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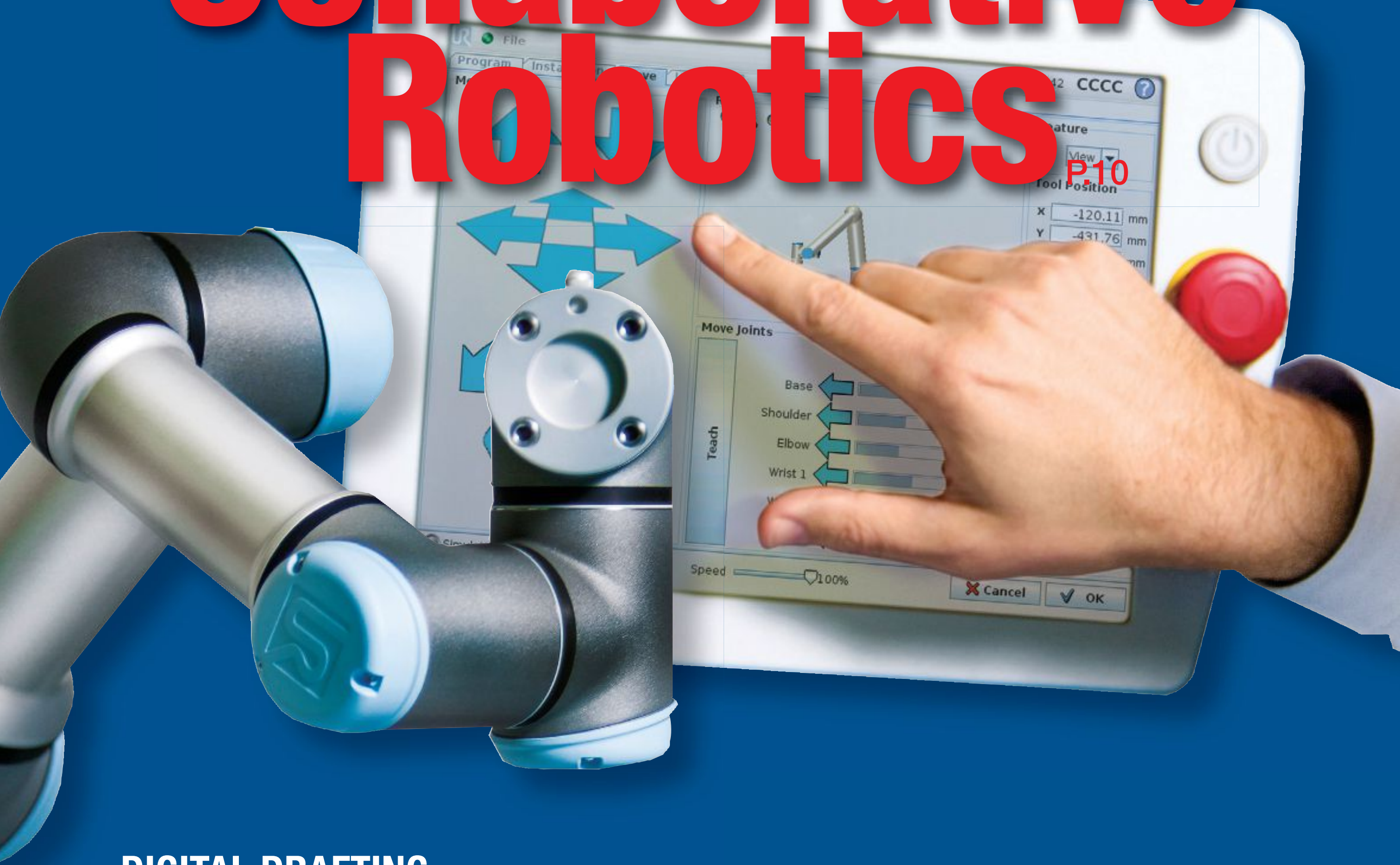
Collaborative Robotics P.10

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Degrees of Freedom

by Jamie J. Gooch

Teach the Robots Well

Maybe it's because I just finally read "Do Androids Dream of Electric Sheep?" the book that the movie "Blade Runner" is based on, that I've noticed so much artificial intelligence in the news lately. The coverage hasn't approached the post-apocalyptic nightmare of the fiction, but neither has it cemented a shiny utopian future for those following along.

It started off innocently enough. In March, the AlphaGo program, created by Google's DeepMind division, beat a human champion of the complex boardgame Go. Then it turned ugly. Microsoft's Twitter chat bot, Tay, began broadcasting obscenity-laced racist and sexist comments that it picked up from an online group intent on taking advantage of the chatbot's "learning features."

On the could go either way front, Facebook announced tools that allow developers to build bots inside Facebook Messenger, enabling news personalization or automated ordering using conversational language in the messaging app; then IBM announced that its cognitive computing system Watson is learning to become more of a Sherlock. Eight universities will be involved in teaching Watson to detect cyber crime vulnerabilities over the next year.

There is no shortage of data to feed the machines.

And, finally, in news sure to make Vegas bookmakers take notice, an artificial intelligence platform based on the "swarm intelligence" of actual human beings, correctly predicted the Kentucky Derby Superfecta — that is, the first four horses to finish the race, in order.

The examples above represent just a few of the varied types of neural networks, pattern recognition algorithms, data-driven predictions, machine learning and deep learning that are all being lumped together under the AI moniker. They have important differences, but they all have a huge appetite for data — and engineers are preparing the menus.

Data Dining

Before data is mined, it must be collected. Thanks to the explosion of connected products, there is no shortage of data to feed the machines. Engineering teams are in the perfect position to help determine what that data will be. What sensors will be integrated? How will products communicate with the cloud and one another? What variables will be most telling? The larger the data set, the better for AI — whether it helps factory robots safely collaborate with humans, allows self-driving cars to recognize stop signs or lets you tell a computer what you want on your pizza.

The exciting thing about today's AI is when a product appears to learn to perform an action based on the data it is receiving — as if it is making a human-like decision. To help make those decisions faster, processing power is being driven to the "edge" (which is displacing the cloud as the latest technology buzzword). From a design engineering point of view, that means you'll be designing, specifying and embedding even more computing hardware and software directly into products so they can process data at the source.

"A radical transformation is underway from the cloud to the edge of every major system," said Les Santiago, research director, Wireless and IoT Semiconductors at IDC in a press release. "In an effort to address the opportunity, both edge and cloud infrastructure needs to continue to scale and support trillions of sensors and billions of systems. Increasing intelligence at the edge will be one of the primary drivers of growth of the overall semiconductor market over the next few years against the backdrop of a maturing smartphone and PC market, and a difficult pricing environment in the memory markets."

As Terry Jones, founder of Travelocity and founding chairman of Kayak.com, told Siemens PLM Connection 2016 attendees in his keynote last month: "Location, location, location used to be about 1st and Main, but today location is about the edge of the glass. It's about where the customer is. It's the edge that's important."

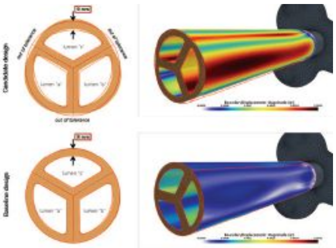
Integration Makes Technology Look Easy

It's not enough for engineers to design the products used on the edge, they need to get a look at the edge themselves. I don't mean camping out on the factory floor or consumers' homes — though that would surely yield interesting data — I mean getting access to usage info, equipment failures, manufacturing logs and other data directly in the software being used to design the next generation of products.

Actionable edge information isn't just for operations, sales and marketing. It is the key to continuously improving increasingly complex products in less and less time. All the major engineering software vendors are focused on data sharing, PLM integration and collaboration because it's critical to innovation. To design smarter products, engineers need access to intelligence from the edge. **DE**

Jamie Gooch *is the editorial director of* DE. *Contact him at de-editors@deskeng.com.*

ON THE COVER: Collaborative robotics image courtesy of Universal Robots.



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by Monica Schnitger /// Molding

Design Considerations for Injection Molding

When you were young, you likely played with a G.I. Joe action figure, a Barbie doll or a flashy toy car. Today your cellphone may have a plastic case and your car can't operate without all of its plastic components. Each of those objects were made using injection molding, a process that was specifically engineered to produce precision parts at a low cost.

Designing plastic parts and their manufacturing process is a combination of art and engineering. A good design means parts are consistently high quality, and can be produced at high volume. A bad part or process design means costly rework, poor quality and disappointed consumers. How can you set yourself up for success? Follow a few relatively simple rules.

The mold is often the biggest investment in the manufacturing process for plastic parts.

1. Design with the Manufacturing Process in Mind

Plastic parts are produced by injecting plastic pellets into a mold that is custom-designed for each part. A mold can cost tens of thousands dollars to even a few million dollars — so, you want that mold design to be right the first time, and certainly before you start cutting metal. To do this, you want to optimize the part and the mold at the same time.

One example of this is to try to keep a consistent wall thickness. Plastic likes to flow along the path of least resistance, and a complex thick/thin setup will cause the plastic to flow to the thick areas first, causing gaps and uneven cooling. If your design doesn't allow for a consistent thickness, play with gate placement or consider a post-molding coring or thinning step that still lets you keep the thickness uniform during injection.

The best way to design the part and manufacturing process in parallel is through simulation. Build a CAD model of the part, simulate the injection process, adjust, try again and so on. Iterations like these cost you the license for the simulation software and a bit of time, but can vastly improve outcomes.

2. Design the Outside of the Part

The outside is what your buyer sees. You want it to be free of seams and welds, sinks, warping, shrinkage or other visible defects. Many designers work on the inside of the part because that is where ribs or bosses and other structural and functional elements reside. Those are important because they enable the part to fulfill its mission, but they're not sufficient to ensure a happy customer. Again, simulation can help answer questions like: Is it possible change a gate location to make it less visible? Can the boss be a bit smaller, so that it's not visible one the lip of the part? Simulation enables you test out many possible scenarios before building a prototype mold so that you reach the best combination of function and form.

3. Play with Materials

Digitally experiment with the materials available to you to come up with a balance between design aesthetic, cost and manufacturability. Amorphous resins, for example, are more viscous and tend to shrink less than crystalline or semi-crystalline plastics, which have better flow characteristics but also shrink more. Your part and mold design must factor in shrinkage, delamination, color streaks, blisters and flow marks — all of which will affect the customers' perception of the part. Also consider cooling: might another material have a different profile, so you can produce more parts in a given time period? All of these affect the economics of part production and are important factors in the overall design.

4. Measure, Measure, Measure

Even the best simulations can only estimate the manufacturing process. Often, a sample mold is used to produce a test run of the part. This step helps determine if adjustments need to be made to the mold, the resin, or its temperature and flow rate. Simulation can speed the front of the design process, allowing time for more creative iterations, but can't completely replace the need for prototyping.

The mold is often the biggest investment in the manufacturing process for plastic parts, so getting it right is critical to the success of the project. You want accuracy and consistency in production, and to get to market at the right time. A mold with the correct gate locations will yield high precision parts, with optimal structural properties and appearance. Getting the mold wrong can be costly — not only in cash terms, as rework increases the cost of the mold and creates production delays, but also in damaged reputations. DE

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Moore's Law for Elements

Most people will be familiar with Moore's Law, which wasn't so much a law, but a 1965 prediction by Intel's Gordon Moore that the number of transistors on a microprocessor chip would roughly double every two years. Currently, the density of components on a silicon wafer is close to reaching its physical limit. But don't worry: There are promising technologies that should supersede transistors to overcome this. Demand from consumers will ensure that this evolution continues.

In the world of finite element analysis (FEA), the pursuit of Moore's Law has meant that we can build more complex models thanks to ever-increasing, affordable computing power. Added to this is the dramatic increase in software program efficiency over the same period.

Does Moore's Law Apply to FEA Models?

I was researching Moore's Law for a training class and I wondered if it might match increasing FEA model size over the years. My first serious use of FEA in industry was in 1976. The preprocessing consisted of sketching a mesh overlay directly onto the drawing board. A typical aircraft lug model took 300 brick elements, created by sketching a 2D mesh and then extruding through depth.

This theory sets the standard for ever-increasing FEA model elements.

The next waypoint is 1985. I have some fragile plots of a satellite bracket meshed with 2000 3D elements. An old report shows a location fixture from 1993 with around 10,000 elements. An archived model of a similar fitting from 2007 uses 400,000 elements. This supported local plastic behavior and fracture mechanics investigations.

I fitted this and other old model data to a Moore's Law type curve. I was little below the doubling factor of 2.0, instead it was around 1.6 every two years. However, that is still a dramatic increase in element count from a humble 300 elements to the modern 400,000 element model.

Baselining Simple Components

I selected structural components of similar scope in both geometry and FEA technology to create my Moore's Law for elements. Many of us build similar basic models day-to-day. I ignored more complex structures, assemblies and analysis. I wanted to see if Moore's Law could predict my basic bracket's future.

The result was startling for this simple structure. To keep up with Moore's Law, I should now be running at around 3 million elements. By 2020 this should be reaching 7.5 million elements. So an interesting question now arises: What is the sensible number of elements to use? The 2007 model really topped out as being perfectly adequate for any kind of structural analysis that I would want to apply. Conversely, the 1976 model at 300 elements was inadequate and required a lot of interpretation to try to predict load paths and accurate stresses.

So, for a lot of basic structures we really have more than adequate computing power right now. Sensible meshing achieves a good level of accuracy. Over-meshing by following Moore's Law does not improve accuracy, but instead fills up computing resource and places a big burden on post processing. This trend is encouraged by decreasing default element size in most FEA meshers and the lack of good local mesh refinement controls in many CAD-embedded FEA meshers.

Better use of available computing resource includes running more design variations for reliability estimates or optimization studies. Postprocessing efficiency is a very big issue when manipulating and viewing results.

Looking Ahead

Despite this mesh fidelity to processing power ratio milestone in finite element analysis, many simulation technologies, such as CFD (computational fluid dynamics), acoustics, crash analysis, and more are not topped out in terms of required mesh fidelity and processing power. For them, Moore's Law continues to be a vital phenomenon. However, for the basic structural bracket, we have reached our zenith and there is a trend to over-mesh and over-model. Perhaps you, the reader, would like to construct a similar Moore's Law of elements and forecast the growth of your favorite FEA models. DE

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by Oliver Winzenried

Security Frameworks to Set the IoT and IIoT in Motion

Security has become a prime concern for manufacturers of IoT (Internet of Things) devices. It is indispensable for using the devices as they were intended, upgrading them without exposing them to tampering and monetizing features in new business models that benefit device makers and users alike.

Current devices often remain standalone and proprietary solutions with unchanging functions. Revenues are often associated with the original sale, and streams of income from maintenance are unpredictable. However, new devices are becoming upgradable with features sold on marketplaces akin to app stores, turning one-time sales into recurring revenue schemes.

Security Vulnerabilities in the IoT

As software has taken the prime position, a new generation of attackers is born. They may come from organized crime, terrorism, secret services or industrial competitors; have virtually unlimited resources for highly sophisticated attacks; and are determined to exploit loopholes in software, firmware or archiving systems. They counterfeit software to run on other devices, reverse-engineer algorithms, unlock functions, manipulate systems with tampered firmware or entire fake identities, or plunder sensitive data of manufacturers, their customers and end users alike. In an era of increasing cybercrime, IP (intellectual property) and tamper protection need uncompromising security.

The market already offers a number of solutions to prevent attacks.

Security Solutions in the IoT

This is not the time to oppose the inevitable transformation or sit on the fence. The market offers a number of solutions to prevent IoT attacks and embrace the industrial revolution.

1. Know-How Protection: The actual assets — the IP in the code — are encrypted with lightweight symmetric encryption and only decrypted on the fly.

2. Product Protection: Counterfeit products cannot be made without decrypting the data, possible only on licensed machines.

3. Flexible Licensing: Allows options like pay-per-use, renting, subscription etc. for software features. Vendors decide how licenses are deployed, either in app stores or user license portals.

4. Tamper Protection: Application code is digitally signed using asymmetric cryptography, with root public keys as securely stored anchors of trust. The devices validate authenticity and integrity themselves.

5. Device Identity: Connected devices need to authenticate themselves, e.g. with tamper-proof private keys. Open standards like OPC UA are excellent solutions for trusted devices of different makes to operate together.

