculum. For example, John Ziegert explained how the advanced manufacturing research group works on high-speed milling of high-aspect-ratio, thin-walled aluminum structures with a thickness down to 25 µm to produce monolithic structures that replace assemblies made with folded sheet joined by bolts and rivets (Figure 3). These techniques find application in the fabrication of aircraft components where the elimination of fasteners and assembly tooling results in significant weight and cost reductions.

Ziegert also emphasised the unique nature of the curriculum at UNCC wherein hands-on learning of manufacturing processes is tightly integrated into the curriculum to ensure that engineers understand the capabilities and limitations of manufacturing processes and its intimate connection with the design process. The conference ended with a closing reception on the UNCC campus.

Concluding remarks

To conclude, the conference again proved to be a worthwhile event with interesting tutorials and presentations combined with a pleasant atmosphere to make connections with fellow precision engineers. ■

REFERENCES

[1] *www.aspe.net/technical-publications/proceedings*

[2] *cpm.uncc.edu*

MEDICAL STITCHING INNOVATION

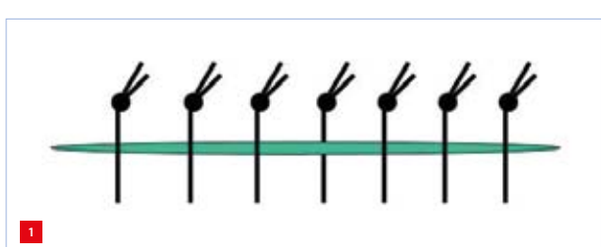
The method of stitching medical sutures has not changed essentially since the ancient Egyptians. Cumbersome traditional 'sewing' by an experienced surgeon requires up to 25 seconds per single stitch under certain conditions. But a recently developed Sutrue semi-automatic stitching instrument is able to perform as much as three excellent stitches per second. Additive manufacturing (AM) proved to be indispensable for prototyping within days instead of weeks with traditional machining. This is impressively illustrated by the creation of 3D-printed gearwheels with a 0.2 mm module.

FRANS ZUURVEEN

Some ten years ago Alex Berry, educated as an architectural designer, watched a documentary about the risk of needlestick injuries during conventional wound suturing. He started thinking about mechanical solutions to eliminate that risk and came upon an inventive idea for a tool for more effective suture stitching. A few years later this resulted in a new, UK-based company called Sutrue Ltd, aimed at investments in patent applications for his brainwaves. For the effective implementation of his ideas in the realm of endoscopic surgery he intensively worked together with Richard Trimlett, an open-minded cardiothoracic surgeon.

Conventional stitching

Traditionally there are many methods to close a wound after an operation or accident, by holding body tissues together. Easy to understand is the simple interrupted stitch type, consisting of a series of stitches secured by a knot, see Figure 1. Figure 2 illustrates the conventional tools available for a surgeon: a pair of forceps, a pair of tweezers and a curved needle. Such a needle is also called a suture and is connected to a swaged thread, absorbable or non-absorbable in human tissue. It will be clear that constructing a knot in two thread ends demands considerable manual dexterity from a surgeon.



1 *Suturing an incision with a series of simple interrupted stitches. (Source: Syneture)*

2 *Conventional stitching tools: forceps, tweezers and a curved needle.*

Curved operation needles or sutures have more or less been standardised by USP, the United States Pharmacopeia. The range extends from size 11-0 with needle diameter 0.01 mm for ophthalmic purposes to size 5 with diameter 0.7 mm for orthopaedics. Manipulating a 10 µm suture with connected thread for eye operations is quite a precision-technological achievement.

Alex Berry's challenge was the creation of an instrument that is able to manipulate a suture, by forcing it to perform the required stitching movement through tissue at both sides of the open wound.

Working principle

Figure 3 shows a prototype of the suturing instrument invented and developed by Berry and Trimlett. A set of rollers transport a curved needle with suturing thread along an arc of 360° through a circular path. Each roller is coupled to a small gearwheel mounted on a common shaft. The gearwheels together form a drive train, driven by a single gearwheel not visible in the picture.

