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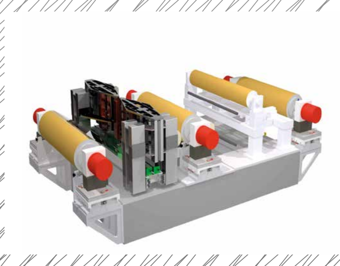
- CONTROL OF **AUTONOMOUS, SELF-DRIVING VEHICLES**
- **ROYAL VISIT** TO LIS
- FUTURE OF **UK PRECISION**
- **SUBMICRON** PRECISION THROUGH **HYDROSTATICS**



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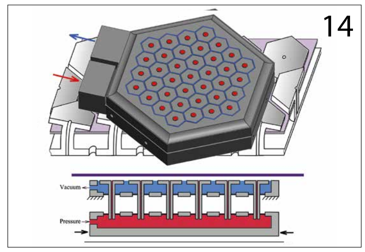
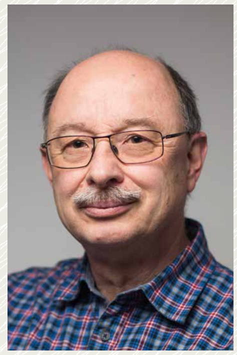


FEATURES

THE FUTURE? LESS COCOONING, MORE FUN!


(Photo: Krystyna Janusz)

As a departing member of the DSPE advisory board, I have the honour of writing this editorial on my vision of the future of precision engineering and DSPE. After almost 40 active years as a mechatronic engineer in design, development, management, university education and research, a very personal drive made me go back to the audio world, which was some 40 years ago the source* of the mechatronic expertise that I have used so well during my career.

When looking back, so many things have changed over these 40 years and so has NVPT/DSPE. I must confess to having been a critical member of the advisory board and I often addressed the risk of over-ambition, but even the most ambitious plans have been achieved, of which the DSPE board can be proud. With this fulfilment of plans, I am struggling to think of something that could be improved for the future, but my changeover to the audio scene has provided a topic, as it appears that hardly any of the recent developments in precision engineering have reached this large field of technology, other than through its products, the semiconductors.

Precision engineering has become more multidisciplinary and several certified courses focus on broadening the scope of engineers to become real mechatronic engineers. This level of multidisciplinary skill is scarcely found in the highly electronic audio world, but to be honest, only a limited number of mechatronic precision engineers really internalise other technology domains outside their mainly mechanical roots. For mechatronic engineers, the internalisation of multiple disciplines like electronics or optics is a prerequisite for success in modern precision engineering design. While a real need exists for these skills, 'cocooning' in one's own specialised domain is a serious risk in fulfilling the needs of industry in the future.

In view of the DSPE initiatives for dedicated courses like the Summer school Opto-Mechatronics, I wonder if it is possible for DSPE to become even more active in stimulating this aspect through dedicated actions. Of course, the challenge is how to achieve this. For internalising knowledge like electronics, one should practise on real hardware, sufficiently connected to mechatronic systems to acquire applicable experience and ignite real interest. Furthermore, it is even better when the hardware can be taken home afterwards to further internalise the technology by experimenting.

In my view it would be wonderful if DSPE could mobilise its members to initiate and co-fund such practical courses with dedicated hardware in cooperation with course providers. No one will be surprised if I suggest letting them design their own feedback-controlled loudspeaker including PWM amplifier. It is really fun and highly instructive!

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* *The role of audio technology as a source of inspiration for the design of Philips/ASML's first electric waferstage is nicely described in the book "NatLab – Kraamkamer van ASML, NXP en de cd" (in Dutch) by Paul van Gerven and René Raaijmakers.*

DRIVERLESS, CONTROL-INTENSIVE

Autonomous and self-driving vehicles require the application of advanced control algorithms. Although this control technology may seem domain-specific at first sight, it shares many commonalities with classical applications in precision engineering in terms of design principles and solution strategies. Here, the control design for trajectory tracking of a self-driving shuttle is described, combining modelling, system identification, and advanced nonlinear control laws. This design has been validated by physical measurements conducted on the WEpod driverless shuttle, which operates in public traffic in the Netherlands.