Alongside top-notch encryption mechanisms, the strongest approach to security relies on secure elements: Hardware components that can be added to a machine or device and that hold the cryptographic keys and the software licenses safely locked. These elements can include dongles, memory cards, Trusted Platform Modules and ASICs (application-specific integrated circuits). In ruggedized environments — subject to extreme temperature, vibration or humidity fluctuations — the selection of secure elements, designed with industrial-grade components able to withstand harsh conditions and operate reliably, is paramount.

There is a plethora of platforms currently supporting manufacturing processes. Their storage and computational capacities are decreasing down the line from industrial computers, to embedded systems, to PLCs and microcontrollers. The core security functions can still be enforced in all of these devices. Security systems and best practices can be applied to new facilities as well as retrofitted existing plants.

Rethinking the Business Model for IoT

IoT devices are connected to the internet to allow for constant tweaks to the entire system. The real-time analysis of Big Data can provide tremendous insights for predictive maintenance, sales models or performance optimization. Whether it's a security patch or a new feature that is being injected over the cloud, IoT introduces dynamic patterns into the game. The entitlement to software updates, upgrades and new functionalities can best be delivered when the complete license lifecycle management is integrated with ERP, CRM and e-commerce platforms.

The integrity of IoT devices can be ensured with cryptographic processes and secure hardware. Properly implemented, such encryption can pave the way for all-new business models. DE

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AI + VR = Holodeck (Almost)

In 2014, in an article that chronicled the emergence of holodeck-like technologies, *New York Times* tech columnist Nick Bilton wrote: "Some scientists and researchers say we could have something like holodecks by 2024." ("Disruptions: The Holodeck Begins to Take Shape," Jan. 26, 2014, bits.blogs.nytimes.com.) Without the backing of a named source, that timeline appears to be more speculative than definitive. Yet, recent advancements in the artificial intelligence (AI) and virtual reality (VR) frontiers suggest the date is not too far-fetched.

The holodeck as depicted in the TV series "Star Trek" is a hologram-powered simulation environment. Its use is primarily recreational. But the show also proposes pragmatic applications of the holodeck's technology. "The Star Trek: Voyager" series features a holographic medical doctor, the Emergency Medical Hologram Mark I. In some episodes, the holodeck is pressed into service as a platform for battle training and forensic analysis.

The concept of reality-mimicking environments constructed with solid holograms remains theoretical. However, similar environments built with convincing pixel-objects are well within reach. From the Google Cardboard ($15) to the more advanced HTC Vive ($799) and Oculus Rift ($599), the headgear required to deploy and display VR content is becoming more affordable.

From CAD to VR

There's no shortage of accurate, detailed 3D content — the cumulative legacy of CAD use in engineering. VR content is usually put together in game engines, such as Unity, Unreal or CryENGINE. Converting CAD data from the engineering world into game engine-compatible VR is not a straightforward task.

"CAD software makers might want to think about the hand-off process to the engine," said Michael Kaplan, NVIDIA's global lead for Media and Entertainment. "Or, would they prefer to develop their own CAD-to-VR conversion software? After all, they're software companies." For some, that might be biting off more than they could chew. Kaplan pointed out: "Most of them have never written real-time VR software."

An attendee gets ready to experience VR at this year's NVIDIA GPU Technology Conference. *Image courtesy of NVIDIA.*

AI, once considered the stuff of science fiction, is picking up momentum. AI programs like autonomous navigation and image recognition in self-driving cars are expected to come from deep learning, a process that uses massively parallel computation to teach programs to see and react to their physical surroundings.

At NVIDIA's GPU Technology Conference, NVIDIA CEO Jen-Hsun Huang unveiled the GTX-1, described as "the world's first deep-learning supercomputer." He also introduced the TESLA P100, "for deep learning [at] 16-bit performance," according to Huang. The new products are augmented by the company's VRWorks software suite for VR application developers.

CPU maker Intel pursues the same market with its Intel Deep Learning Framework. IBM Watson, a supercomputer that defeated its human opponents in the TV gameshow "Jeopardy!" in 2011, also wants a piece of the action in deep learning. As of February, Watson has learned to detect signs of human emotion.

Benefits of Convergence

Currently, AI and VR are separate industries, each pursuing its own objectives, each wrestling with its own challenges. In my view (which, I must admit, is influenced by an overactive imagination), the convergence of the two could propel digital simulation to new heights. A VR environment running on autonomous agents and deep learning algorithms could give us unprecedented insights into products and processes.

In a holodeck-like simulation environment, a design study is more than a quality assessment. A virtual product trial could be a stirring, searing, unforgettable experience that induces laughter, tears or fear. If powered by AI and deep learning algorithms, such an environment could suggest design changes and configurations that engineers might have never conceived solely by intuition and expertise alone.

If IBM Watson's emotional intelligence is a harbinger of things to come, future simulation programs might be able to detect how we feel about suggested design changes. If next-gen simulation environments are to look more like the holodeck and less like the standard finite element analysis software interface, then the challenge for developers is to come up with a new way of posing questions — not through dropdown menus and input fields, but through a more natural interaction. Voice command, for example, would be consistent with the holodeck.

VR-powered simulation is still too far away to worry about, you say? By my calculation, 2024 is only eight years away. **DE**

This commentary is the opinion of **Kenneth Wong,** DE's *resident blogger and senior editor. Email him at kennethwong@deskeng.com or share your thoughts on this column at deskeng.com/facebook.*

Robots Un-Caged

Collaborative robots fuel job growth and innovation.

BY MICHAEL BELFIORE

Fetch CEO Melonee Wise with Fetch and Freight robots. *Image courtesy of Fetch Robotics.*

It's a good time to start a robot company. That's the word from David Askey, an MIT-trained roboticist specializing in machine vision who heads startup Ascend Robotics. He says advances in processors and sensors, as well as an influx of investment from industries facing labor shortages, make it so.

"You can do a lot of video processing real time on the robot," Askey says. For example, a graphics processing unit (GPU) chip originally designed, as Askey puts it, "as a very fast pixel pipe," can now be programmed as a general purpose visual processor for robots. The result is increased capabilities at a lower cost.

Mark Woods, head of Autonomy and Robotics at UK-based SCISYS, says much of the investment from robotics is moving from public-sector to private-sector financing. The DARPA-sponsored robotics competitions like the series of autonomous vehicle races it hosted in the 2000s and the more recent DARPA Robotics Challenges of 2013 and 2015 have resulted in a sea change not just in robotics technologies, but also in how they are perceived by investors and customers. "The big change I've noticed is that people have started to challenge the notion that humans are the best control system," Woods says.

Thanks to these trends, robots are entering the manufacturing workplace as never before, as innovators like Askey bring more user-friendly and affordable so-called collaborative robots to market. These machines eschew the cages that confine bigger, more expensive and potentially more dangerous factory robots. And manufacturers of everything from electronics to packaged foods are reaping the benefits.

Scott Mabie, general manager for the Americas at Denmark-based Universal Robots (UR), confirms that the biggest markets for his company are in the small and mid-size businesses that would never have considered robots before because of their expense and elaborate setups that require cages and specialized programming. By contrast, his company's UR3, UR5 and UR10 robots are small enough to be wheeled around on carts, cost less than $50,000, and can be programmed by the line workers who use them. Teradyne, based in North Reading, MA, acquired UR last year for a reported $285 million.

Robots on the Go

It's not just collaborative robotic arms like those produced by UR and its competitors that are making their presence felt in factories and warehouses, but also mobile robots that are designed to work among humans.

Askey cites Amazon's acquisition of mobile robot maker Kiva Systems in 2012 for $775 million as a major validation of mobile robots in the workplace. Amazon doubled the number of Kiva robots that are moving products in its fulfillment centers between 2014 and 2015, from 15,000 to 30,000, according to *Business Insider*.

Melonee Wise, CEO of Fetch Robotics, which launched in 2014 and raised $20 million in series A financing last year, said her company's mobile robots "enable people to transit goods within their facilities from point A to point B without humans." That is, without human effort, but still among humans, at places like data centers, distribution centers and factories.

Robots like these are even preparing to break out of the confines of the workplace entirely and hit public sidewalks to deliver groceries and other goods directly to customers. Starship Technologies, with offices in Estonia and the UK, showed off one of its machines at the recent RoboUniverse conference and gave at-

Universal Robots' General Manager for the Americas Scott Mabie demonstrates how to program one of his company's robots. *Image courtesy of Michael Belfiore.*

tendees a rundown of its capabilities.

Starship's robots are designed to be "99%" autonomous, according to Lauri Väin, VP of Engineering. If the machine encounters an unforeseen obstacle — for example a piece of trash blowing across one or more of its nine cameras — it is programmed to stop and wait for a human operator at a remote control center to take over. Human pilots will also help it cross intersections. The company aims to complete trials in London and Washington, DC, this year.

Not only are such robots designed to work with humans and take over their more tedious jobs, but some of them will get paid like them too; both Fetch and Starship operate on a "robots-as-a-service" business model, which has customers paying monthly fees rather than purchasing the robots outright. Essentially, robot owners are hiring them out, which, says Wise, makes them more affordable. "In many of our cases, a manager at a facility has the budget ... to start with our product without having to go to corporate."

Far from eliminating jobs, the new robots are actually fueling a jobs boom, says the Association for Advancing Automation. In a recent paper titled *Robots Fuel the Next Wave of U.S. Productivity and Job Growth*, the trade association asserts that: "Today's robotics offer manufacturers improvements in efficiency that are driving up profits and employment." The paper plots rising U.S. employment against a rise in shipments of robots and argues "the correlation between robotics implementation and employment growth is clear."

Jim Lawton, chief product and marketing officer at Boston-based Rethink Robotics, says that collaborative robots enable product designers to iterate more quickly, driving innovation. "If I [run] a factory now where I have the ability to have a bunch of smart ... robots working side-by-side with people and my goals at the top level are to reduce costs, be more responsive to customers or to iterate design more rapidly," says Lawton, "that would enable innovation."

As for the future, both Askey and Wise see robots that combine the best features of robot arms and mobile robots as the next frontier. Wise's Fetch is developing a mobile stock-picking robotic arm to go with its available stock-transporting bot, and Askey's Ascend is preparing to launch this year with a combined robotic picking and transporting solution of its own.

Existing robot arms have to be manually programmed for each task, for example picking up and placing specific objects on an assembly line. But an arm that could learn to manipulate objects of varying sizes and shapes on the fly would bring a whole new level of capability to collaborative robots. "People are good at just interacting with something and learning about it as they interact with it," says Askey. "To the extent a robot can do that, that has big implications." **DE**

Michael Belfiore's *book, The Department of Mad Scientists, is the first to go behind the scenes at DARPA, the government agency that gave us the Internet. He writes about disruptive innovation for a variety of publications. Reach him via michaelbelfiore.com.*

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The IoT is Not a DIY Project

Scalable, secure connected product platform availability means you no longer have to do IoT yourself.

The numbers are in. The world's top research firms and business technology prognosticators all agree that the Internet of Things is growing at an amazing pace, opening up new revenue models for businesses that any executive would be foolish to ignore. That means design engineering teams across every industry have been tasked with building connectivity into products — from automobiles to industrial machinery to consumer goods

Design engineers, always up to a good challenge, responded the way one might expect: they built in that connectivity themselves. Bringing together open source and proprietary software, sensors and databases, they've rolled out products that are collecting and transmitting a huge amount of data. Now what?

Now the real challenge begins, and what a challenge it is. DIYers are realizing there is more to the IoT than connecting products. Important questions are being asked, such as:

- How can we visualize the data being collected?
- How can we secure the collected data to protect our intellectual property and our clients' information?
- How do we manage groups of connected products and users efficiently?
- How can we scale up to meet demand?
- How can we create more business value with the data collected from connected products via new service-oriented revenue streams, sales enablement and/or marketing support?
- How do we do all of the above and continue to meet our product development goals?

Turnkey Solutions Available Now

That's typically when early adopters turn to outside expertise for answers and a more robust platform. Now that IoT development has become a business necessity, rather than a pilot program for many businesses, design engineers have the option of skipping the delays and dead ends inherent in many do-it-yourself projects. A third-party provider can help map out a successful strategy for connected product management from square one, or help take a homegrown solution to the next level.

For example, Xively by LogMeIn has worked with early adopters of IoT product design to successfully and repeatedly bring connected products to market. The company uses its real-world experience and its product simulator to help companies outline the business case for connected products. The simulator can be used to model and test connected devices; and to create

The IoT by the Numbers

6.4 BILLION: The number of connected "things" that will be in use this year, up 30% from 2015, according to Gartner, Inc.

20.8 - 50.1 BILLION: The high and low estimates of connected devices expected by 2020 by various research firms.

$546 BILLION AND $868 BILLION: The endpoint hardware spending this year by consumers and enterprise, respectively, driven by the IoT, according to Gartner, Inc.

37% of enterprises plan to go live with machine-to-machine projects in 2017, according to Vodafone.

43% of very large organizations (>$500 million in revenues) have initiated some form of IoT project, according to Machina Research.

40% of the top 100 discrete manufacturers will rely on connected products to provide products as a service by 2018, according to IDC.

23% of enterprises were using the IoT in the first quarter of 2016, with another 29% planning to do so within the next 12 months, according to Forrester Research.

$1.3 TRILLION: The amount of IoT spending worldwide by 2019, as predicted by research firm IDC.

$3.9-$11.1 TRILLION: The potential economic impact of the IoT in 2025 according to McKinsey Global Institute.

81% of companies with IoT project underway have tried to take the lead role on the project themselves, while 59% of those waiting to adopt an IoT solution are planning to work with IoT provider partners, according to Machina Research.

rules that determine data flow, third-party integration and customer interaction. It helps manufacturers validate business models, use cases and processes around a connected product.

For those ready to launch connected products or looking for a better way to manage them, Xively's Connected Product Application Suite provides a real-time view of connected products in the field. It shows product details, trend data, product health, connectivity status, device location, firmware versions and events associated with the products. Dashboards allow decision makers from various departments to visualize product management, development and services. It also allows companies to manage users and devices associated with connected products regardless of the underlying connectivity platform, whether it's a proprietary solution, Microsoft Azure or Amazon Web Services.

Design engineering teams play an important role in guiding the creation of connected products, but they don't have to take on the burden alone. The can-do spirit of DIYers is commendable, but it's not practical when it comes to connected product management, which represents a huge business opportunity and requires cross-departmental buy-in. By turning to a third-party for help, design engineering teams can avoid common IoT setbacks and focus on creating innovative products and services.

For more information, download "Making the Case for Connected Product Management" at deskeng.com/de/cpm.

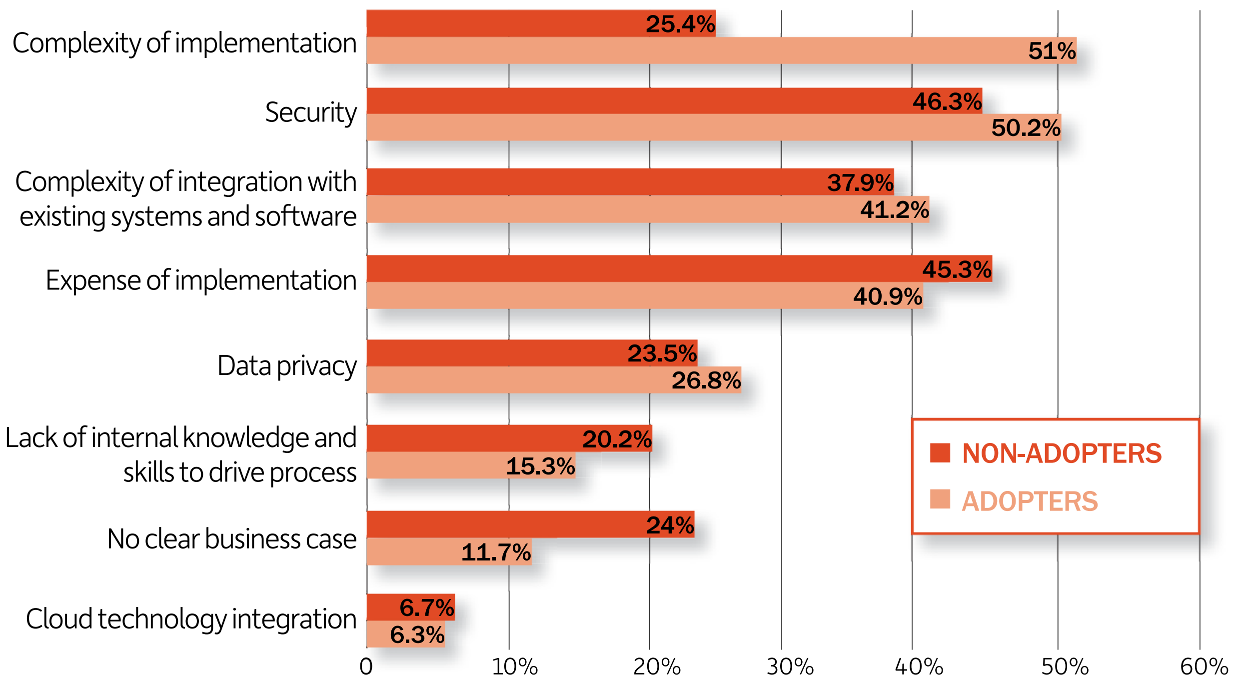
Making the Case for Connected Product Management

Design engineering teams and executives who are struggling to meet demands for connected products need expertise and an out-of-the-box, scalable solution.