AUTHOR'S NOTE

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

3 *Prototype of the Sutrue suturing instrument, transporting a curved needle along an arc of 360° through a circular path.*

4 *Two handheld prototypes for suturing with curved needles with a length of 26 and 48 mm, respectively.*

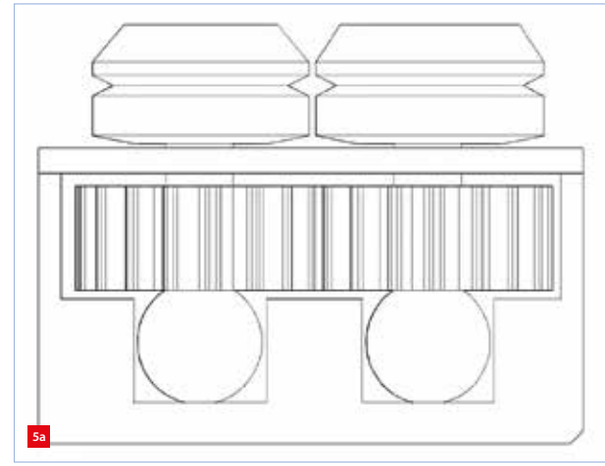
5 *Transporting a curved needle.*
(a) Rollers and gears at rest.
(b) Moving the needle by pre-tensioning the rollers touching the needle.

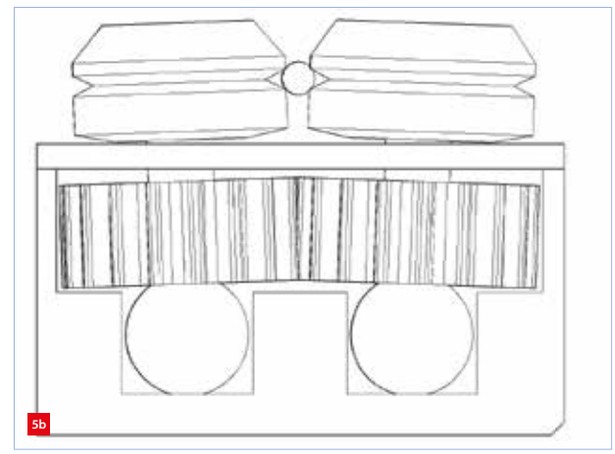
6 *Overview of the Sutrue stitching instrument.*
(a) The complete drive train with gearwheels.
(b) Exploded view.

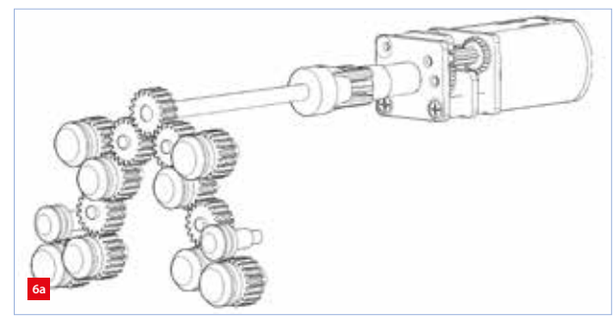
Two working prototypes are depicted in Figure 4. These are handheld instruments designed to manipulate curved needles with a length of 26 and 48 mm, respectively. The drive motor is encased in the handle, driving a single gearwheel in the small casing between handle and stitching instrument. A much smaller prototype is designed for performing endoscopic stitching during beating-heart operations with keyhole surgery. This miniature device should be able to pass through trocars with a diameter of 10 mm.

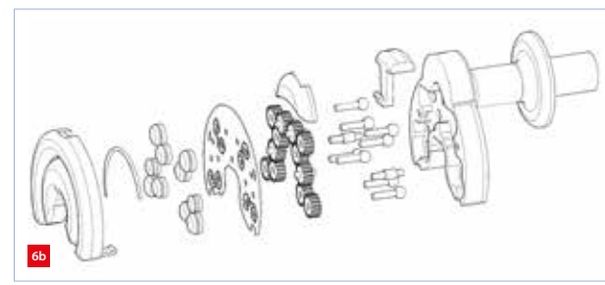
It is quite clear that the Sutrue instrument can produce stitches as shown in Figure 1. But is this instrument able to place knots, the most time-consumable part of stitching wounds? Berry explains: “The surgeon uses one pair of forceps to position the thread in the device head after which an additional rotation starts the knot – they then reverse the thread in the head and a second rotation finalises the knot.” This sounds rather cryptic, but instead of a more detailed explanation the precision mechanics of the instrument will be highlighted here.

Figures 5 and 6 belong to Sutrue patent applications. Figure 5 shows how the mounting of the gear and roller shafts on a spring plate helps to improve the grip of the rollers on the needle. As a result of the proper choice of roller groove dimensions, two co-operating rollers exert forces on the needle, causing frictional forces to facilitate needle transport. Figure 6 shows the complete drive train and an exploded view with all components, the majority of which were produced by AM-SLM (selective laser melting) technology.