DRAGAN KOSTIĆ, REMCO DE LANGE, HUGO VAN DEN BRAND, KOEN LEKKERKERKER, FLORIS GAISSER, PIETER JONKER, RIENDER HAPPEE AND JAN WILLEM VAN DER WIEL

Introduction

Autonomous public transportation is receiving increasing attention in the Netherlands and abroad. Examples of self-driving vehicles already in operation include the Rotterdam Rivium shuttle bus and the Heathrow shuttles in London, but such vehicles operate on dedicated lanes. On the other hand, in the Dutch Province of Gelderland, for the first time in the world, self-driving shuttles, called WEpods, are now being tested on public roads.

On the initiative of the Province of Gelderland, Delft University of Technology and several companies have been running the innovative WEpods pilot project with an aim of realising the first application of automated driving vehicles in mixed traffic on public roads in the Netherlands. The goal of the project is to use existing infrastructure with no or very limited adjustments or additions to this infrastructure. The WEpod vehicles (Figure 1) are designed to drive fully autonomously and have no steering wheel. They can, however, drive in semi-autonomous and manual modes when needed.

1 *WEpod driverless shuttle.*

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Automated driving in mixed traffic is a very complex and safety-critical matter. That is why the WEpods project is split in several work packages, each focusing on a particular aspect of relevance for automated driving. One of these work packages is High Level Control (HLC), which is in charge of the control of the vehicle and ensures the safety of the passengers and the other road users. Besides fully autonomous functions, HLC also enables a manual control function in which a steward can manually modify the speed and lateral position of the vehicle by means of a joystick. The presence of the steward is required to obtain permission to drive the shuttles on public roads.

At the request of Delft University of Technology, Sogeti Nederland has been involved in the development and implementation of HLC. In collaboration with other project partners, Sogeti has developed manual, semi-autonomous and autonomous modes for the vehicle control. Each mode has been implemented in the embedded control software and successfully tested on the physical vehicle in different traffic scenarios. In this paper we describe the control design process and report on the test results.
In the next part we introduce the WEpod vehicle and briefly explain the position of the HLC in the overall system architecture. After that we present the vehicle model and system identification results that serve as a basis for the control design. This is followed by a description of the HLC laws. The quality of these laws is demonstrated by the test results. Concluding remarks are included in the last section.

WEpod system architecture

The WEpod vehicle is an upgrade of the EZ10, a driverless electric shuttle designed to cover short distances and predefined routes in multi-use environments. The original EZ10 vehicles were developed by French company EasyMile [1]. The WEpods consortium has equipped these vehicles with additional technical equipment, such as cameras, lasers, GPS-RTK, and LIDAR to better detect and interpret the surroundings and enable safe autonomous driving [2]. The WEpod has six seats for passengers and one for a steward.

The functional system architecture of the WEpod shuttle is depicted in Figure 2. In this architecture, the HLC has a central position, since it is in charge of the control of the vehicle and ensures the safety of the passengers and the other road users. It executes the planned path by performing trajectory control and object following when a slower object is in front of the vehicle. It predicts if other road users intersect with the vehicle's trajectory and performs collision avoidance by braking. The HLC directly interfaces with the low-level control (LLC) functions of the vehicle through the vehicles CAN bus. It also reads this bus and sends relevant vehicle states to the risk assessment system. The LLC is directly responsible for actuation of the vehicle forward speed and steering.

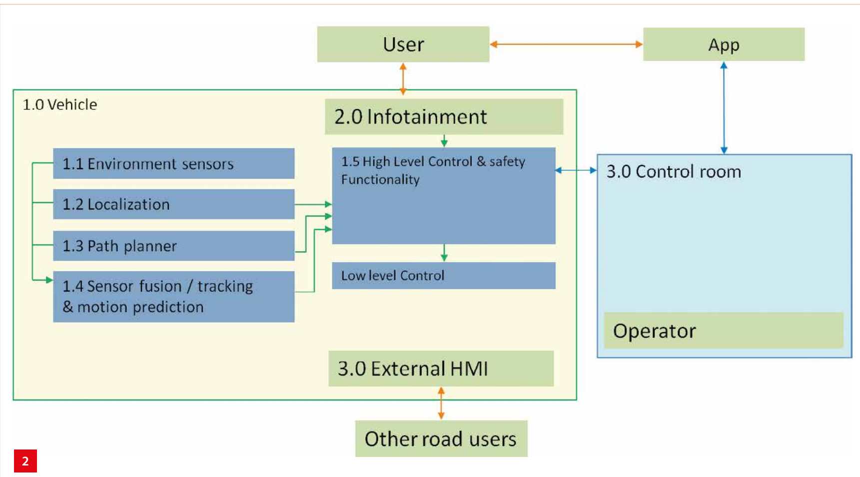
WEpod vehicles run under surveillance of a control room with a human operator who has a permanent overview of the vehicle condition and the traffic situation around the vehicle. The operator can communicate with people inside and outside the vehicle.