"Making the Case for Connected Product Management" is a new report developed by Desktop Engineering on behalf of Xively by LogMeIn. It explains the current state of connected product development, in which engineering teams are trying to cobble together their own platforms for creating, managing and tracking connected products. Packed with statistics and real-world examples, it then provides concrete evidence that supports a better approach to building a connected product management platform. "Making the Case for Connected Product Management" shows how partnering with a third-party provider allows engineering teams to focus on their core strength of product development.

Download your free copy of "Making the Case for Connected Product Management" at deskeng.com/de/cpm.

What are your primary concerns in pursuing IoT solutions?



According to a Machina Research survey, complexity of IoT implementation is a top concern. Companies who have undertaken an IoT initiative say the implementation was more complex than expected. Relying on partners to assist with IoT implementations reduces complexity and allows companies to focus on efforts that impact the business. *Source: "Lessons Learned from Early Adopters of the IoT: A Global Study of Connected Businesses" by Machina* Research.

Brüel & Kjær's NVH Simulator lets users view and hear their integrated test data through an automotive configuration. ***Image courtesy of Brüel & Kjær.***

Did You Hear **That?**

New tools are emerging that help engineers run more comprehensive noise, vibration and harshness analysis.

BY JESS LULKA

If you own a car, you're aware how noisy they can be. To properly maintain a vehicle, it's important to listen for any odd sounds and investigate any vibrations that might indicate an issue. A good sound and feel are a mark of automotive quality, so engineers are constantly assessing noise, vibration and harshness (NVH) to ensure safety and an optimal consumer experience.

Engineers rely on a variety of technology to help them test for NVH, ranging from traditional data acquisition hardware to CAE-based simulators. With expanding options from a host of technology and service providers, more teams are able to test in an environment configured specifically for their needs.

"The application will typically define the hardware and software requirements for a NVH test. Normally, you cannot mix and match analysis software with data acquisition hardware. However, there are a few companies that do offer cross platform support. Most companies will normally adopt a vendor's technology based on functionality, channel count, technical capabilities and of course the cost," says Neil Coleman, president and CEO of Signalysis.

Getting Started

As with any testing workflow, engineers need to start with some sort of data, whether it's in a CAE model or collected directly from the field. To help teams collect data, companies such as DTS offer data acquisition systems that can be used for in-field recording.

"In lab-based situations where size of the data acquisition system (DAS), power requirements and ruggedness are not required (such as in test cells) or bench top, just about any DAS on the market will do the job," says Hans Hellsund, director, Sales and Marketing at Diversified Technical Systems (DTS).

Outside the lab, DAS requirements vary with the terrain. For its off-road applications, DTS offers SLICE MICRO, NANO and PRO systems. These devices are self-contained, portable and can work directly with sensors commonly used for NVH. "The primary differentiator of the SLICE systems [compared to the rest of the market] is that they are uniquely suited for situations where an embedded data recorder is desired or required because they are small, lightweight and non-obtrusive, and can be situated close to the sensor locations," Hellsund notes.

SLICE standalone data acquisition systems are designed for embedded applications with challenging space limitations and rugged test environments. *Image courtesy of DTS.*

One company pairing software with new hardware advancements is the Siemens PLM Software LMS Test.Lab division. The organization recently debuted the LMS SCADAS XS, which makes NVH data acquisition more mobile, explains Scott MacDonald, senior applications engineer at Siemens PLM Software. "A big advancement for us was the mobile platform, where we can take those units out of the lab and put them in a vehicle, helicopter or airplane," he says. "The XS [unit] takes mobility to the extreme, for literal 'go anywhere' testing." Important features include extensive battery life and Wi-Fi tablet connectivity, which can add flexibility to in-field data collection.

Going Visual

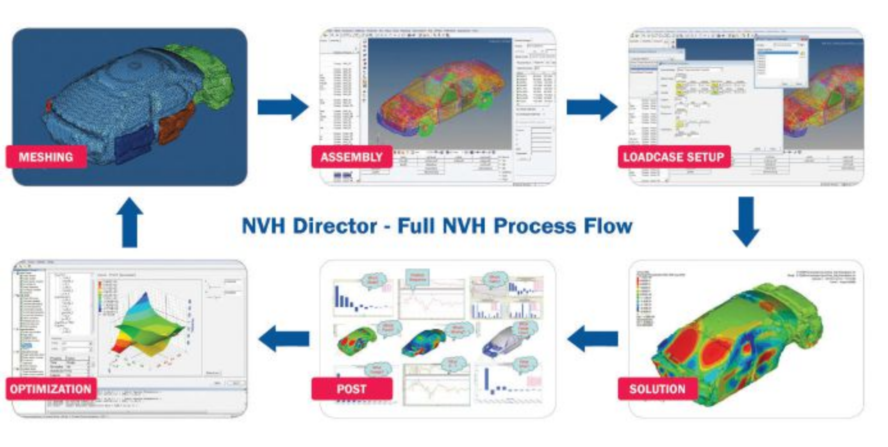
In addition to using data collection hardware, engineers are now using CAE and additional simulation offerings to conduct NVH analyses. Advances in software and technology are upsetting the status quo of primarily using physical test systems during product development.

"With the gains in computational efficiency, an NVH analyst can also look at manufacturing variation, and conduct design space exploration and optimization studies to develop a fundamental understanding of the best architecture for the intended application, factoring in manufacturing processes, cost, weight, as well as performance factors such as durability and efficiency," says Brian Wilson, president and CEO, Advanced Drivetrain & Engineering Technologies (ADET). "With this advancement in CAE efficiency, hardware testing can be conducted for verification purposes, and not for expensive development studies — or, at least limited development."

Using simulation software also enables up-front engineering, notes Jianmin Guan, director of Vibrations and Acoustics Solutions at Altair. This is especially important when addressing product complexity, shorter design cycles to bring cars to market and working with engineers beyond the NVH department. Visually representing test data through simulation can help non-NVH engineers and product managers realize the significance of certain design changes that may not be conveyed through graphical data.

This emergence of using simulation for NVH has led to more immersive solutions such as Brüel & Kjær's NVH simulator. The offering pairs sound testing with visuals on the desktop, on the road or in a CAVE-like environment. "The normal output is a graph or a set of numbers — some visual representation of the sound or vibration. As people, we don't understand sound and vibration as numbers, we understand it by actually listening and feeling it," says Dave Bogema, senior application engineer at Brüel & Kjær. "You really have to experience [sound] to understand what it means."

The goal of this simulator, Bogema explains, is to help bridge the gap between the objective hard data and the real world. Adding context to the situation through a vir-



Altair's NVH Director draws on HyperWorks and OptiStruct capabilities to deliver a comprehensive simulation workflow. ***Image courtesy of Altair.***

Consider This

When selecting the hardware for NVH, Hans Hellsund, director, Sales and Marketing at Diversified Technical Systems (DTS) notes that engineers' specific needs will dictate what type of data acquisition system and sensors are used. These include:

- How many data channels are needed.
- What kind of sensor power/signal conditioning is required.
- Any size and weight constraints in the test environment.
- Environmental factors (temperature, humidity, shock, vibration).
- How the system will be powered.
- The duration of the test cycle (this affects things like battery life and on-board memory capacity).

From the design side, there may also be additional requirements from the customer. "The most common design mistake is not clearly understanding the 'voice of the customer' (VOC), and integrating this into the drive-train NVH design process," says Brian Wilson, president and CEO of ADET. For example, engineers may typically aim to reduce gear whine by 6dB. However, if they find that customer requirements are in the range of 10dB or more, they will be required to consider a completely different approach to address this challenge.

"If the drivetrain is released for production without properly considering the VOC upfront, which often happens, the drivetrain NVH team may be forced to deal with market concerns, trackable using metrics such as increased TGW (total gross weight), increased warranty and lower vehicle residual values," he says.

tual environment can help engineers more effectively make decisions about noise levels. "When you drive a car, you don't listen to [just] the wind noise. You listen to the whole car. That's how people evaluate their environment. If you just had your wind noise generated and listen to that, it's beneficial, but it's nowhere near as beneficial as being able to mix that in with some road noise and powertrain noise and make it sound like a real car would," he says.

The visual component may also shift how someone responds to a sound, Bogema notes. Oftentimes, he's played road noise of 70 mph to people just through calibrated headphones, and they find it too loud. However, once he plays the noise on the NVH simulator with a screen, steering wheel and car pedals, the same 70 mph gets a positive response and isn't as harsh to listeners.

Siemens is also giving additional context and visualization to NVH with its High Definition Acoustic Camera and 3D Acoustic Camera. If you have a noise you either like or don't, these tools paint a hotspot of where that sound is coming from on a picture or digital model, says MacDonald. This ability to use sound source localization, he notes, can help save time and calculations. "[It's a] visual companion to NVH data," he says.

ESI Group is well established in the industry through its Virtual Performance Solution (VPS). This offering includes tools for NVH as an integrated module within its full portfolio to help address issues that appear later in the design process, says Williem van Hal, product manager of NVH, VPS. "[The VPS modules] share the same materials, boundary conditions and connectivity techniques, so what NVH needs from a structural standpoint is a subset of what is already there," he says.

The module can combine porous elastic and finite element model data to help engineers make deeper and more accurate predictions on the functional behavior of the structure, according to van Hal. ESI's VPS will also "reuse data that is already existing, saving [our customers] time on generating new models dedicated to NVH," he says.

Also drawing on its established offerings, Altair released the NVH Director back in 2012. "The NVH Director is a tool created specifically for NVH simulation at a very high end, [meaning] full-vehicle simulation," says Guan. "[Altair has] covered the entire flow of simulation from the beginning of modeling the CAD geometry to finding a better solution." It's an integrated offering, Guan explains, linking most of the products that Altair has, including HyperMesh,

The new High Definition Acoustic Camera can help engineers pinpoint hotspots for NVH generation. *Image courtesy of Siemens PLM Software.*

OptiStruct, HyperWorks, HyperStudy and HyperView.

This marks a recent commercial solution and also brings accessibility to NVH CAE, Guan adds. "In the past, full-vehicle simulation was closely held by OEMs (original equipment manufacturers). Each [company] would have their own way of validating NVH and it was done by the top OEMs. With the NVH Director, now every OEM has access to all the capabilities we've built into the software. It makes it much easier for them to catch up to best practices."

Collaboration is Still Key

Even with many companies developing their own proprietary solutions for NVH analysis and testing, organizations are still finding ways to expand their networks and offer more extensive solutions to their customers.

To ensure its software offerings can support more simulation formats, Brüel & Kjær forms partnerships directly with CAE suppliers. "[These companies] are really excited that we can offer their customers a way to actually experience their data and we're happy to help them do the same," Bogema says. Current collaborations include MSC Software, Altair, Dassault Systèmes, Exa Corporation and Siemens PLM Software.

In addition to industry partnerships, engineering teams can also work with service providers to address their NVH testing and analysis needs. ADET continues to develop its network of industry experts for addressing multiple drivetrain design issues, Wilson states. "Often, a company may employ a drivetrain NVH expert, but this individual is normally skilled in either CAE or test, and quite often, is fully utilized and spread fairly thin. ADET has NVH experts available in both CAE and test, and can help address resource or skills issues," he explains.

A New Standard?

With the emergence and development of a whole new set of NVH simulation tools that enable a more visual workflow, some may wonder if this means a future that isn't dependent on lab-based testing. Most experts don't see engineers abandoning traditional data acquisition systems and techniques any time soon. Instead, they believe the new NVH process will foster a hybrid of lab-derived data, simulation and virtual models.

"You need to verify that the assumptions made in the simulations are correct," says DTS' Hellsund. "The analysis results need to be compared with real-world experimental data until you are certain the simulation inputs are correct. If any design changes are made, this verification process needs to be repeated. They go hand in hand."

"Test has always had a place to verify and understand how the models were working, so I think there's always going to be a partnership between the two," says MacDonald. "As we see computing technology and processing capability continue to grow, we will be able to at least attempt to simulate things that are just so much faster and easier to get with a test. But I think there are always going to be [unknown elements] that are only figured out through test. I never think it'll be a one pony show." **DE**

Jess Lulka *is associate editor of* DE. *Send e-mail about this article to DE-Editors@deskeng.com.*

INFO ➜ **Altair:** Altair.com

➜ **ADET:** DrivetrainExperts.com

➜ **Brüel & Kjær:** BKSV.com

➜ **DTS Systems:** DTSWeb.com

➜ **ESI Group:** ESI-Group.com

➜ **Siemens PLM Software:** Siemens.com/PLM

➜ **Signalysis:** Signalysis.com

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The Universal Language

Show, don't tell when it's time to explain design intent.

If you've ever visited a foreign country where you didn't speak the language, you have an idea what it must be like for non-engineers to understand design intent. Speaking more slowly or loudly doesn't help. Showing a layman schematics, Excel tables or even simulation visualizations is the engineering equivalent of a tourist asking directions to the airport by stretching out their arms to pantomime a plane. You might get your idea across, but it will take awhile — and time is a luxury most design engineers don't have.

Design engineers speak the same language. Tolerances, loads, stresses, thermal envelopes and more make it easy for engineers to communicate requirements, development issues and engineering change orders. However, not all clients and colleagues speak that language, which stymies collaboration and results in inefficiencies and lost opportunities. If only you could show them exactly what you had in mind in a way anyone could understand. That's what rendering allows you to do.

Rendering can be the universal language of manufacturing by enabling true visual collaboration among designers, clients, executives and other key stakeholders. Where in the past rendering was a complex, time-consuming task that required expert assistance and expensive computing resources, software and hardware tools now exist that put powerful rendering capabilities into the hands of designers. A picture maybe worth 1,000 words, but rendering can be worth much more as it allows you to fully express the intent of your design, help win bids, market products, identify flaws and imperfections, and explore future concepts.

Communicate Early and Often

The design process has been compressed. Customers expect more complex products in an increasingly short timeframe, which has made communication throughout the process even more critical.

Prototypes, while extremely useful in communicating the look and feel of a design, are expensive to build and often aren't created until later in the design process when most of the key decisions have already been made. Lacking the ability to quickly and effectively communicate design intent and the impact of change orders to all stakeholders inhibits collaboration.

Quality rendering, however, can cut through the technical noise early in the design process, allowing colleagues and clients to experience the "ah-ha" moments that can lead to new ideas, faster change approvals, clearer communication,

RENDERING brings an idea to life in a way a 2D schematic or even a 3D CAD model cannot. *Image courtesy of Daniel Simon.*

and ultimately better and more satisfying designs. Rendering can help you quickly lead colleagues and clients to better decisions with easily understandable visual information. From initial concepts, through multiple design changes and to the final presentation, rendering provides all stakeholders with a clear view of the project.

Equipped with the right hardware, including overclocked workstations, powerful GPUs and render nodes built to enable faster, iterative visualization of designs, engineers can work faster, provide better results and truly collaborate with other team members, customers and colleagues in various disciplines in ways that weren't previously possible.

Making the Case for Visual Collaboration

A paper produced by *Desktop Engineering* on behalf of BOXX Technologies makes the case for investing in the hardware, software and workflow to support visual collaboration. It explains how rendering can improve the design process, enhance collaboration and enable better customer interactions through real-world examples.

Download "Making the Case for Visual Collaboration" for free at deskeng.com/de/visual.

Reinventing Drawing and Drafting for Tablets

Software developers bring back natural drawing to engineers trained on mouse and keyboard.