7 *Rollers, gearwheels and spring plate of the endoscopic miniature suturing device.*

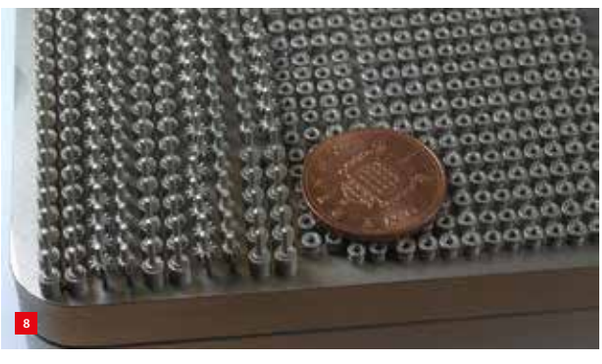
8 *An AM build plate with printed components for the endoscopic instrument.*

9 *Exercising with a small Sutrue instrument: suturing arterial (pig) tissue.*

How AM-SLM helps

Figure 7 shows a gear-and-roller assembly of the endoscopic suturing instrument, consisting of rollers, gearwheels and spring plate. The gearwheels are equipped with 12 teeth and dimensioned with a 0.2 mm module (ratio of the reference diameter and the number of teeth). This means a nominal tooth pitch of 0.628 mm and a teeth thickness of about 300 µm.

Using AM-SLM, Sutrue was able to produce these gearwheels accurately enough to drop them straight into the head section of the instrument, in order to start running immediately. Although they may need running in to remove some of the surface texture and improve operation, the average particle size (5-40 µm, depending on the sintering powder selected) is sufficiently small to achieve a high level of detail.
For the prototype printing of the components the Mlab LaserCUSING machine from Concept Laser was used, which operates by means of the powder-bed-based laser melting of metals. This AM machine has been provided by ES Technology, the UK distributor of Concept Laser, now part of GE Additive. An AM build plate with many 3D-printed components for the endoscopic instrument is shown in Figure 8. The depicted British penny (with a diameter of 20.3 mm) illustrates their tiny dimensions, as well as the capability of the SLM process to produce many precision products within a relatively short period.



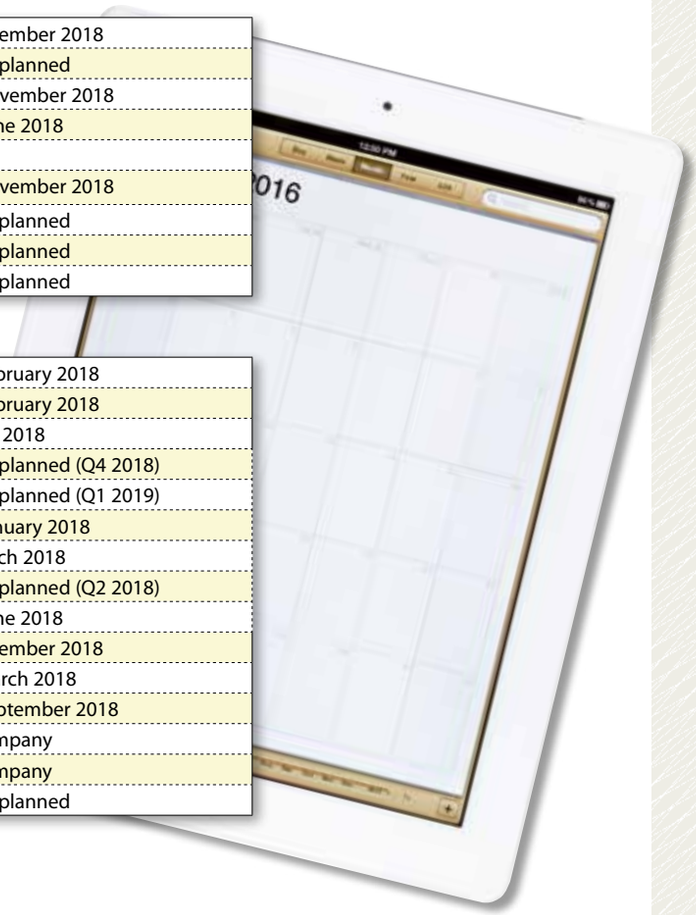
Prospects

A lot of work is required before the Sutrue suturing instruments will actually be in use in operation rooms. To that end, complicated, lengthy healthcare procedures have to be followed. In the meantime, Sutrue is practicing with its instruments, stitching artificial wounds in non-living tissue. This will be followed by the testing of the instruments on animal tissues. Figure 9 shows the suturing of arterial tissue with a small Sutrue instrument. In any case, the outlook for faster and more reliable operative wound suturing is more than promising, both for heart surgery and a lot of other medical applications. It is most certainly worthwhile for Sutrue to continue its activities with the same enthusiasm. ■