Vehicle modelling

The motion equations of the vehicle are based on the reduced nonlinear single-track model [3], see Figure 3. In this model, pairs of wheels at the front and rear axles are lumped together into single equivalent front and rear wheels depicted by dashed lines in Figure 3. Another assumption is that the front and rear steering angles are of equal amplitude but opposite in the steering direction, which leads to the counter-steering driving mode also depicted in Figure 3.

2 Functional system architecture of the WEpod vehicle.

3 Kinematics of the single-track vehicle model with counter-steering.



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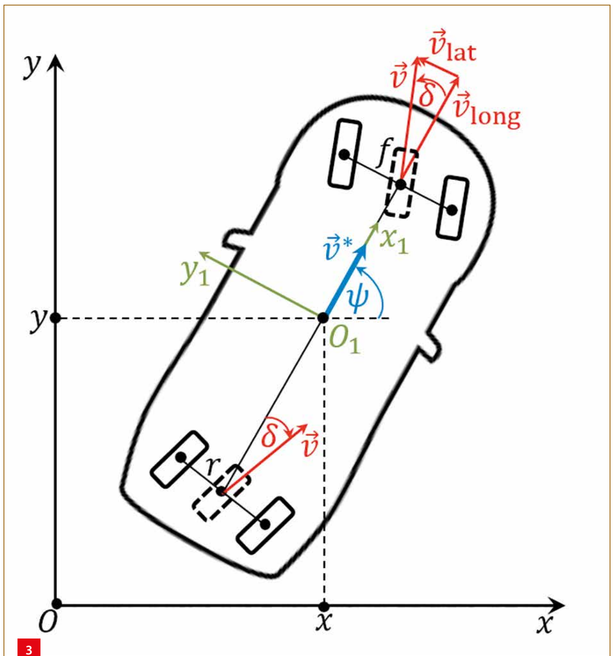

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With reference to Figure 3, the vehicle position in the global coordinate frame Oxy is defined by Cartesian coordinates x and y and the heading angle ψ. The low-level control (LLC) inputs to the WEpod vehicle are the speed of tyres v and the steering angle δ. Here, v is magnitude of the tyres speed vector $\vec{v}$ shown in Figure 3, $v = |\vec{v}|$. For the sake of vehicle high-level control (HLC), it is required to establish a relation between the vehicle coordinates x, y and ψ and the inputs v and δ. For this, we consider obvious trigonometric relations between the vehicle Cartesian speeds $\dot{x}$ and $\dot{y}$ and the translational vehicle speed $\vec{v}^*$:

$$\begin{aligned} \dot{x} &= v^* \cos(\psi) \\ \dot{y} &= v^* \sin(\psi) \end{aligned} \tag{1}$$

Here:

$$v^* = |\vec{v}^*| = \sqrt{(\dot{x}^2 + \dot{y}^2)} \tag{2}$$

The vehicle angular speed ω^* is determined by the time-derivative of the heading angle:

$$\omega^* = \dot{\psi} \tag{3}$$

The objective of the HLC is to find the vehicle inputs v and δ that let the vehicle travel along the reference trajectory supplied by the path planner, see Figure 2:

$$x(t) \to x_r(t); \quad y(t) \to y_r(t); \quad \psi(t) \to \psi_r(t) \tag{4}$$

Here, t denotes time. By inspecting Figure 3, it is obvious that $\vec{v}^* = \vec{v}_{long}$ where $\vec{v}_{long}$ is the longitudinal component of