BY KENNETH WONG

How do you draw blueprints and cross-sectional views with a mouse and a keyboard? That was one of the conundrums for the digitization of design in the era of desktops. In the absence of hardware that could closely reproduce the established workflow of the drafting board, early design software makers had to invent novel ways to draw lines, arcs, circles and rectangles using a mouse and a keyboard. They hit on a multistep system that makes use of points of origins (like the center of a circle or the first corner of a rectangle), offset distances and commands. The resulting protocols — though a far cry from the pen-and-paper approach — came to be the standard. Even though drawing with a mouse and a keyboard was anything but intuitive, this digital-drawing paradigm was so widely adopted that CAD users began to describe user interfaces (UIs) that adhered to the established method as intuitive.

The emergence of touch-enabled mobile tablets and pressure-sensitive styluses presents the software developers with an interesting challenge: How do you reinvent drafting and drawing so it feels natural to the generation that learned to draw with a keyboard and a mouse? The task is made all the more complicated by two competing input methods, both of which are to be found in some devices: drawing with fingertips or blunt-tipped

Lenovo's ThinkPad P40 Yoga has a keyboard that can bend all the way back, making it both a mobile workstation and a drawing tablet. ***Image courtesy of Lenovo.***

styluses; and drawing with pen-like, sharp-tipped styluses. To make a natural UI for drawing on tablets, software developers also have to combat habits from the mouse-and-keyboard era.

Catching the Consumer Market's Energy

Last June, Siemens PLM Software's Online Community Manager Amy Allen revealed the product Catchbook in a blog post ("Catchbook: Sketch with a Purpose," June 23, 2015). She described the software as "a tool anyone can use to draw accurately … whether you're a 25-year veteran of the CAD industry or a 5-year-old child who is just learning to write." The software is now officially available for iOS devices. The software will soon be available for Android, iOS and Windows devices.

According to Ken Hosch, Siemens PLM Software's director of Innovation, Research and Strategy, the impetus to develop Catchbook came from watching professional engineers struggle to build drawings using primitive shapes in PowerPoint — a presentation program pressed into service as a drafting app because it comes preloaded with editable geometric shapes.

With mobile tablets offering robust CPU and GPU (graphics processing unit) horsepower, and with the option to stream apps from the cloud, Hosch feels software developers now have a lot more flexibility in platform choices. The trick is to design a UI that's specific to the target device.

"If you just convert a desktop program into a mobile app, you can still bring up the menu on the tablet's 8-in. screen, but it's not going to be a lot of fun," Hosch said. Invariably the ribbon buttons from the desktop version will be much too small for the mobile display, and the dropdown menus designed for maximum efficiency for the mouse won't work well with fingertips.

The strength of Catchbook rests with its ability to recognize and autocorrect what you draw. The software can convert your shaky scribbles and doodles into mathematically perfect squares, circles, curves and lines, with the option to further refine it.

"We spent much of our time rethinking the workflow and understanding how to make the interaction as natural as working with pen and paper," Hosch said. "The pen-stylus gives you a tip you can see. With fingertips, you can't see where the point is registering on the screen." Catchbook works better with a pointed stylus, but can be used with a finger as well. The version of Catchbook for fingertip-drawing devices "makes more aggressive use of snapping to make it easier to draw with a finger," Hosch explains.

Siemens PLM Software maintains a software portfolio that caters to professional engineers. However, Hosch believes Catchbook can appeal to the broader consumer market. "Catchbook bridges both worlds [consumer and professional] because you can export drawings directly to DXF or SVG for instant use in CAD or artistic design solutions," he adds.

In converting AutoCAD to mobile devices, developers reassessed what to highlight and what to rewrite to accommodate the stylus-centric working mode. ***Image courtesy of Autodesk.***

Autodesk also ventured into the consumer market when it released its tablet-friendly drawing program SketchBook. The professional version ($29.99 a year via subscription) includes Perspective Tools, which makes orthogonal projections and architectural drawing much easier. The application is popular among artists and illustrators, but can be put to use for conceptual drawing by engineers. It's intended to produce raster images, not vector lines and editable splines; therefore, drawings exported from it can only be used as a background layer for guidance in CAD.

AutoCAD 360 for the Browser and Tablet Generation

As the leader of the 2D pack, Autodesk's AutoCAD software largely influenced the current digital drawing paradigm. The task to break the established mold fell on developers of AutoCAD 360, the official AutoCAD mobile app. "Roughly 80% of the customers only use 20% of the software. The adaptation to tablet allows us to reassess every decision we made in the past on which features to highlight. We're rebuilding AutoCAD for the future," says Elad Lebovitch, senior manager of AutoCAD 360.

Looking at the universe filled with competing input devices, the development team decided that the most sensible approach is to let the software detect the user's input device and adapt. "When you work with the Apple Pencil, the software will automatically switch to the Smart Pen mode," explains Lebovitch.

But the approach is not always clear-cut because users tend to muddle the differences between the input systems. "We thought that customers would use the digital pencils [styluses] like real pencils [in sketching operations]. But customers also expect them to behave like fingers on touch-enabled tablets [for example, dragging objects across the screen]," Lebovitch points out.

In 2015, Autodesk rolled out a set of tools called Quick Tools in AutoCAD 360. The technology "understands whether you're drawing a square, rectangle or circle, and will automatically refine it and let you adjust it to the measurement you want," says Lebovitch. The shape recognition in Autodesk's AutoCAD 360 and Siemens PLM Software's CatchBook are similar in principle. It suggests the feature may become a standard part of future engineering drawing apps and software.

Sensitivity Training with Yoga

Last December, Lenovo unveiled ThinkPad P40 Yoga, a mobile workstation. When its keyboard is fully bent backward (an impressive yoga pose for a computer), the device functions as a tablet. "People sometimes compare the Yoga P40 to Microsoft Surface Pro or iPad Pro with Apple Pencil, because these devices bring sketching and drawing to the forefront," says Lane Jesseph, product manager for Mobile Workstations at Lenovo.

But Jesseph believes the ThinkPad P40 Yoga is a better choice for the professional design and engineering market. "Our competitors are consumer devices. Ours is a workstation with sketching capability," he says. Both the Surface Pro and the ThinkPad P40 Yoga run on Intel Core CPUs. Whereas the Surface Book comes with a NVIDIA GeForce GPU, the Yoga P40 comes with a NVIDIA Quadro-class GPU.

Lenovo's partner for input devices is Wacom, known for its Wacom Cintiq tablets that cater to the professional illustrators and digital artists. "Their technology is more accurate around the edges of the display. It comes with 2,048 degrees of pressure sensitivity," Jesseph says.

In software and mobile apps for digital artists, industrial designers and illustrators, pressure sensitivity mimics the way paint brushes work. The harder you press, the thicker and bolder the strokes. (Such is the case with Autodesk SketchBook drawing app for tablets.) Almost all engineering 2D drafting and drawing programs (AutoCAD and its rivals) were originally developed for the mouse, a device with no pressure variation. Engineering software makers continue to wrestle with new ideas to make good use of the styluses' pressure variation.

In most engineering software, 2D sketching and 3D modeling coexist but as separate environments. With the ability to easily transition from 2D to 3D, products like Autodesk Alias and Dassault Systèmes' CATIA Natural Sketch are ideal for tablet users. In such programs, you can reuse hand-drawn 2D curves and splines in developing a 3D model, a method that works well for conceptual design. Since hand-drawn sketches play an important role in these software offerings, a superior stylus technology contributes to the user experience.

Multi-Device or Consolidation?

Some people treat their mobile tablet as the primary computing device, a replacement for the desktop PC. But Autodesk's Lebovitch isn't so sure engineering software users can abandon the desktop workstation altogether. "Some operations currently are available only in the desktop version," he points out.

In the concept design phase, you may now use a digital pen and a tablet, fingertips on a tablet, or a mouse and a keyboard to produce detailed 2D profiles and floor plans. In design review, you may also choose one of these three approaches, or toggle from one to the other, to rotate and inspect your parts and assemblies. The ease with which these operations are accomplished is nearly identical, depending on your mastery of the medium. However, in the 3D modeling phase, certain operations (like using surfaces to trim solids or Boolean geometry construction methods) still prove easier to execute in the desktop environment.

"Mechanical designers, industrial designers and engineers usually start out with a sketch. We're learning that, even when using workstations, they do a lot more sketching than we previously realized. With hardware like the ThinkPad P40 Yoga, you'll start seeing a blend of sketching and modeling," says Jesseph.

Autodesk's Lebovitch says: "Autodesk sees a future is in the tablets, so we're bringing all the technologies available on the desktop to the mobile platform. With the amount of R&D we're doing in this area, I'd say you can do certain workflows from start to finish on mobile devices."

Whether engineers will eventually come to consider the tablet as their primary computing device or use it to augment their workstation is an open question. But compared to a mouse and keyboard, the stylus and tablet are much closer in form factor to their pre-digital ancestors — pen and paper and the drafting board. The challenge is to invent a digital drafting and drawing environment that can accommodate both the natural drawing methods (the stylus-centric approach) and the familiar methods (the mouse-centric approach). The UI development process, says Siemens PLM Software's Hosch, "has been a learning experience for all of us." **DE**

Kenneth Wong *is* Desktop Engineering's *resident blogger and senior editor. Email him at kennethwong@deskeng.com or share your thoughts on this article at deskeng.com/facebook.*

INFO ➜ Autodesk: Autodesk.com

➜ **Dassault Systèmes:** 3ds.com

➜ **Lenovo:** ThinkWorkstations.com

➜ **Siemens PLM Software:** Siemens.com/plm

For more information on this topic, visit deskeng.com.

Editor's Picks

by Anthony J. Lockwood

Each week, Tony Lockwood combs through dozens of new products to bring you the ones he thinks will help you do your job better, smarter and faster. Here are Lockwood's most recent musings about the products that have really grabbed his attention.

AMD Releases FirePro W4300

The low-profile graphics card is suited for CAD applications.

The FirePro W4300 is built with AMD's Graphics Core Next (GCN) architecture, which optimizes GPU (graphics processing unit) use and maximizes performance, letting the system CPU focus on the things it does best. With the GCN architecture, the FirePro W4300 comes with a GPU and 4GB of GDDR5 GPU memory.

Then, there's GeometryBoost. Basically, this lets the GPU process geometry data at a rate of twice per clock cycle, doubling the rate of primitive and vertex processing. It also has Direct Graphics Memory Access, which reduces CPU usage.

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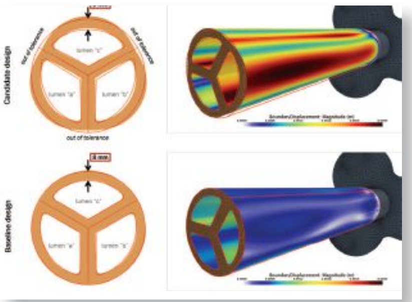

STAR-CCM+ v11.02 Now Available

New data visualization and remeshing capabilities have been added.

STAR-CCM+ v11.02 has a bevy of new capabilities – some 40 alone derived from user suggestions. Two stand out: Local Surface Remeshing and Data Focus. Both nail CD-adapco's Multidisciplinary Design eXploration (MDX) philosophy.

Local Surface Remeshing lets users remesh selected mesh areas after you change some parameters or finish dealing with a design change.

Data Focus lets users link, explore and interrogate live quantitative numerical data and qualitative visual data in scenes interactively. LInked results in a 3D scene can be updated as desired.

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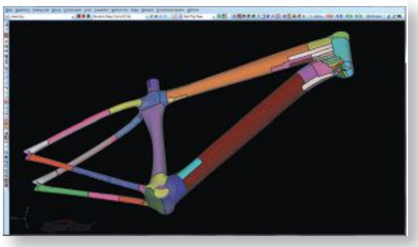

HyperSizer Express Ships

Software automates composite laminate optimzation.

Collier Research's new HyperSizer Express provides you with the essential tools for composite laminate optimization with an interface streamlined for more efficient operation. Its capabilities are drawn from the company's high-end design, analysis and optimization system.

The HyperSizer Express interactive workflow uses wizards to step users through the optimization process. Users have the ability to get into it and fiddle with things like model areas to cut down more weight or add more stiffness, and it offers a bunch of user-selectable failure criteria. Materials can be added through a database or user-specific material.

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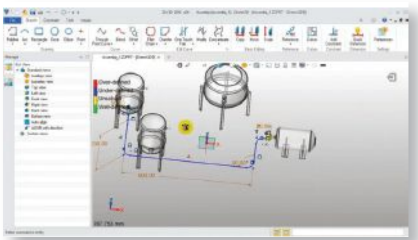

ZWSOFT Announces ZW3D 2016

Release includes updated annotation tools.

On the CAD side, ZW3D 2016 has capabilities for 3D solid-surface hybrid modeling, 2D drawing, parametric modeling and direct editing, file translation with healing/repair tools and support for all sorts of file export formats. It has tools to manage, animate and render files. Also debuting is a product manufacturing information annotation function.

CAM capabilities run the gamut from support for 2- to 5-axis machining to toolpath editing, and from draft and thickness analyses to automatic BOM (bill of materials) and hole table generation. It also has the features to calculate mass properties and stock size of geometries.

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SENSORS

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June 2016 // deskeng.com

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Bluetooth Smart: An Agent of Change

By Tom Kevan

The latest update of Bluetooth Smart, version 4.2, promises to redefine the limits of edge-device design, expanding connectivity and enabling sensor-based devices to better collect and transmit data for aggregation and analysis. A number of the new features in the specification make the technology more relevant to the Internet of Things landscape, such as changing the way that ultra-low-power devices communicate with the web. But perhaps the biggest change lies in the way the specification promotes inter-device cooperation. This capacity opens the door for ambient intelligence gathering, where electronic devices acquire and share data and perceptions among themselves to make the lives of people easier, safer and richer.

Faster is Better

The updated standard boosts sensor connectivity in multiple ways, all of which give the designer greater flexibility. It introduces a data-rate option that more than doubles data transfer speeds to around 300 Kbps and provides a 10-fold increase in the packet size. Combined, these features will enable faster, more stable firmware updates and allow designers to reduce wearable energy consumption by shortening the time required to complete transmissions.

One of the factors contributing to this performance improvement can be found in better management of connection intervals — the time between two Bluetooth Smart connection events. The specification allows connection intervals ranging from 7.5 milliseconds to 4 seconds, and it allows a Bluetooth Smart peripheral to skip a number of connection events. In so doing, it enables the device to sleep longer.

This feature allows tradeoffs among latency, responsiveness and power consumption. For example, when developing a smartphone or wearable that tracks your movements using a variety of sensors, the design engineer will usually opt for shorter connection intervals, but when developing a battery-operated instrument, the engineer might use the feature to reduce power consumption with a longer connection interval.

Go the Extra Mile

Perhaps best of all, Bluetooth Smart 4.2 makes it possible for devices to connect directly to the internet over a Bluetooth connection via IPv6/6LoWPAN. This means that Bluetooth-enabled devices can communicate directly with one another, opening the door for the gathering and use of ambient intelligence (AmI). AmI seeks to broaden the interaction between people and digital information technology through the use of ubiquitous computing devices and sensors, with an eye on improving quality of life.

The ability to connect with the internet by way of 6LowPAN will also make wearable devices more autonomous, eliminating the need for a go-between device like a smartphone. Using this new connective tissue, Bluetooth-equipped devices will be able to access app content and services via 6LowPAN networks. This feature will also allow designers to make wearable control devices for such applications as smart home appliances.

Energy and Privacy Issues

In addition to connectivity, the IoT has ramped up pressure on engineers to achieve greater energy efficiency and provide better privacy in their designs, particularly for battery-operated devices. Bluetooth Smart 4.2 helps with both issues by changing the way it resolves addresses for private devices.

Under the specification, the Bluetooth controller resolves addresses for private devices, not the host CPU. Because the CPU no longer has to engage in this process, it does not have to wake up, so it consumes less power.

Moving the functionality to the Bluetooth controller also prevents "untrusted" devices from accessing too much information on the device. Under version 4.2, other devices can access additional data only if they have been granted "trusted" status by the discoverable device.

On the Right Track

As the IoT ecosystem continues to grow, the challenge for device designers is to facilitate mass production of smaller, energy-efficient devices that can leverage expanding connectivity. Given these market forces, Bluetooth Smart 4.2 seems to be a technology that has arrived at the right time, with the right feature set.