INFORMATION
WWW.SUTRUE.COM
WWW.CONCEPT-LASER.DE

ECP² COURSE CALENDAR

COURSE (content partner)	ECP² points	Provider	Starting date
FOUNDATION			
Mechatronics System Design - part 1 (MA)	5	HTI	9 April 2018
Fundamentals of Metrology	4	NPL	to be planned
Mechatronics System Design - part 2 (MA)	5	HTI	29 October 2018
Design Principles	3	MC	7 March 2018
System Architecting (S&SA)	5	HTI	19 March 2018
Design Principles Basic (MA)	5	HTI	to be planned (Q2 2018)
Motion Control Tuning (MA)	6	HTI	13 June 2018
ADVANCED			
Metrology and Calibration of Mechatronic Systems (MA)	3	HTI	6 November 2018
Surface Metrology; Instrumentation and Characterisation	3	HUD	to be planned
Actuation and Power Electronics (MA)	3	HTI	20 November 2018
Thermal Effects in Mechatronic Systems (MA)	3	HTI	12 June 2018
Summer school Opto-Mechatronics (DSPE/MA)	5	HTI	-
Dynamics and Modelling (MA)	3	HTI	26 November 2018
Manufacturability	5	LiS	to be planned
Green Belt Design for Six Sigma	4	HI	to be planned
RF1 Life Data Analysis and Reliability Testing	3	HI	to be planned
SPECIFIC			
Applied Optics (T2Prof)	6.5	HTI	22 February 2018
Applied Optics	6.5	MC	22 February 2018
Machine Vision for Mechatronic Systems (MA)	2	HTI	3 July 2018
Electronics for Non-Electronic Engineers – Analog (T2Prof)	6	HTI	to be planned (Q4 2018)
Electronics for Non-Electronic Engineers – Digital (T2Prof)	4	HTI	to be planned (Q1 2019)
Modern Optics for Optical Designers (T2Prof)	10	HTI	19 January 2018
Tribology	4	MC	6 March 2018
Basics & Design Principles for Ultra-Clean Vacuum (MA)	4	HTI	to be planned (Q2 2018)
Experimental Techniques in Mechatronics (MA)	3	HTI	19 June 2018
Advanced Motion Control (MA)	5	HTI	5 November 2018
Advanced Feedforward Control (MA)	2	HTI	21 March 2018
Advanced Mechatronic System Design (MA)	6	HTI	26 September 2018
Finite Element Method	5	ENG	in-company
Design for Manufacturing – Design Decision Method	3	SCHOUT	in-company
Precision Engineering Industrial Short Course	5	CRANF	to be planned



ECP² program powered by euspen

The European Certified Precision Engineering Course Program (ECP²) has been developed to meet the demands in the market for continuous professional development and training of post-academic engineers (B.Sc. or M.Sc. with 2-10 years of work experience) within the fields of precision engineering and nanotechnology. They can earn certification points by following selected courses. Once participants have earned a total of 45 points, they will be certified. The ECP² certificate is an industrial standard for professional recognition and acknowledgement of precision engineering-related knowledge and skills, and allows the use of the ECP² title.

ECP2EU.WPENGINE.COM

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
- Holland Innovative (HI) WWW.HOLLANDINNOVATIVE.NL
- Cranfield University (CRANF) WWW.CRANFIELD.AC.UK
- Univ. of Huddersfield (HUD) WWW.HUD.AC.UK
- National Physical Lab. (NPL) WWW.NPL.CO.UK

Content partners

- DSPE WWW.DSPE.NL
- Mechatronics Academy (MA) WWW.MECHATRONICS-ACADEMY.NL
- Technical Training for Prof.; (T2Prof) WWW.T2PROF.NL
- Systems & Software Academy (S&SA)

BRONZE ECP² CERTIFICATE FOR FRANK DE GROOT OF TEGEMA

Frank de Groot, senior engineer at Tegema, has been awarded the Bronze certificate from the ECP² programme: the European certified precision engineering course program. ECP² is a collaboration between the European and the Dutch Association for precision engineering, euspen and DSPE, respectively.

Starting in spring 2014, Frank de Groot followed the Tribology and Design principles for precision technology courses at Mikrocentrum, and the Mechatronics system design - part 1 and part 2, Thermal effects in mechatronic systems, and Design principles for ultra-clean vacuum applications courses at The High Tech Institute. He also took part in the LiS Academy Summer School on Manufacturability, organised by the Leiden Instrument Makers School. With a total of 29 points (each point represents one course day) he amply fulfilled the condition of obtaining 25 points for courses achieved within five years. On 1 December, he was put in the spotlight.