CONSIDERATIONS IN CHOOSING A 5-AXIS MACHINE

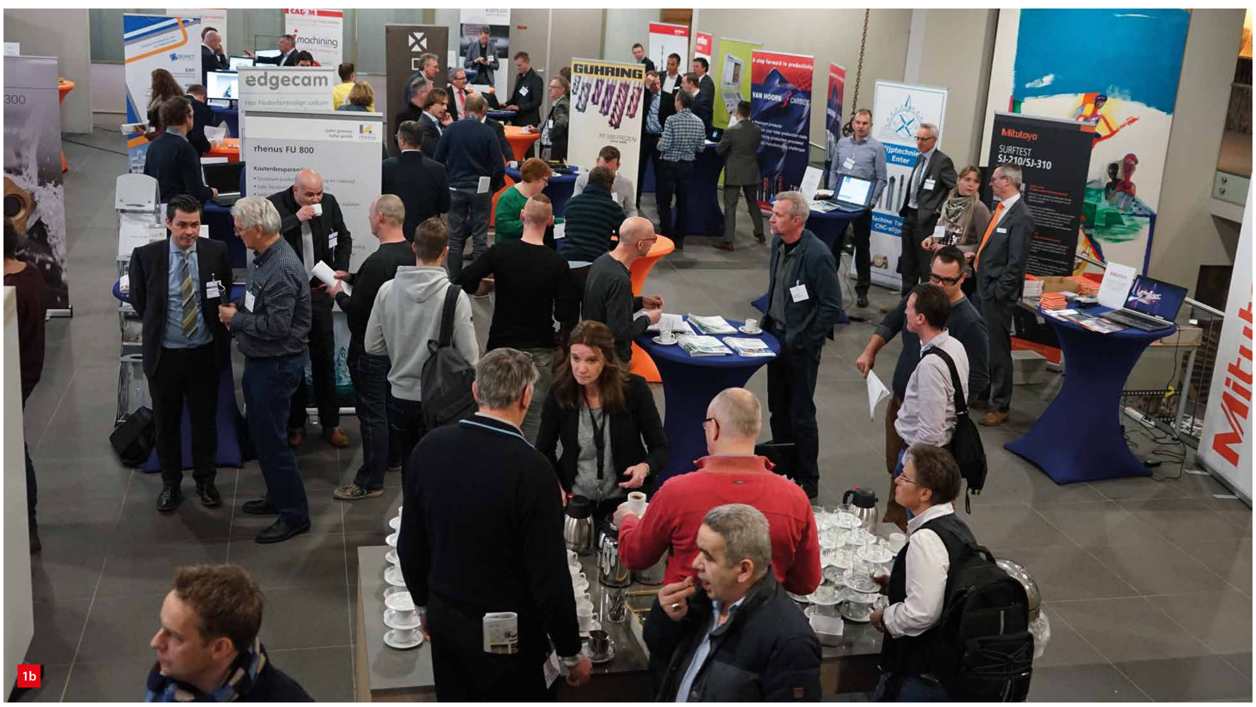
The coming years will see increasingly stringent requirements for component accuracy and surface quality with a growing demand for higher functionality, which translates into greater complexity and the use of more sophisticated materials that don't generally lend themselves to machining. So all the more reason to pay careful attention to the machine's design the next time you invest in a five-axis machining centre, because that literally is the foundation of what is feasible.


1b

JAN OONK

The above-mentioned vision was illustrated during the Verspanen 2020 (Machining 2020) seminar, recently organised by Mikrocentrum in Veldhoven, the Netherlands. This scenario will come as no surprise to most entrepreneurs operating in the machining sector. Aside from the requirements mentioned above, we must not lose sight of productivity, which is a significant driver of international competition.
That makes it ever more important to look at the machine's build and the qualities associated with it when purchasing a new machining centre. Because regardless of whether it is about accuracy, productivity or reliability, the machine is, in all cases, the primary component and is largely determinative of what is feasible. Another crucial aspect is the capability to control temperature and vibrations – the biggest culprits that undermine the milling process.