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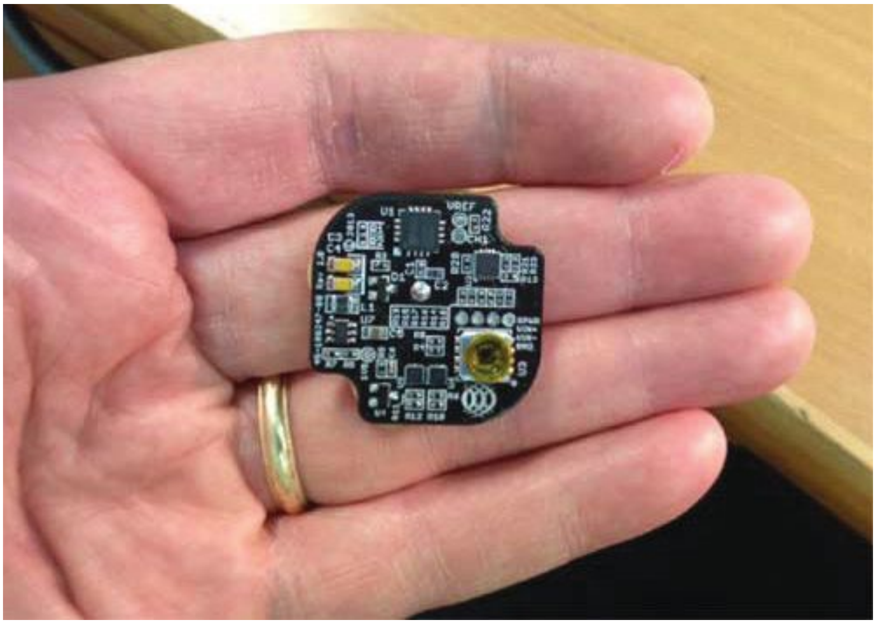
Sensor Power Primer

A new generation of smart, networked sensors requires new methods of powering themselves.

By Randall S. Newton

Sensors in factories are as common as the oil stains on the floor. For generations they have been designed to obey three rules: Be sensitive to the measured property; be insensitive to any other property; and don't influence the measured property. But, as with everything else touched by the internet, the three rules of sensors are about to be turned on their collective head.



The circuit board of a new Phase IV passive RFID energy harvesting tag. *Image courtesy of Phase IV.*

The Internet of Things (IoT) is the buzzword behind the change, and it conjures up images of washing machines sending usage data to the manufacturer's computer. But in reality, the connectivity is not really between appliances or factory equipment and a computer. The real IoT is a network of sensors attached, embedded and aimed at every kind of manufactured "thing." Those sensors are digital processors, factors of 10 more sophisticated than any analog sensor ever could be.

MEMS (micro-electro-mechanical systems) sensors are also often deployed in an IoT setup. These tiny accelerometers, gyroscopes and magnetometers represent key enabling technologies for motion tracking and location awareness in portable devices at consumer price points. And they consume as much, if not more, power than more passive sensors. (See "The Sensor Swarm Arrives" on page 26 of the March 2016 issue of *DE:* deskeng.com/de/?p=28974)

And they all need power to operate. Nobody imagines the factory of the future with wires going everywhere to power all the IoT sensors required for machine-to-machine communications. But we probably don't think about changing batteries either. The new generation of smart, networked sensors requires new methods of power.

Energy Harvesting

It is generally acknowledged that battery-powered sensor nodes cannot adequately meet all the requirements of IoT sensors: lifetime, cost, reliability and transmission coverage. Taking advantage of both heat and motion, a new generation of technologies is coming to market that convert ambient energy into electricity, giving digital sensors a built-in source of electricity. Possible power sources include light, heat, magnetic fields or motion. The field is known as energy harvesting.

According to research by Purushottam Kulkarni of IIT, by exploiting recharge opportunities and tuning performance parameters, energy harvesting sensor nodes have the potential "to address the conflicting design goals of lifetime and performance."

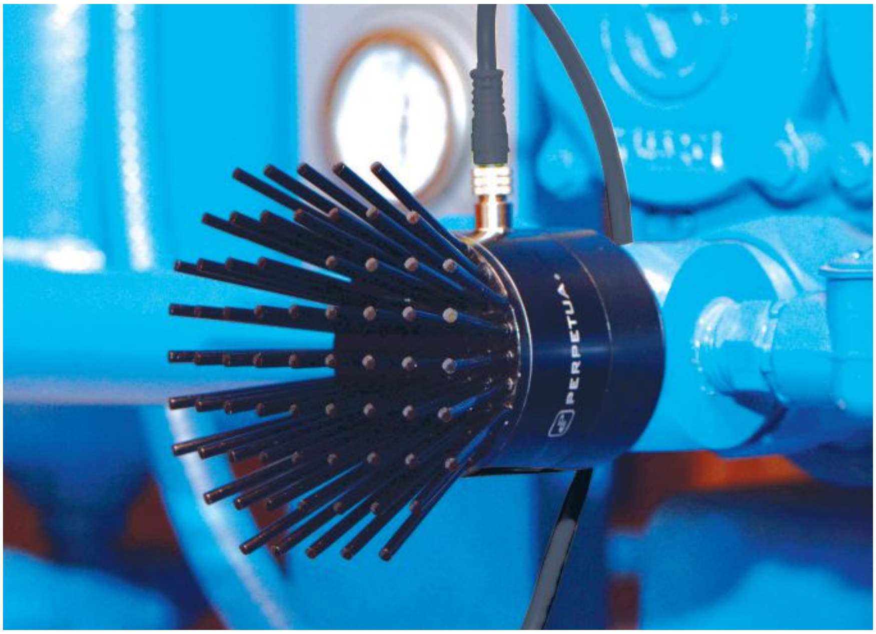
Demand for self-powered sensors is growing rapidly. According to business research firm Markets & Markets, the market for energy harvesting sensors in 2015 was $974 million; M&M expects the market to grow at a compound annual growth rate of 19% between now and 2022.

Pennsylvania State University is one of many research institutions looking into how to power the Internet of Things. Aman Haque, professor, department of Nuclear and Mechanical Engineering, says the challenge is enormous. "It is estimated that by 2025 basically everything will have its own IP address, just like our computers, and they will be able to send and receive data," Haque said. The requirement that these new digital sensor nodes send and receive data increases their power consumption. Haque and his team are researching new methods of powering digital sensors. "The challenge is how to get a very small amount of power from almost nothing," Haque said. "If we're using light, it would be very low light. If we're using heat, it would be only as hot as human body temperature."

Haque's group is focusing on harvesting energy from very low intensity sources to inexpensively power the wireless sensors. Possible power sources include light, heat, magnetic fields or motion. Side-by-side with the university research, Haque has created a startup to commercialize the energy harvesting technologies they develop.

Three-Way Hitter

One of the leaders in the nascent energy harvesting wireless sensor industry is EnOcean. The Oberhaching, Germany, company holds what may be the oldest patent on sensor energy harvesting technology. The Siemens spin-off now sells energy harvesting for motion (kinetic), solar and thermal conversion. The sensors broadcast their data in three of the most common bands, 868MHz, 902MHz, and 928MHz, for broad global compatibility. "Telegrams" from the sensors (data transmissions) are one millisecond in length at a speed of 125 kilobits per second. Each module has a unique 32-bit ID number.



The Perpetua Power Puck is a thermal energy harvester, generating electricity from changes in ambient temperature. *Image courtesy of Perpetua.*

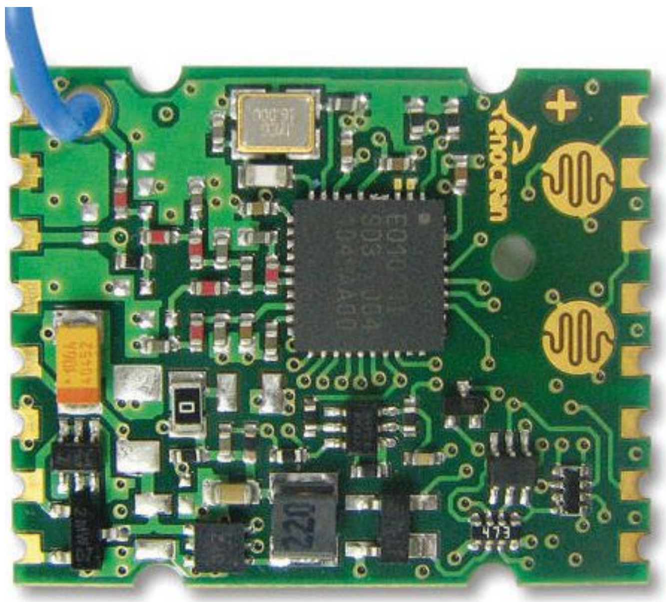
"Battery-free wireless sensors will make an entry into many different areas of our lives," says EnOcean CEO Wald Siskens.

Energy Harvesting at Chevron

At the 2015 Emerson Global Users Exchange in Denver, Chevron engineer Greg LaFramboise shared how his company uses thermal energy harvesting technology for both wired and wireless devices. Realized benefits include lower installation costs and the ability to deploy additional monitoring points. Chevron has been replacing legacy field monitoring equipment at production facilities with new wireless sensor. LaFramboise said they found the new sensors improved monitoring ability because of the new automated data acquisition. Additional trending data is now being accumulated from all the remote sensors, at a minimal cost.

But with the increased data sending comes increased power use. Some sensors report in as often as every second. Access to these sensors is often difficult, making reliance on just batteries problematic. Chevron linked their new sensors with the Power Puck thermal energy harvester from Perpetua. LaFramboise said the combination increased Chevron's flexibility for installation, as one Power Puck could provide power for three transmitters.

Deployments for energy harvesters and sensors at Chevron have included multiple wireless transmitters with a single Power Puck in steam injection fields, and powering mobile test units with Perpetua's Power Tile energy harvesters. LaFramboise said Chevron benefitted by being able to set update rates as fast as one second in the steam injection applications and eliminated large lead acid batteries in the mobile test unit applications.



Siemens spin-off EnOcean makes a variety of energy harvesting wireless sensors that run in the most common global frequencies. *Image courtesy of EnOcean.*

Lowering power requirements for sensor networks is as important as finding new sources of energy. The open-source Waspmote wireless sensor network platform from Libelium consumes only 0.07 µAin in hibernation mode. *Image courtesy of Libelium.*

"Perpetua's energy harvesting solutions for both wired and wireless instruments at Chevron overcame the limitations of batteries for steam injection and the lack of reliable remote power in the mobile test units," says Jon Hofmeister, Perpetua president.

RFID and Energy Harvesting

Radio frequency identification (RFID) is rising in use, as an intelligent but passive sensing device. An RFID tag is enabled by the radio source scanning it for data. Delta Airlines has announced its intentions to use RFID luggage tags to replace the existing barcode technology. Phase IV has long been a significant player in RFID technology. It recently brought to market energy harvesting technology adapted to RFID use.

Phase IV's energy harvesting circuit captures and stores RF energy for the sensor circuit, keeping it separately from the antenna circuit. Phase IV says it "effectively doubles the read range of the same purely passive standard tag," making it possible for more power-sensitive sensors to be deployed in any given situation.

From Sensors to Networks

As remote sensing for IoT matures, the sensors in the field will communicate with each other as well as the home base. Two European firms — Imec and Renesas Electronics — are collaborating on research to enhance ultra low power wireless technologies. The goal is to enable short-range communications for industrial and automotive applications.

Renesas has already succeeded in lowering the power consumption in its sensor radios by a factor of three over previous models, and they comply with emerging wireless standards including Bluetooth Low Energy and ZigBee.

Other vendors are also working on reducing power requirements for wireless sensor networks. Libelium sells a line of sensor nodes based on a open-source wireless network platform. More than 2,000 developers have contributed to the Waspmote platform.

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Imec: Imec.be

Libelium: Libelium.com

Pennsylvania State University: PSU.edu

Phase IV: PhaseIVEngr.com

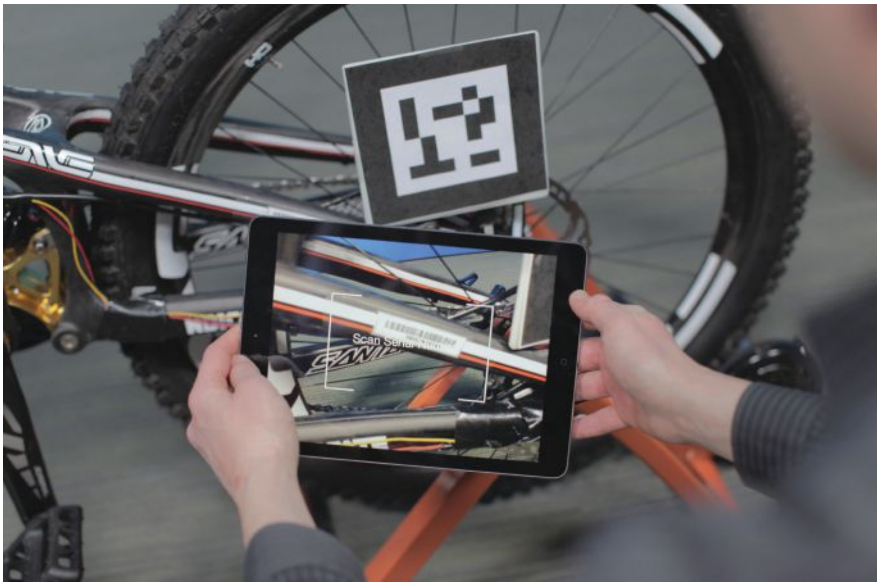
Rensas: AM.Rensas.com

Sensors Support New Data-Driven Design Workflows

Looping in-field product intelligence back into engineering workflows gives companies better insight into how to evolve product designs.

By Beth Stackpole

For every requirements document, customer survey and competitive intelligence report, design engineers are too often guided by something far less concrete — their intuition and a lot of guesswork about how a product performs in the field. This gut-level approach seems poised for big change, however, as the Internet of Things (IoT) ushers in the potential for new workflows that key design decisions to real, in-field product performance and use cases — not just supposition.



PTC plans to leverage augmented reality capabilities from its Vuforia acquisition to enhance its IoT-driven design workflows. *Image courtesy of PTC.*

According to a PwC report, *The Internet of Things: What it Means for the U.S. and Manufacturing,* 38% of manufacturers are already embedding sensors in products to collect usage and health data. Their goal is to leverage it in a variety of ways, including predictive and preventive maintenance as well as to drive future product innovations. In fact, 34% of respondents in that group said it is "extremely critical" that U.S. manufacturers infuse an IoT strategy into their digital operations as a means of maintaining a competitive edge.

For engineering, the promise of IoT is generating the data-driven feedback that can help guide future product directions, resulting in designs that are optimized for materials costs, quality improvements and more efficient manufacturing. That's a big shift from today's workflows, where engineers are often removed from any direct insights into product performance in the field other than spotty anecdotal discussions.

"For a long time, most products have been fire and forget," says Stan Przybylinski, vice president of Research for CIMdata, a market research firm focused on the engineering sector. "Engineers were lucky if they got some warranty data, which is typically old and very after-the-fact, or if a product needed to be maintained, they might get some better information. One of the promises of IoT is a better opportunity to keep track of what the physical state of a product is."

As engineers map out the next product iteration, most typically get answers to questions like, "can the product use less power," or "can this component handle more vibration," via informal discussions with people on the ground, perhaps support engineers, sales people or in the optimal case, customers. However, this feedback is based on personal experiences, not data, which means it is skewed by individual preferences and emotions, notes Brian Thompson, senior vice president of the CAD

Creo 4.0 will have built-in connections to the ThingWorx IoT platform to feed live, in-use data about products like this bike example, directly into the engineering workflow. *Image courtesy of PTC.*

segment for PTC. "Invariably, an engineer would feel a lot more comfortable knowing and answering those questions if they had insight into how their existing product was behaving in the environment they're being asked about," Thompson says. "If you could learn from the product directly, there is no filter and you get real information."

Still Early Days

Just because IoT devices have the capacity to collect a lot of potentially useful design data doesn't mean it's going to be easy to tap into that data, especially establishing workflows that loop it back into engineering and specifically, into existing 3D models created in CAD and simulation tools, experts say. For one thing, products in use in the field need to have been properly instrumented with sensors to collect the kind of data that can actually help advance subsequent designs — a bit of a "chicken and egg situation" for engineering groups just getting their feet wet with IoT, Thompson says.