The courses mentioned, which cover a broad palette, are in line with Frank de Groot's ambition to become a technical specialist in the area of precision technology. That is according to Albert Coolen, manager of secondment at Tegema, multidisciplinary high-tech engineering firm based in Son and Arnhem, the Netherlands. "Tegema encourages the self-development of its employees. Frank has, for example, worked at several departments within ASML, and found that he was fully developed as a senior engineer. Together with him I have set out a long-term path to realise his ambition of becoming a technical specialist and he is following this path at a rapid pace. The drive really comes from within him. We coach our employees and offer them opportunities, but the initiative must come from them. In this respect Frank, who is also celebrating the milestone of a 12.5-year contract with Tegema this month, is certainly an example for others."

Frank de Groot is the fourth engineer to receive the Bronze ECP² certificate since certifying engineering courses started in 2009. In 2015, the DSPE initiative was scaled up to the European level.

WWW.EUSPEN.EU

WWW.TEGEMA.NL

DSPE Conference on Precision Mechatronics 2018

The fourth edition of the DSPE Conference on Precision Mechatronics will be held in Sint Michielsgestel, the Netherlands, on 4-5 September 2018. This year's theme 'Precision Imagineering' represents the combination of precision, imagination and engineering. An enterprise may start with a dream or 'imagination', but it takes 'engineering' skills in the broadest sense to actually transform an initial idea into a successful product, service or business. When it comes to precision products, it is evident that mastery in great depth of the various aspects of precision engineering (design principles, dynamics, control, thermomechanics, contamination, ...) is required.

But the development of modern mechatronic devices, such as IC equipment, electron microscopes, harvesting machines or surgical robots, also requires mastering the art of managing complexity by adopting a systems engineering approach and having a keen eye on the growing importance of software and the possibilities and challenges that new developments, such as artificial intelligence and deep learning, offer to the precision engineering community.

Hence, DSPE strives to extend the traditional core topics of the conference with a session about software and systems engineering aspects in the development of precision equipment. The conference will therefore be open to members of the SASG (System Architecture Study Group), besides the original target group, which includes technologists, designers and architects in precision mechatronics, who, through their respective organisations, are connected to DSPE, the mechatronics contact groups MCG and MSKE, or selected companies and research/educational institutes.

WWW.DSPE-CONFERENCE.NL

Symposium 'From measuring to knowing'

In mid-October, the Association for the Promotion of Training as an Instrumentmaker, or the alumni association of the Leiden Instrumentmakers School (LiS), organised a symposium for instrumentmakers. The theme 'From measuring to knowing' came from the credo attributed to Heike Kamerlingh Onnes, a professor in Leiden who was the founder of the LiS (in 1901) and a Nobel Prize winner in Physics (in 1913). The symposium's speakers came from VSL, Mitutoyo, Össur, VDL ETG and Heidenhain.

Jan Sturre from Heidenhain kicked it off with a presentation on direct versus indirect positive feedback, and the advantages that linear encoders offer for precision positioning compared to rotary encoders, especially where thermal effects can disrupt the positioning accuracy.
Frans-Peter d'Hooghe from Mitutoyo showed how close co-ordinate measuring machines (CMM) can operate on production lines. Fully automated product measurements are performed with the help of robot arms that take products out of the processing machines and/or self-driving trolleys and place them in the CMM. This means that crucial dimensions for 100% of the products are measured between the production steps, before self-driving trolleys take the products to the next processing centre.
Össur is engaged with improving people's mobility using non-invasive orthopaedic devices, and their representative Wiebe Heidema discussed innovative prosthesis techniques. One such technique is where people have sensors placed subcutaneously on their muscles. The signals from these sensors are then used to control a motorised prosthesis, for example a knee prosthesis that can produce movement of the lower leg and foot that is as natural as possible. For a lower arm prosthesis with a hand, the same technique is used for wrist, finger and thumb movements.

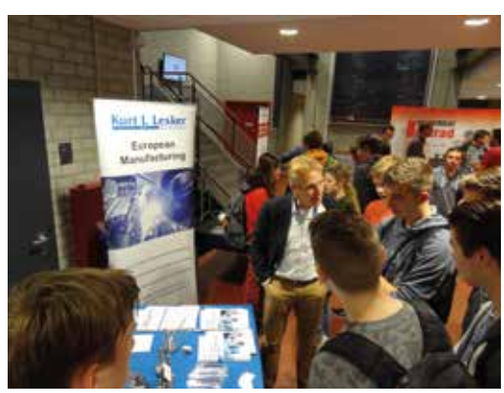
Xander Janssen from VDL ETG gave a lecture on the precision operations and measurements they perform in Eindhoven for the production of components from oxygen-poor (OFE) copper. The high-precision components, used in linear accelerators, are made with tolerances down to 4 µm and a roughness of < 25 nm. Janssen explained what is involved in their production, including the use of diamond cutting tools and the unsuitability of conventional cooling and cutting fluids. He also discussed facets of metrology and keeping the products extremely clean. All in all, making and assembling these parts is a complex branch of sport.