The best results are obviously achieved when a machine is built to specifications for a specific product and the applicable requirements. Because volume machining a large aluminium component requires different specifications than milling a titanium component, where accuracy and a perfect finish are required. A machine that can meet all milling requirements is unfortunately an illusion, as Willem van Dam made clear in his presentation at Verspanen 2020. Different markets require



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1 *Impression of the Verspanen 2020 seminar.*
(a) *The exhibition. (Photo courtesy of Mikrocentrum)*
(b) *Presentation by Willem van Dam of Dymato.*

AUTHOR'S NOTE

Jan Oonk is a freelance journalist at Oonk Tekstbureau voor Industrie en Techniek. He writes about technology and the machine and metal industry.
This article was written at the request of Dymato, supplier of various leading brands of metalworking machines, headquartered in Veenendaal, the Netherlands. The Belgian magazine Metallerie will publish a Dutch-language version of this article.

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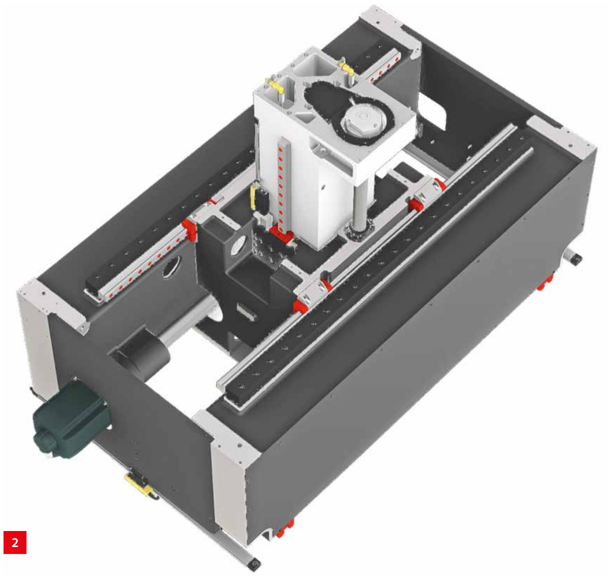

different solutions, according to the area sales manager for machine importer Dymato. In its approach to the market, Dymato draws a distinction between universal machining, high-speed milling and large workpiece machining.

Universal machining centre

As mentioned above, the best quality-returns combination is achieved when a machining centre is programmed to perform a specific machining operation. In practice, however, a supplier can rarely dedicate a machine to a specific task or a set of similar machining operations. Because there is usually a great diversity of products, materials and operations involved, cost considerations tend to favour a universal machine. An all-rounder that delivers the best average results across the board. But even then, it is important to conduct a critical assessment of the capabilities.

Where the width of the machining range is concerned, a portal structure is the most appropriate solution, according to Van Dam (Figure 2). Structurally, the symmetrical design of this machine offers the best capabilities for controlling the forces and temperature effects (thermo-symmetrical design). In a five-axis model, these machines can be equipped with pan/tilt tables. Fitted with direct-drive motors, both the A and C axes can be controlled quickly and with high precision due to the lack of worm gears.

A good example of universal machining centres is the series of Hyundai Wia machines in the Dymato program. In the newest five-axis machining centre, the XF6300, the bed and column are made from a single mono-block piece (Figure 3) to ensure maximum stiffness and accuracy. This is additionally reinforced by the fact that the mono-block frame encloses the A axis motors. The X and Y axes are designed to the box-in-box principle, ensuring a mechanical and thermo-symmetrical design with high stiffness in that respect as well.

Direct measuring systems on linear and rotary axes as well as angle encoders ensure that all remaining temperature effects on the machine frame are effectively eliminated. This way, according to Van Dam, a positioning accuracy of 5 μm and surface roughness of about R_a = 0.5 μm are also feasible on a universal machine (Figure 4). The XF6300 is available with three different spindles (15,000 / 24,000 / 40,000 rpm), so as to offer the most customer-specific solution possible (Figure 5).

2 *The portal version offers the best capabilities structurally to achieve a symmetrical design, with effective control of forces and temperature effects. The box-in-box principle of the X and Y axes also contributes to this.*

3 *The mono-block structure, where the frame is made from a single piece, results in a high degree of stiffness and stability. Especially since the A axis motors are completely enclosed by the frame.*

4 *A positioning accuracy of 5 μm and surface roughness of about R_a = 0.5 μm are feasible on the Hyundai Wia XF6300 machining centre.*

5 *Because the Hyundai Wia XF6300 is available with three different spindles, it brings a customer-specific model of a universal machine that much closer within reach.*