Beyond sensors and connectivity, data plays a huge role in delivering design insights, and there is currently a huge gap in the skills and tools necessary to meld this element into traditional engineering solutions and workflows, experts say. Engineering, with support from the IT organization and design tool vendors, will need to build out solutions that aggregate and normalize data coming in from multiple products in the field. They will also need to construct the analytics and presentation layer necessary for transforming the data deluge into valuable insights while delivering them in a way that's compelling and readily accessible to the average design engineer.

While CAD and simulation vendors are doing their part to evolve their product lines to address these issues, most of the early IoT-led design workflow is falling to internal engineering and IT groups, which are being tasked with a lot of heavy lifting in the areas of integration and customization. "This is not mainstream — it's for bleeding edge early adopters who are willing to do a lot of integration work themselves," says Mark Hindsbo, vice president of marketing for ANSYS. "It's not out of the box, and it's a project every single time."

Understanding the strategy for the smart connected product as well as exactly what you want in terms of collected data is the first step towards mapping out these new design workflows, notes PTC's Thompson. Knowing, for example, that the thermal performance of a product in the field might be critical for future design enhancements is central to creating a sensoring strategy and leads directly into the next step, which is

An example of how GE Predix and ANSYS can work together in assessing the environmental, health and safety impact of a plume dispersion from a potential gas pipeline rupture (left); detecting anomalies (top right) and realizing the digital twin of a blowout preventer (bottom right). It's virtual diagnostics/root cause analysis and prognostics/lifting. *Images courtesy of ANSYS.*

figuring out what to do with the data once it's collected.

Consider a design team that takes its lead from marketing requirements that specify that a front loader product portfolio be able to universally support a load of 1 ton, says Thompson, providing an example to illustrate his point. Data collected from front loaders out in the field, however, reveals that units used in specific parts of the world rarely carry a load greater than 500 pounds, which means the product is being overdesigned. "It starts with getting your feet wet, understanding the value of the data and then using it to inform a strategy for designing the next iteration," Thompson explains. "Now you can design a more optimized front end load assembly to handle that load, which reduces cost and still meets customer requirements."

Vendors At Work

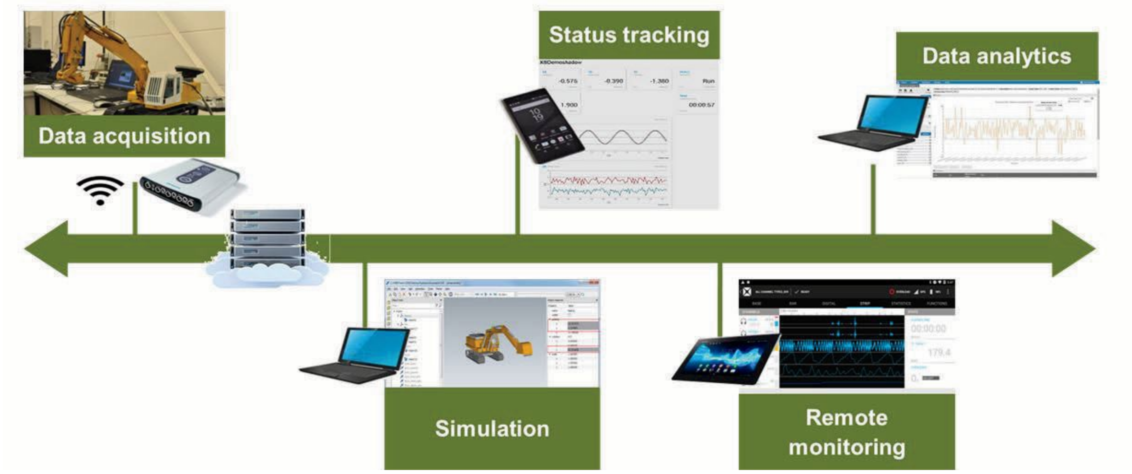
To help facilitate such workflows, PTC is actively building "plumbing" into Creo that will make a connection to the ThingWorx IoT platform and API (application programming interface), Thompson says. Slated for delivery in Creo 4.0, these capabilities will formalize what PTC has been demonstrating on the road: A sensor-equipped bike feeding real-time usage data such as wheel speed and suspension pressure as it's ridden directly into a Creo digital model of the bike by way of the ThingWorx platform. While the demonstration shows the power of a digital twin collecting data from one specific bike, PTC envisions data being collected from hundreds, maybe thousands, of bikes in the field, brought into ThingWorx and condensed down to a couple of critical design insights, which are then fed back to the engineering team via CAD.

"The ThingWorx layer could represent a summary of performance of 10,000 bikes averaged out over five weeks," Thompson says, explaining the need for a step that would boil that fire hose of IoT data into something useful for the design engineer. "A data aggregation step has to occur if you want true product population data instead of single, one-to-one connection." As part of that effort, Creo's ThingWorx API could also cull data from other enterprise systems like PLM (product lifecycle management) or CRM (customer relationship management) in addition to physical IoT-enabled products, he adds.

Siemens PLM Software plans to leverage its acquisition of the LMS testing and simulation software to retool its CAD and Teamcenter PLM products to handle in-coming sensor data, according to says Peter De Clerck, director of Business Segment at Siemens PLM Software. LMS' experience with incompatible data formats due to range of testing devices the software supports, coupled with its ability to process massive quantities of test data, are key assets in Siemens' plan for dealing with the disparity and scope of big data emanating from sensored products, De Clerck says.

"With that part of the Siemens portfolio, we are already working with sensor data, not coming from IoT devices, but coming from instruments," he explains. "We do a lot of time data manipulations, we do durability testing, and we calculate the fatigue life of components — that type of analysis isn't much different than the type of analysis with IoT."

In addition to the LMS simulation software, Siemens' Omneo Performance Analytics cloud-based platform, gleaned from its Camstar acquisition, along with recently acquired CD-adapco simulation software and its Teamcenter PLM backbone, will be central in melding IoT data into design workflows. "To close the loop, you need a backbone that has traceability across everything, including the IoT data," says Ravi Shankar, director for Simulation Product Marketing at Siemens. Instead of storing a massive database in a backbone like Teamcenter, you also



Siemens PLM Software's Predictive Engineering Analytics strategy aims to leverage data from multiple sources coupled with analytics to improve product designs. *Image courtesy of Siemens PLM Software.*

need capabilities for reducing the data in intelligent ways and then only storing what's necessary to help the next iteration of the design, he explains.

At Dassault Systèmes, the CATIA Systems modeling tool, EXALEAD Big Data search and analytics tool, and the 3DEXPERIENCE platform are the core building blocks of its strategy for integrating IoT data directly into the engineering workflow, according to Olivier Ribet, vice president of High Tech Industry. In addition, Dassault is committed to keeping an open platform approach and forging key alliances with partners in the IoT space, Ribet says. "IoT is fantastic in the sense that it continuously helps engineers do the right engineering — not under-engineer or over-engineer," he says.

For its part, ANSYS is doubling the surface of its open APIs across its entire product line and steering more solutions to the cloud to foster IoT data-driven design workflows. "Today, CAD, simulation and PLM are more point solutions than an integrated workflow so you might be able to exchange data or import data, but having fully open APIs and pre-built workflows is different from sending flat files back and forth," explains Hindsbo. By opening up APIs across 80% to 85% of its product set and by building pre-built connections to IoT platforms like GE Digital's Predix, ANSYS hopes to facilitate a data-driven design workflow that automates a lot of the process, including feedback insights back to engineers, as opposed to requiring custom integration, he says.

Putting cloud capabilities in place to support on-demand simulation bursts, instituting new elastic licensing terms, and building additional security and encryption capabilities into its offerings to protect simulation model IP (intellectual property) are other areas ANSYS is pursuing to address existing challenges to IoT-driven design workflows.

TRUMPF, a manufacturer of general purpose machines that cut sheet metal, is already leveraging live data collected from its equipment in use in the field to inform future design decisions as opposed to operating off assumptions, according to Stephan Fischer, head of the Software Development for the firm. Leveraging an IoT connectivity platform from C-Labs, the company is collecting in-field data, which is providing reliable evidence about how products are actually used and how they perform. "Knowing which material the customer prefers helps us to develop more specialized machines," he says.

TRUMPF enforces the new data-driven design workflow by upholding an expectation that engineers don't make any product decisions without comparing assumptions against in-field data. "This evidence-based decision making ensures that we focus on customer value based on reality, not assumptions, when iterating product designs," Fischer says.

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UAV Design Challenges: **Game On**

Sensors are helping engineers address drone operating requirements.

By Jim Romeo

Imagine this: You go online, order a pair of shoes and have it delivered to your door in 30 minutes. But the delivery vehicle isn't a human driving a truck, car, or motorcycle. It's an unmanned aerial vehicle (UAV). Sounds like science fiction, but it is quickly becoming reality.

Amazon Prime Air is working to offer delivery services via UAVs, getting products to consumers faster. *Image courtesy of Amazon.*

Amazon Prime Air — the company's proposed package delivery service of the future, will deliver packages up to five pounds in 30 minutes or less using small drones. According to Amazon, the UAVs will fly under 400 ft. and take advantage of sophisticated "sense and avoid" technology, as well as a high degree of automation, to safely operate beyond the line of sight to distances of 10 miles or more.

Amazon's announcements have encouraged others considering drones for this type of use, and many others.

According to market research conducted by the firm Tractica, drones are expected to grow in number from about 80,000 units today to nearly 2.7 million in 2025. They expect this surge in drone production and use could generate revenues of $8.2 billion annually.

For many design engineers, this is a whole new arena. Within it are components that make it go: highly engineered sensors that use wireless channels. Designers will test their innovation savvy by creating UAVs that meet the limitations of size, weight and power. Their efforts could mimic the ingenuity of Orville and Wilbur Wright as they pioneered flight, against the odds, over 100 years ago. However, design engineers face many challenges in the incorporation of sensors in UAV design.

SWAP: Size, Weight and Power

According to Raghvendra Cowlagi, assistant professor in the Aerospace Engineering Program at Worcester (MA) Polytechnic Institute, the main challenges are summarized in what is called SWAP: size, weight and power.

"Bulky sensors introduce undesirable aerodynamic drag," he says. "Heavy sensors can cause undesirable shifts in center of gravity location, which in turn can cause instability during flight, and call for expensive design modifications to produce additional lift to sustain the heavy sensors, or reduce the amount of fuel [or] size of batteries that can be carried — and consequently reduce duration of flight. Similarly, sensor power requirements directly and adversely affect the UAV flight time, because all power supplies, either batteries or fossil fuel engines, must obviously be carried onboard."

Dr. C. J. Reddy, vice president of Business Development for Electromagnetics at Altair, also sees SWAP as the pervasive challenge. "Most of the UAVs are usually much smaller than any other platform — fixed wing aircraft or rotorcrafts," he says. "And also [the] size of UAVs are decreasing to make them more viable for commercial use. This limits the real estate on the UAV to place different sensors. Weight of the sensor contributes to fuel consumption and power requirement adds to the battery power and size of the battery onboard."

Another option is to build larger drones, such as the SB1 that SkyBridge UAS designed and is initially being used for precision agriculture applications. The SB1's fuel-injected engine and on-board generator provides up to 60W of electrical power for avionics and sensors, according to the company. At the Siemens PLM Connection conference last month, SkyBridge COO Ian Henderson said the multi-spectral infra-red sensors used in precision ag only account for about 2 lbs. of payload, leaving an additional 20 lbs. of payload that can be used for other sensors. SkyBridge engineers used Siemens PLM Software's Solid Edge to design the SB1 to accept pods of different sensors so it can be easily adapted for different uses.

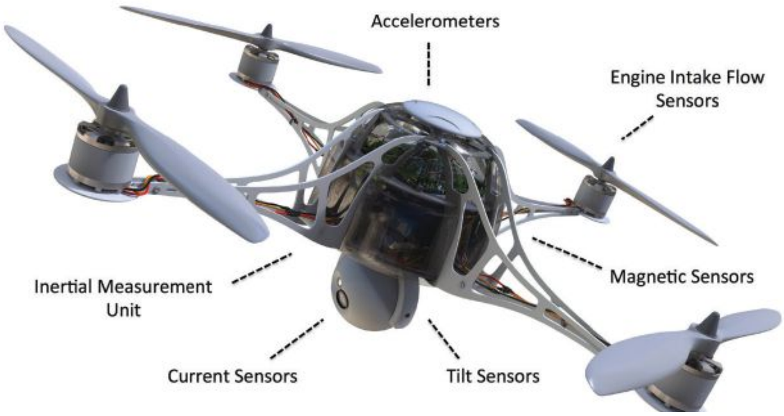
Connectivity

Connectivity poses another set of challenges. The wireless channels by which UAVs operate can be a limiting factor when deploying them.

According to Derek Campbell, a senior applications engineer at Altair, wireless connectivity is rapidly expanding in both popularity and potential, and will be useful in connecting with UAVs and their sensors via antenna arrays.

"Incorporating antenna arrays on both ends of the wireless channel realizes this potential by facilitating beam steering and increased directivity. From an operations vantage point, these capabilities reduce transmit power, increase data rates and extend communication range," says Campbell. "Antenna arrays also facilitate forming nulls toward antagonistic regions to hide information and thwart easily accessible jamming devices."

Campbell adds that these performance characteristics of antenna arrays address several critically important challenges for UAV operation. Maintaining wireless communication channels over extended ranges that can potentially cross into antagonistic regions helps accomplish precise, adaptable mission objectives. In addition, efficiently utilizing power, a scarce commodity often drawn from solar panels, facilitates extended flight durations. Finally, the reduced transmit power also reduces the aircraft weight that can further extend flight duration.



Each UAV requires a multitude of sensors to provide operating feedback and collect in-flight data. *Image courtesy of MEMSIC.*

Integration and High Performance

As a way to address various UAV operating requirements, some engineers may turn to higher levels of integration, notes Chris Winkler, senior product manager for Emerging Markets at MEMSIC in Andover, MA. MEMSIC provides component and systems solutions for a variety of advanced sensing applications.

"There are many performance benefits to integrating common circuits and sensors on monolithic ICs (integrated circuits)," he says. "For example, devices can often achieve better symmetry — not pulling units from different wafer lots, smaller parasitic effects on performance due to elimination of extra connections and wire bonds. There can also be optimization of trimming and calibration by devices being integrated and on-chip rather than discretely connected."

Winkler adds that the greatest impact of integration comes from improved cost structures and reduced component size. The ability to shrink devices and place them into smaller form factors, with lower weight, is critical to SWAP and expanding their reach and growth.

According to Phil Solis, research director of Semiconductors and Strategic Technologies at ABI Research, sensor designs and overall UAV design will be ramping up to meet the demands of high performing UAVs. He predicts that you will see more semiconductor vendors doing what Qualcomm did – reworking smartphone-integrated platforms and sensor hubs to be used for UAVs as well as other robotic products.

"These markets are experiencing explosive growth with new applications rapidly appearing at a break-neck pace," says Winkler. "Consider that drones and UAVs will replace many functions that humans perform today – and doing them more reliably and ideally more safely: Delivery of medical supplies, surveying and monitoring in remote hazardous locations and law enforcement to name a few."

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Worcester Polytechnic Institute: WPI.edu

NEW SENSORS

1 ABB Releases Smart Sensor for Monitoring

The smart sensor provides information on operating and condition parameters and calculates power consumption for low-voltage motors. The data is analyzed by a software program and provided to a plant operator via graphics for maintenance planning.

It enables downtime reductions of up to 70%, according to ABB. At the same time, the lifetime of the motors can extended by up to 30% and energy consumption reduced by as much as 10%, says the company. The sensors can be installed at the factory or retrofitted on already operating low-voltage motors.

"This innovative solution makes condition monitoring the new standard for low-voltage motors," says Pekka Tiitinen, president of the ABB's Discrete Automation and Motion division. "Optimized maintenance schedules help reduce maintenance costs greatly. Unscheduled outages are reduced considerably or even eliminated completely. Increased availability significantly boosts our customers' productivity."

ABB.com

Tekscan Launches OEM Development Kit

The kit combines a MicroView display module, USB programmer interface, and analog front-end FlexiForce Quickstart board. This package, along with open-source software and two FlexiForce sensors, results in a development solution that enables engineers to test how FlexiForce sensors will behave in specific product or application environment, the company says.

"We're excited that this tool will help reduce design and development time by offering a quick and easy proof-of-concept solution," says Mark Lowe, vice president of Sensors at Tekscan.