Heike Kamerlingh Onnes, founder of the LiS and Nobel Prize winner in Physics.

Marijn van Veghel from the national measurement institute VSL discussed metrological traceability to SI units and the laboratory conditions that are essential for reliable measurements. These conditions are challenging, but even so they now have taken the step to performing geometrical measurements in an industrial environment. All this with a very low measurement uncertainty, taking into account environmental conditions around production lines, for example for solar panels with nanostructures, light traps and/or grating structures, where an AFM head measures the surfaces. The calibration method used is a so-called virtual standard that can realise step heights at picometer level.
After the symposium, there was an opportunity to talk and network with canapés and drinks. There was also ample attention given to the products and services from exhibitors/sponsors Pfeiffer Vacuum, Leiden Cryogenics, Hositrad Vacuum Technology, Jeveka, Leybold, SRON, A. de Jong TH, LouwersHanique and Kurt J. Lesker.

Alumni association

The organisation was therefore in the hands of the Association for the Promotion of Training as an Instrumentmaker (*Vereeniging ter Bevordering van de Opleiding tot Instrumentmaker*). The double-e in *Vereeniging* (Association) suggests that its creation lies in a distant past. Indeed; in 1901 to be exact, when the LiS also started. Since 2016, the Association has again become active in organising events for its members, starting with a very successful LiS reunion at the end of 2016. Every year there is a symposium, always with a different theme, where presentations related to the profession are given. The Association also organises company visits, in which participating instrumentmakers are given the opportunity to become acquainted with the specialisations and skills of the company concerned. Sponsors make it possible to organise the symposia.



Impressions of the symposium.

(This report was provided by the board of the Association)

ALUMNI@LIS.NL

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TNO and TU/e HTSC join forces in Nano Opto-Mechatronics Instruments

TU Eindhoven's High Tech Systems Center (HTSC) is joining forces with TNO in the NOMI (Nano Opto-Mechatronics Instruments) collaboration. Together they will drive technology innovations to develop instruments to image, measure and fabricate devices at the level of individual atoms. The applications include nanometrology and nanomanufacturing for nanoelectronics, bio-medical and scientific explorations. Last month, Arnold Stokking, managing director Industry of TNO, and Katja Pahnke, managing director of HTSC, signed a memo of understanding at the Annual 3D Nano-Manufacturing Dissemination Workshop in Delft, the Netherlands.

NOMI's ambition is to turn inventions into innovations (and valorise on the ecosystem investments) by collaboration with existing commercial partners but also act as an incubator to start new/joint ventures (example: Nearfield Instruments). These ventures make use of the NOMI-ecosystem technology research. NOMI will continue to seek expansion on its current partnership in industry and the scientific community in the near future.

Dr. Hamed Sadeghian, principal scientist at TNO, Scientific director of NOMI and since 1 November 2017 associate professor at TU/e: "We are now at a point where further scaling down in for instance semiconductor industry is as much a manufacturing as it is a metrology challenge, which cannot be tackled anymore by existing technologies. Also for the other fields such as biomedical and scientific explorations there is this need for disruptive technology development that drives NOMI. It will bring new technologies from world-leading fundamental research towards the industrial applications that need it."

With a strong track record in nanoscale physics NOMI is linked to mechatronics instrumentation and (market) applications and a solid IP background. Sadeghian: "We are confident that this collaboration will pave the way for new discoveries in instrumentation and tools for emerging applications, e.g. Cognitive computing, Internet of Things, and Quantum Computing".

TU/e HTSC will bring fundamental research and scientific excellence in this collaboration. The focus is in the areas of, a.o., advanced control and dynamics, mechatronics systems design, nano- and micro-manufacturing, and relevant physics and biomedical expertise.

WWW.TNO.NL

WWW.TUE.NL/HTSC

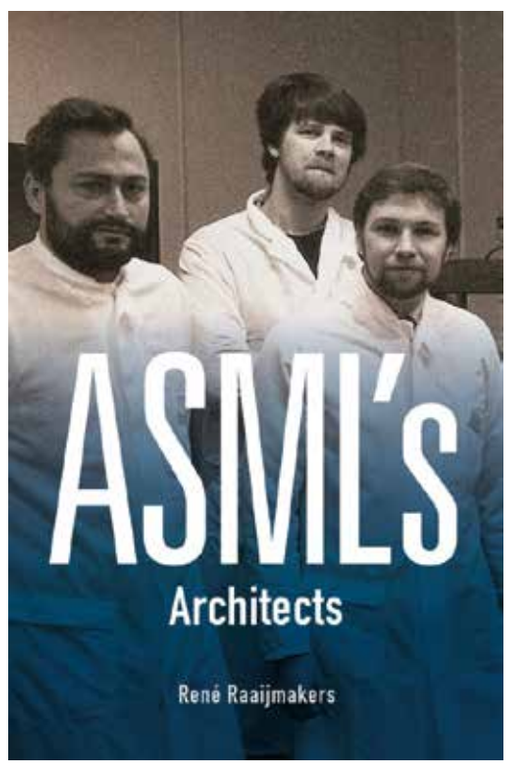
Crowdfunding has started for "ASML's Architects"

The book "ASML's Architects" describes "how a hopeless research and business activity was transformed into a billion-dollar machine and a world-leading company". The Dutch enterprise ASML pulled it off, and technology writer René Raaijmakers, CEO of Techwatch, the publisher of the Dutch magazines Bits & Chips and Mechatronica&Machinebouw, reveals exactly how.

"ASML's Architects" travels back to the origins, struggles, success factors and sheer luck of a company that was barely alive at the beginning of the 80s, yet managed to become the uncontested world leader in chip lithography. Today, ASML determines the pace at which all information technology advances.

The book covers the technology and the business, but the real story is about the people behind them. Throughout its pages, the interviewed engineers, scientists and managers speak frankly about their struggles, their fights and the gruelling teamwork behind the scenes.

This spring, the book was published in Dutch, "De architecten van ASML". The professional English translation is a work in progress – and crowd-funding has started. Once the first 400 orders have been received, the job will be finished. The English version is an extended and exclusive print edition, and contains more historical pictures and illustrations than the original book.



WWW.TECHWATCHBOOKS.NL

MI-Partners' tenth anniversary

In 2007, Leo Sanders, from Philips CFT, founded his own company, AMI, which later changed it name to MI-Partners, partners in mechatronic innovation. Partners of the first hour were Bart van den Broek (Magnetic Innovations), Jan van Eijk (former CEO Mechatronics at Philips Applied Technologies and emeritus professor of Advanced Mechatronics at TU Delft) and Maarten Steinbuch (professor of control systems technology at the TU/e). At the end of October, MI-Partners celebrated their tenth anniversary.

Sanders started in the NTS-Group's building in Eindhoven, the Netherlands, and later moved to an adjoining building. MI-Partners now has thirty employees and customers are located all over the world, from Eindhoven to Silicon Valley and from Brazil to Singapore, in the semicon, healthcare, optics and other sectors (up to trailer construction).
MI-Partners primarily focuses on the advanced development of high-tech mechatronic systems and does not have the ambition to grow strongly with production and/or own products. However, there is now a spin-off, Seismic Mechatronics, which develops and builds 'shakers' for seismic research.

The jubilee celebration took place entirely in the spirit of founder Leo Sanders, with an informal and well-catered gathering for employees, customers and other partners. Sanders opened with a brief historical overview, followed by a portrait of him by an employee and a humorous speech by 'KUL professor' Lucien Vanderpolle entitled: "Ten years of partnership in mechatronic innovation – isn't it time for a wedding?" Finally, the employees surprised their director with an original gift: a mechatronic, therefore dynamic, implementation of the company logo. It showed the commitment and creativity of MI-Partners.

The dynamic MI-Partners logo team presented by the employees.

WWW.MI-PARTNERS.NL

If you can't stand the heat

As the scale of manufacturing gets smaller, factors that at the macroscale are of no or limited importance become critical. One such is the effect of thermal issues when machining, and this is an area that both CRC/TR 96 and euspen have been focused on for many years, with an eye to solving the conflict between reducing energy consumption while increasing accuracy and productivity in machining. Euspen organises a joint conference on Thermal Issues in Machine Tools with CRC/TR 96, 21-23 March 2018 in Dresden, Germany.

Thermal issues in machining control, as well as modelling and model reduction techniques, will be covered at the conference, featuring: measurement of thermal influences (using, e.g., acoustic thermometry) on machine tools and workpieces; compensation and correction of thermal effects; design principles for thermally robust machine tools (machine tool elements, machine structures); testwork pieces and assessment; and thermo-energetic design.

At the conference, experts from academia and industry in the field of thermal modeling and optimal thermal design of machine tools will present and discuss their findings on a high scientific level. The topics of modelling and simulation, experimental methodology, design, and benchmarking were all discussed in five previous CRC/TR 96-workshops. The joint euspen CRC/TR 96 conference follows up on this path and offers parallel sessions concerning these topics. The event is sponsored by CIRP International Academy for Production Engineering and Deutsche Forschungsgemeneinschaft DFG.