Tekscan.com

2 SICK Ships 3vistor-T, a 3D Vision Sensor

According to a company press release, the 3vistor-T vision sensor features 3D-snapshot time-of-flight technology that provides real-time depth information for each pixel, even for stationary applications. The output can be either pure 3D raw data or reduced data, depending on the application requirements.

The 3vistor-T can record up to 30 3D images per second for distance values of 144x176 pixels per snapshot and features a depth reproducibility of 3 and 30 mm at 1 and 7 m distances, respectively. The 3vistor-T captures more than 25,000 distance and intensity values in a single shot, which means that no actuator is required. In addition, the sensor has an IP 67 enclosure rating and is resistant to sunlight up to 50 klx.

SICK.com

New Accelerometers Available from IMI Sensors

The devices are designed for predictive maintenance vibration monitoring. The new IMI Sensors offerings are:

- Model 601A92 is a 500 mV/g ICP accelerometer with a measurement range of ±10g and a frequency range (±3 dB) of 0.17 to 10,000 Hz. The sensor is housed in a 316L stainless steel housing with ¼-28 female mounting thread and top exit connector.
- Model 602D91 is a 100 mV/g ICP accelerometer with a measurement range of ±50g and a frequency range (±3 dB) of 0.5 to 8,000 Hz. The sensor is housed in a 316L stainless steel housing with ¼-28 male mounting thread in thru-bolt design and side exit connector.
- Model 603C91 is a 100 mV/g ICP accelerometer with a measurement range of ±50g and a frequency range (±3 dB) of 0.5 to 10,000 Hz. The sensor is housed in a 316L stainless steel housing with ¼-28 female mounting thread and top exit connector.

IMI-sensors.com

3 Sensirion Releases New Temperature Sensor

The STS3x temperature sensor is based on the same chip as the SHT3x humidity sensors and comes in a tiny eight-pin DFN package measuring only 2.5 × 2.5mm^2 with a height of 0.9mm.

Its tiny size and the wide supply voltage range of 2.4 V to 5.5 V allow for integration in a variety of applications. The sensor delivers outstanding performance and a remarkably high accuracy of +/–0.3°C over an extensive temperature range combined with low power consumption — an especially important consideration for battery-operated devices, the company states. It is based off of CMOSens technology, has user-selectable I2C addresses and communication seeds of up to 1MHz.

The STS3x is suited for data logger and temperature condensation applications. It can also be used in wearable devices, automotive components and HVAC use cases.
Sensirion.com

Quanergy Systems' New LiDAR Sensor

The S3-Qi has a 1x1.5 in. footprint, weighs about 100 grams and has low power consumption. The small form factor and cost-effective design make the S3-Qi suited to multiple applications including drones, intelligent robotics, security, smart homes and industrial automation, the company says.

"The S3-Qi is a testament to our focus on the user and our investment in innovation for game-changing smart sensing solutions offered at price points that make their use ubiquitous," says Louay Eldada, Quanergy CEO.
Quanergy.com

4 Humidity and Temperature Sensors

An integrated, proprietary coating protects E+E Elektronik's new sensors from pollution and leads to long-term stability even under harsh conditions, according to the company.

Precise humidity and temperature factory adjustment ensures a high accuracy of ±2% RH and ±0.3°C. The measured values are available on I²C, PWM and PDM digital interfaces. Additionally, EEH210 features an SPI interface, while EEH110 offers an analog output for relative humidity. The choice of supply voltage, 5 V for EEH110 and 3 V for EEH210, increases the versatility of the sensors. The sensors measure 3.6x2.8x0.75mm.
Epluse.com

OCEASOFT Creates LoRA-Enabled Sensors

The devices were created as part of the LoRa Alliance, which seeks to standardize long-range, low-power wireless networks. The sensors can cover temperature ranges from -200 to +200°C and feature increased precision and ease of use.

"The emergence of new long-range, low-power wireless networks will enable customers to deploy our connected smart sensors faster and more easily," says Laurent Rousseau, CEO of OCEASOFT.
OCEASOFT.com

5 MEMSIC Launches New Magnetometers

A series of AMR magnetometers targets mobile device designers and manufacturers, along with other industry verticals requiring high performance motion sensing, the company says.

The family includes an integrated monolithic 3-axis AMR sensor and a signal conditioning ASIC into an 1.2x1.2x0.5mm BGA package. It has a ±30G range, 600MHz sensing bandwidth, self-degaussing capabilities and low system level power consumption and processing time.
MEMSIC.com

Exar Corporation Ships XR18910 Sensor Interface

The device measures 3.5x3.5mm, offers 14-bit signal path linearity and is designed to connect analog sensors to a microcontroller or FPGA (field-programmable gate array) with an embedded ADC.

The onboard 10-bit DAC (digital-to-analog converter) offers ±560mV of offset correction and allows an independent offset value for each of the eight differential inputs. The programmable gain instrumentation amplifier offers eight fixed-gain settings (from 2V/V to 760V/V), ensuring the amplified sensor signal falls within the optimum input range of the downstream ADC, according to a press release.
Exar.com

6 TT Electronics Introduces TPL Series

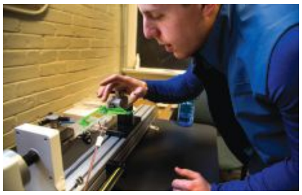
The TPL product family is suited for industrial automation, hydraulics and pneumatics, agricultural and off-road vehicle, HVAC, water treatment and general instrumentation sectors.

The TPL series pressure transmitters offer a ratiometric output 0.5V to 4.5V and a ±0.25% non-linearity, hysteresis and repeatability specification (BFSL) over a wide operating temperature range of -40° to +125°C. Gauge pressure is detected using a four-arm, active strain-gauge bridge incorporating highly stable resistors, according to the company. The resistors are fused to a high purity ceramic element and changes in pressure on that element result in bridge voltage changes, conditioned by on-board processing electronics.
TTElectronics.com

Sensing Ship Damage

3D printing helps students develop low-cost sensors for the U.S. Navy.

By Gabe Cherry



A 3D printable strain sensor developed by University of Michigan researchers could provide the U.S. Navy and commercial shippers with a more accurate, less expensive way to assess damage to their vessels, helping to keep sailors safe in the aftermath of an attack, storm or other incident.

Called the Strain Application Sensor, or SAS, the first-of-its kind device detects tiny flexing movements in the metal parts of ships — movements that can alert crews to damage before cracks or other visual signs can be seen by the naked eye. This can be vital information when a ship has been damaged and crews need to quickly determine what to do next.

"If we can measure how much a given part is flexing, we can predict a failure before it happens," said Mark Groden, one of the sensor's creators.

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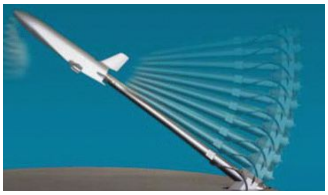
Perfecting Wind Tunnel Balances

Triumph Force Measurement Systems relies on Micro-Measurements' sensors to ensure accurate wind tunnel testing.



Designers of devices ranging from aircraft to wind turbine blades to helmets must understand the effects of wind currents on performance and efficiencies. Smoke trails can illustrate how the wind passes over and around an object, but can't determine the forces exerted by the wind on the object. For that, strain gage wind tunnel balances are required — extremely complex, six-degrees-of-freedom transducers to which models are mounted to determine behavior during wind tunnel testing. These transducers can cost as much as $40,000 and take up to a year to design, fabricate, and calibrate.

Strain gages must not only be exceptionally small, but must also be robust and reliable once installed.

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Bringing On-Board Computing to Robotics

Stanley Innovation integrates sensors for a navigation-oriented robot.

When Stanley Innovation was approached by a world-renowned research university wanting to develop a robot that could perform a variety of navigation tasks, the solution was obvious: Build a Robotic Mobility Platform (RMP) compatible with Robot Operating System (ROS), with top-notch sensor technology.

The request from researchers challenged Stanley engineers to create a mobile robot not only capable of performing at a high level in today's research laboratories but also to provide a foundation for researchers eager to tackle next generation navigation algorithm research. Stanley's solution was a ROS-compatible Segway RMP integrated with the sensors required for the requested navigation capabilities.

MORE: deskeng.com/de/?p=30323

Saw Mill's Positioning Sensors Cut Costs

Technology decreases downtime for Arauco's machine maintenance.

By Matt Hankinson

In industrial-scale sawmills, dozens of machines debark, cut and sand lumber at intense speeds. As the demand for engineered wood grows, these Composite Panel mills face increasing pressure to maximize space and cut costs while maintaining a safe workplace. To meet these needs, engineers at Arauco, a leading producer of engineered wood products, have implemented new solutions.

Arauco replaced a traditional encoder system with a Temposonics R-Series Model RD4 sensor from MTS Systems Corp., Sensors Division. It eliminated downtime and expense associated with changing belts prematurely due to damage.

MORE: deskeng.com/de/?p=30315

3D Printing with Composite Materials

Make stronger, lighter parts with a variety of additive manufacturing options.

BY PAMELA J. WATERMAN

Just a few years ago, any article focused on 3D printing with composite materials was a fairly short piece. Now, the same subject could possibly fill a magazine, given the recent wave of materials and systems developments aimed at 3D printing stronger and lighter parts.

Parts made from carbon fiber reinforced plastics (CFRPs) have been used for decades because of their high strength-to-weight ratios; polymers such as nylon and fillers such as fiberglass are also widely used. However, traditional composite-manufacturing processes often involve hand lay-ups and require post-processing such as autoclaving and vacuum-molding. Such tasks can demand higher skills and greater costs than working with standard plastics or metals. Because designers are always looking for stronger materials to use with 3D printing/additive manufacturing (AM) systems, it is no wonder that this material concept is getting increased attention. *DE* takes a look at AM composite handling systems and materials now available or coming soon, as well as at efforts in supporting areas.

Hardware for 3D Printing with Composites

The A2V2 by Italian manufacturer 3ntr is a fused filament fabrication (FFF) system whose wide operating temperature range (up to 410°C) allows it to run several composite filament types including nylon/carbon and PA66 nylon/glass. With a print volume of 24.4x13.7x19.2 in. it is targeted to industrial production. Plural Additive Manufacturing carries the system in the U.S.

Cincinnati Incorporated (CI) has made headlines in recent years for its Big Area Additive Manufacturing (BAAM) extrusion equipment, which has been run mostly with carbon fiber reinforced ABS (acrylonitrile butadiene styrene) plastic composite

Wingtip 3D-printed with Arevo Labs composite materials. *Image courtesy of Arevo Labs.*

Sample high-strength parts, including ball-joints, 3D printed from continuous carbon fiber reinforced nylon on the new industrial Mark Two system from MarkForged. *Image courtesy of MarkForged.*

Carbon fiber composite folding drone propellers, with finished surfaces, built on an Impossible Objects composite-based additive manufacturing (CBAM) system. *Image courtesy of Impossible Objects.*

materials. The company worked with Local Motors to 3D print both the Strati car and the Shelby Cobra reproduction, a kick-off to a planned line of community-designed, locally produced vehicles. According to Matt Garbarino, marketing manager for CI, Local Motors now owns three BAAM systems, including one at Local Motors' headquarters in Chandler, AZ, and one being installed at its National Harbor, MD, Microfactory. Garbarino says the rate of improvements for the system, materials and programming software is very fast right now; another one of their customers, SABIC IP, is devoting its machine entirely to material development. SABIC's THERMOCOMP chopped carbon fiber compound was used to build the Strati vehicle.

Also operating in the FFF additive manufacturing space, but addressing the need for "medium-sized" parts is Cosine Additive. Founded in 2013, the company even terms its AM1 system a MAAM — a take-off on CI's BAAM — offering a build volume of 43x33x35 in. Andrew McCalip, CTO, stated that his company is specifically pursuing the molding and forming market: The AM1 system is designed to produce composite-based tooling to produce economical first articles. "We've found huge value in compounding mostly carbon fiber (in polycarbonates); it vastly increases the stiffness of the mold. We're able to use less material and still meet the heat deflection requirements and the pressure requirements of these forming processes," he explains.

McCalip says ultimately their forms are compared to aluminum molds; with a high enough fiber content, composite molds achieve similar compressive yield and stiffness. The company is agnostic to what flows through the AM1 nozzles, but has worked with glass-filled nylon and is looking into using higher-temperature polyphenylsulfide (PPS) with higher carbon fiber content to be a drop-in for Al 6061.

Having made a big splash at last year's RAPID show, Impossible Objects continues to develop its composite-based additive manufacturing (CBAM) technology based on a unique layering process. A proprietary, low-viscosity fluid is jetted in a CAD-directed pattern onto thin sheets of carbon fiber, Kevlar, fiberglass or other fiber material. A thermoplastic powder (e.g., nylon PA12, high density polyethylene, PEEK) is deposited and adheres just to the wetted areas. The complete set of layers is compressed and heated, melting the thermoplastic and creating a fully dense part once excess material is removed. Functioning currently as a service bureau, Impossible Objects is working on a beta program for production machines, touting the process' speed for creating strong, complex AM parts.

This past March, MarkForged, developer of the first continuous composite fiber filament AM systems, introduced the Mark Two, replacing the Mark One. This improved model can lay carbon fiber (alongside nylon) in volumes 15 times smaller than the Mark One, producing smaller parts that are even stronger and bigger parts that are stiffer near edges and corners, all at a 40% faster speed. The Standard system prints with two choices of composite — fiberglass and carbon fiber; the Professional model can also use continuous Kevlar fibers; and the Enterprise version adds the option of new high strength, high-temperature (HSHT) fiberglass. The latter is the first in a series of new materials that will be coming out this year.

Greg Mark, founder and president of MarkForged, says that the Mark Two features a new print head, electronics, software and stainless-steel drive mechanism, optional telemetry monitoring and other improvements aimed at keeping customers up and running when using these challenging, abrasive composite materials. "Everything in [the Mark] Two is hardened compared to the One, and in the Enterprise kit, everything [in the print head area] is hardened more than the rest," he notes.

Composite AM Materials

Several companies have decades of experience developing composite AM materials for laser sintering (LS) AM systems such as those from 3D Systems and EOS. Advanced Laser Materials (ALM), a wholly owned subsidiary of EOS, continues to develop laser-sintering plastics including versions of PA11 nylon (filled with carbon or glass fiber) and PA12 nylon (filled with aluminum, glass spheres or fibers of carbon, glass, or miner-

Software for Optimizing 3D-Printed Part Properties

When Arevo Labs was founded, "our vision was to produce production parts [from composites]," says Hemant Bheda, the company's president. Arevo Labs developed a family of high-strength composite filaments with a range of properties, but that solved only part of the problem. "AM offers freedom to make parts in many different ways — even 10,000 ways," notes Bheda, "but what is the best way? We realized that we needed some software tool that would predict the properties so we could optimize the design and the orientation; otherwise, we would be building parts blind."

Bheda says this had never been done before, but they are now developing a product called AFEA that does just that. This software, based on a finite element analysis algorithm, runs on Windows, Mac and the cloud, and will support engineers to control fiber-orientation while taking advantage of the unique design freedom of AM. "We want engineers to explore designs, asking 'can I get this end-property' and making a test part to confirm the calculations." Arevo Labs is working with a set of strategic partners toward an initial software release in Q3 2016.

The need for simulation/optimization software is widely recognized for making 3D printing viable as true manufacturing: producing parts with desired, predictable and repeatable results, whether one-off or in volume. Other companies ranging from Avante Technology to Dassault Systèmes' SIMULIA are tackling this challenge, so stay tuned. – *PJW* als). CRP Technology is well known for its high-performance Windform powders; the product line includes polyamide-based materials that offer high strength, high stiffness, waterproof/water-resistant performance and/or flexibility. And for stereolithography (SLA) systems, look to DSM Somos' PerFORM, a ceramic plastic resin that produces stiff, off-white, high-temperature-resistant parts ideal for injection tooling and wind-tunnel testing applications.