Resonator used for acoustic thermometry. (Courtsey: NPL)

WWW.EUSPEN.EU

Linear motion

Faulhaber has extended its Linear DC-Servomotor product family with the new LM 1483. With a continuous force of 6.2 N and a peak force up to 18.4 N, it fits perfectly into the current portfolio of Faulhaber Linear DC-Servomotors, and gives the user a complete force range of 1.02-9.2 N (2.74-27.6 N peak). As for the other models in this family, the new LM 1483 combines highly dynamic motion (acceleration up to 220 m/s^2) with high precision and repeatability (down to 120 µm and 40 µm, respectively).

Faulhaber Linear DC-Servomotors are a solution for small and micro linear motion applications. They combine the dynamic motion performance and robust design typical of a pneumatic system with the high reliability and silence of a brushless motor. Applications include pick-and-place solutions where highly dynamic positioning and a long lifetime (millions of cycles) are required.

WWW.FAULHABER.COM

Settels transfers its shares in High Tech Institute to Techwatch

Settels Savenije, a group of high-tech companies, headquartered in Eindhoven, the Netherlands, is transferring all of its shares in TheHigh Tech Institute (HTI) to Techwatch. The publisher of Dutch magazines Bits & Chips and Mechatronica&Machinebouw now becomes the full owner of the training institute. Settels and Techwatch interacted with one another as equal shareholders for five years. Settels has now decided to focus on its technical activities.

HTI is a training institute for highly-skilled professionals in high-tech. At the start in 2011, the portfolio consisted mainly of training courses that were split off in 2010 by Philips' Center for Technical Training (CTT). When CTT closed, the group transferred training in electronics and optics, mechatronics and precision technology, system architecture, software and leadership to four parties in the Brainport region: Mechatronics Academy, T2Prof (electronics and optics), Systems & Software Academy, and Settels Savenije Friedrich (leadership for technicians). These content providers act as knowledge partners within HTI.

"Our organisation is currently growing strongly", says John Settels, director of Settels Savenije, about transferring his shares in HTI. "Together with my management team I have decided to focus on our engineering firm and the expansion of production in new cleanrooms at Strijp-T (in Eindhoven, ed. note)." Settels remains involved with HTI as a supplier of courses and lecturers in the field of design principles, vacuum technology, leadership, communication and social skills. "All content partners are enthusiastic about the new structure", says René Raaijmakers, director of HTI. "The training institute fits with the mission of Techwatch as supplier of independent information and knowledge."

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Long-lifetime linear encoder

The new LIP 6000 exposed linear encoder from Heidenhain, featuring interferential scanning, enables exceptionally accurate position measurement as well as permanently reliable signals, all within in a compact design. With a very small interpolation error of only ±3 nm, a low noise level of just 1 nm rms, and a baseline error of less than ±0.175 µm at a 5 mm interval, this encoder is predestined for applications requiring constant speed control or high positioning stability at standstill.

The LIP 6000 owes its exceptional characteristics in part to the new Heidenhain signal processing ASIC HSP 1.0, which ensures consistently high-quality scanning signals throughout the entire service life of the encoder. To this end, it continuously monitors the scanning signal: if the signal amplitude decreases, then the HSP 1.0 readjusts it by increasing the LED current. The resulting increase in LED light intensity has only a minimal worsening effect on the noise component in the scanning signals, even during heavy signal-stabilising intervention. This stands in stark contrast to systems that perform amplification within the signal path. At the same time, the HSP 1.0 also ensures that the original, ideal signal shape is maintained despite contamination.

WWW.HEIDENHAIN.COM

Automation Technology

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Festo is a leading world-wide supplier of automation technology and the performance leader in industrial training and education programs.

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Cleanrooms

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Brecon Group can attribute a large proportion of its fame as a cleanroom builder to continuity in the delivery of quality products within the semiconductor industry, with ASML as the most important associate in the past decades.

Brecon is active with cleanrooms in a high number of sectors on:
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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.

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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.

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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.

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Sioux CCM is a technology partner with a strong focus on mechatronics.
We help leading companies with the high-tech development, industrialization and creation of their products, from concept stage to a prototype and/or delivery of series production.
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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.

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Mechatronics Development

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MI-Partners is active in R&D of high-end mechatronic products and systems. We are specialised in concept generation and validation for ultra-fast (>10g), extremely accurate (sub-nanometers) or complex positioning systems and breakthrough production equipment.

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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.

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April 2, 2018
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May 15, 2018
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June 15, 2018
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September 4-5, 2018
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