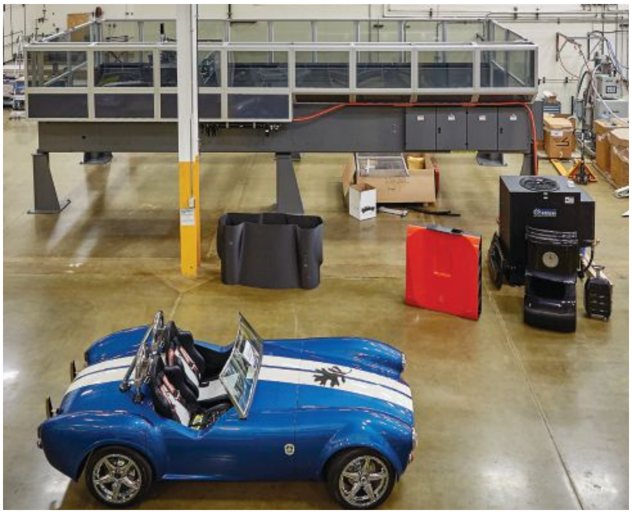
Back in the FFF realm, Arevo Labs of Santa Clara, CA, has not only developed a family of proprietary composite thermoplastic filaments but has a number of related projects underway. Currently available are Katevo (high-strength PEEK/carbon fiber), Quantevo (PAEK/carbon fiber or carbon nanotube) and Xanevo (PARA/glass). The company sees interest, for example, in the electronics industry because test-jigs made from Quantevo with carbon nanotubes provide electrostatic-discharge (ESD) protection, and in the medical field because parts made from Xanevo, due to its stiffness, can serve as economical, single-use replacements for metal surgical guides.

"We are developing continuous-fiber-based composites that will be announced later this year. These materials, in conjunction with our software, will enable 3D printing large aerospace and industrial parts with comparable strength to metal but at one third the weight," says Hemant Bheda, president of Arevo Labs. Last year the company also started offering a turn-key 6-axis robotic 3D printing platform; the ultimate goal is to define a build process that continuously re-orients a part to avoid the need for support material (see youtu.be/67x9dhrJlgw).

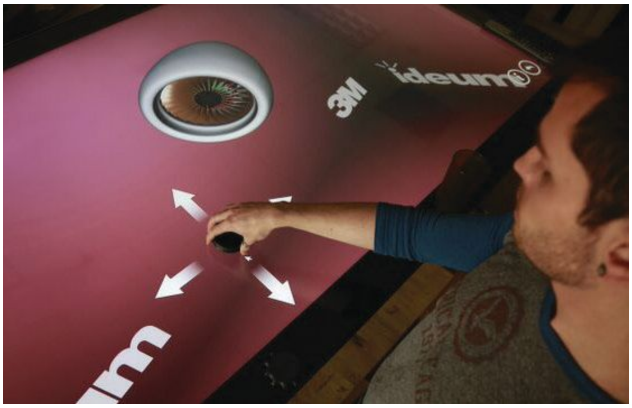
Almost two years ago Avante Technology announced its first product in a line of engineering grade AM materials, FilaOne GREEN Advanced Composite filament, designed for use in cost-saving desktop 3D printers. The company says this proprietary material is stronger and more resilient than ABS and PLA (polylactic acid), safer and easier to print than ABS or nylon (with no harmful out-gassing), and is not affected by moisture or humidity. FilaOne GREEN prints at 210 C and will also degrade in landfill.

The company has now introduced FilaOne GRAY, a tough yet flexible filament that is also hydrophobic, prints at 220°C and has been shown to be highly chemical resistant. Avante Technology president Bob Zollo says: "One of the unique properties of this carbon-nanotube-reinforced material is its combination of high flexural strength with high resilience; it recovers with minimal crazing or cracking under heavy loads." He adds, "The industry needs hundreds of new materials and formulations. We're trying to develop a line of materials that produce 'real' parts on affordable systems." The company also markets print-bed adhesion sheets optimized for each of its filaments and Emendo STL file repair/validation software.

Graphene 3D Lab has seen a very positive response to its composite materials for 3D printing. An impressive application of its graphene filament is capacitive-touch interactive devices for Ideum smart-tables, such as used in the guided wine-tasting experience created for JCB Tasting Salon in Yountville, CA; this employs 3D-printed capacitive bases on the wine glasses to trigger changing information displays (goo.gl/9YQ5ZR). A more engineering-related example is a 3D-printed joystick or stylus unit that allows users to interact with 3D CAD files on Ideum displays (youtu.be/2sYFscup0Dk). Conductive circuitry and EMI/RF shielding are additional applications.



Finished Shelby Cobra car plus as-built parts, 3D-printed from composite filament on the Cincinnati Inc. Big Area Additive Manufacturing (BAAM) system; design by Local Motors. ***Image courtesy of Cincinnati Inc.***



A 3D-printed joystick, made from Graphene 3D Lab's conductive filament, provides a capacitive connection to an interactive smart-table display. ***Image courtesy of Graphene 3D Lab.***

The company recently announced a PLA/iron filament that is magnetically conductive, suited to making switches, sensors and actuators. In addition, Graphene 3D Lab has several divisions working on a variety of advanced technology projects targeted to next-generation 3D printers. "We make advanced materials for 3D printing and outside of 3D printing. To keep

Medium Area Additive Manufacturing (MAAM) filament-based system from Cosine Additive is pictured. The company is particularly targeting the molding and forming market with this system that runs high-fiber-content composite materials. *Image courtesy of Cosine Additive.*

the excitement and challenge, we want to make not only static objects, but get to where we can 3D print electronics, light sources, batteries, and so on. We are not limited to filaments; future 3D printers will combine different techniques," says Elena Stolyarov, co-CEO and president of Graphene 3D Lab.

In a Class of Their Own

Of course, Stratasys offers what can be considered composite material options, with its Connex3 PolyJet Digital Materials technology creating parts with varying properties in real time during a print run. But if you think you're aware of all possible approaches to 3D printing in general and using composites in particular, you may have to think again.

Consider the medical implant company Amedica of Salt Lake City, UT. In 2008, it received 510(k) clearance from the FDA for the first spinal fusion device made from silicon nitride. The company is now in the first phase of working with this proprietary ceramic composite in slurry form, using a robotic deposition (3D fabrication) process to create other implants (e.g., spine, knee, hip). Mike Houston, vice president of Commercialization for Amedica, says the project's phase-two goal is to generate parts with greater resolution, enabling them to 3D print finer products such as dental implants. "Our third phase is to improve the process to make porous silicon-nitride implants, and not just for orthopedic applications. To be able to 3D print and customize a resorbable scaffold for reconstructive surgery that is load-bearing, bone-friendly and anti-bacterial — we're excited about what the future holds in that realm," he says.

Aeroprobe, based in Christiansburg, VA, is progressing from a quiet nine years of R&D into the commercialization phase of its additive friction-stir deposition technology. Company CEO Nanci Hardwick explains that this process, developed in general about 30 years ago, produces results similar to those of other solid-state processes. "Any time you're not melting metals," she says, "it has benefits. People who develop metal powders know that rapid solidification offers higher strength; if you melt it, you lose that strength."

The Aeroprobe system supports building really large parts at a high deposition rate, feeding from two material hoppers. The company has worked with a wide range of base materials such as magnesium, aluminum, steel and nickel alloys, plus solid or powder reinforcement materials such as silicon carbide, tungsten, tantalum and niobium. Hardwick points out that this is an open system, and her company will work with customers to optimize parts either for strength or ductility. Quoting is now underway.

Lastly, two other composites research programs worth following involve 3D printing a UV-cured resin containing ultrasonically aligned glass microfibers (Advanced Composites Centre for Innovation and Science, University of Bristol) and development of design guidelines for AM with composites (pd|z Product Development Group, ETH Zurich). DE

Contributing Editor **Pamela Waterman**, DE's *simulation expert, is an electrical engineer and freelance technical writer based in Arizona. You can send her e-mail to DE-Editors@deskeng.com.*

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- ➜ **SABIC:** SABIC-IP.com
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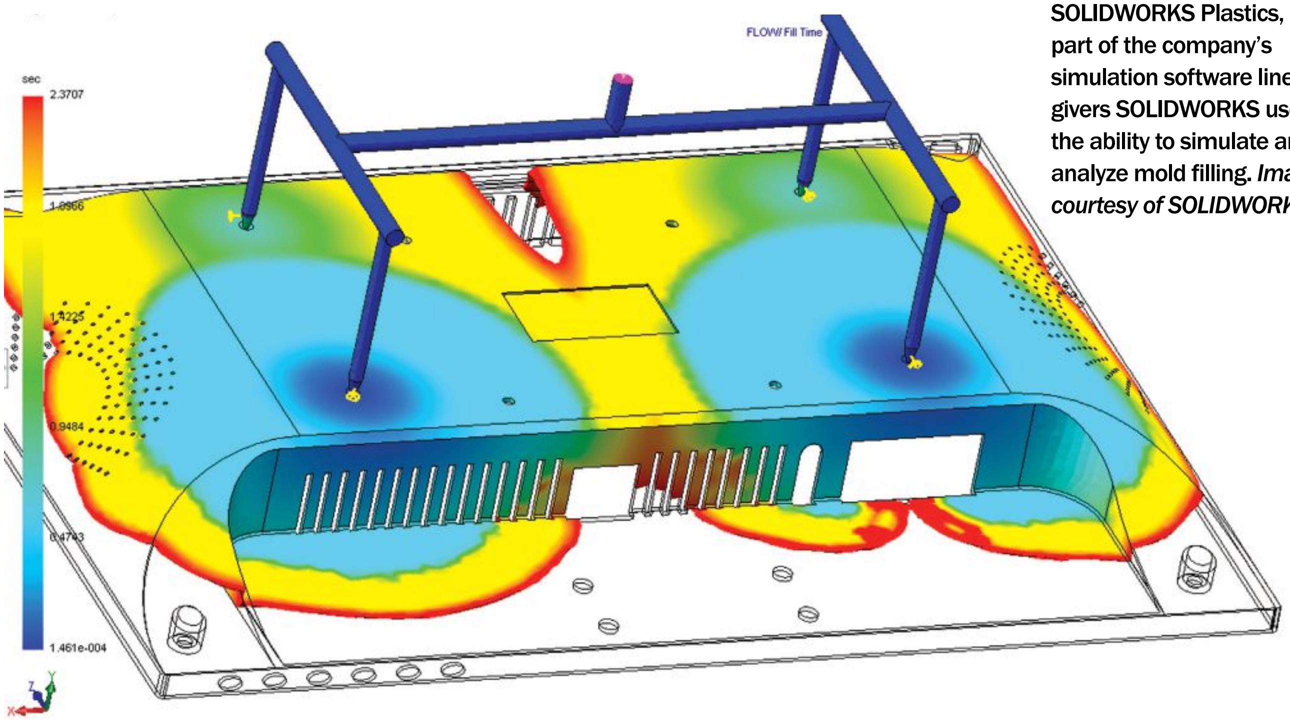


SOLIDWORKS Plastics, part of the company's simulation software lineup, givers SOLIDWORKS users the ability to simulate and analyze mold filling. *Image courtesy of SOLIDWORKS.*

Thin, Transparent and Tapping into the Cloud

Plastic simulation evolves to include transparency analysis, GPU acceleration and cloud processing.

BY KENNETH WONG

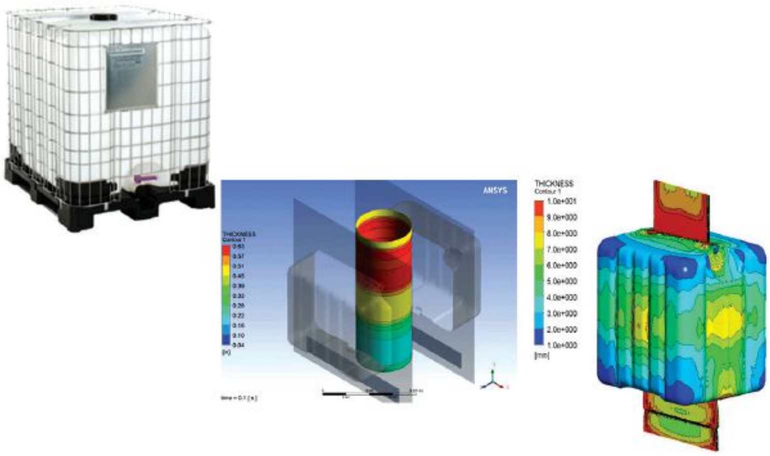
The classic dilemma in plastic product design still remains the same: Make it as light as possible, but also strong enough for the job. The thin walls in plastic containers, for example, must retain sufficient strength to hold the heavy liquid content without collapsing; therefore it requires balancing lightweight goals vs. structural requirements. And the issues related to plastic molding — warpage, flow consistency, and cooling behavior — still remain unchanged.

But the technology to simulate plastic molding is evolving. Transparency — the way products look through the plastic skin — is now part of the simulation. With intense parallel computation, mold simulation algorithms are finding ways to run faster in a GPU (graphics processing unit) multicore architecture. Such developments don't raise eyebrows, elicit exclamations and prompt enterprise restructuring the way subscription licensing, browser-based software and mobile apps have done. But for those who make a living in the plastic industry, these are meaningful steps that contribute to waste reduction, better-looking products and shorter development cycles.

Tricky Transparency

Belgium-based PolyFlow was first acquired by Fluent in 1996. When Fluent itself was acquired by ANSYS in 2006, Fluent's technology assets, including PolyFlow, became part of ANSYS's portfolio. PolyFlow's 25-year-old fluid dynamics technology for simulating polymer, glass and metals originated in university research labs, recalls Bernard Hocq, a senior project manager for ANSYS.

"There's a relationship between stretching and optical clarity. The non-isotropic stretching usually leads to optical defects that might make the consumer think there is some-



Simulating the blow molding of a 1000-liter water container completed using PolyFlow software from ANSYS. *Image courtesy of ANSYS.*

thing in the water, so you have to think of the acceptable stretching anisotropy as a constraint in the simulation," explains Hocq.

PolyFlow can help designers visualize not only the thickness distribution but also the stretching orientation and distribution which translate to optical quality. Though not one of the performance criteria, perfect clarity can affect the product's success or failure. Transparency imperfection in a plastic container could make the crystal clear water within less appealing. "It's difficult to put a number to perfect transparency, because it's not really a performance attribute but a cosmetic issue," Hocq notes.

Hocq says PolyFlow's solver offers higher accuracy compared to its competitors because of its complex viscoelastic models. PolyFlow solver is a direct solver — different from iterative solvers. "Our solver might take a little more time than an iterative solver, but it can also do much more than an iterative solver can do," he explained.

PolyFlow's solver supports GPU acceleration. It uses the NVIDIA CUDA (compute unified device architecture) library. The program works faster on hardware with single or multiple Tesla GPUs, NVIDIA's product line for high-performance computing (HPC).

Plastic Extension

PTC's Creo Parametric (formerly Pro/ENGINEER) offers plastic molding simulation through the Creo Mold Analysis (CMA) extension, developed by PTC partner Moldex. Describing the product, PTC writes: "As a material, plastic has a certain charm: It's lightweight, inexpensive and can be molded into almost any design. But just wait until that first warped or blistered part emerges from the mold. Designing a part so it can be manufactured easily and efficiently is critical to your product's success."

PTC Creo Parametric software comes with basic plastic analysis functions, including "3D thickness check to analyze your model's geometry and fix basic issues," the company states. The CMA Extension goes a step further. It lets you "quickly and accurately simulate the injection molding of plastic parts within PTC Creo Parametric … you can also perform such analyses as moldability, sink mark and weld line," according to the company.

The common challenges with plastic design are designing for strength and cosmetic appeal, says Russell Hsu, CAD product manager at PTC. "For example, the wall thickness of plastic parts shall be as uniform as possible," he says. "Thick walls are subject to weakness that could result in undesirable characteristics like higher stress areas, shrinkage, sink marks, and voids. Cosmetic appearance of a product's external components is often a significant factor in quality perception, but can also lead to high production cost."

Software performance is often an issue with mold simulation. But the highly parallel computation involved is an opportunity for the GPU and clusters. Both PTC Creo Parametric and its companion CMA extension are GPU-accelerated. If a GPU is present, users will see an improvement in Creo Parametric's anti-aliasing, lighting and enhanced shaded-with-edges display mode, Hsu explains. The extension also supports batch run and cloud computation.

More CAD-Integrated Simulation

In 2008, Autodesk paid $297 million to purchase Moldflow Corporation, which develops specialized software for simulating plastic injection. Announcing the acquisition, Autodesk CEO Carl Bass said: "Autodesk sees plastics and composites as some of the fastest-growing engineering materials. Given its relatively low weight and durability, plastic materials are ideally suited to help our customers attain their sustainability initiatives. Moldflow, with its industry-leading plastics simulation, is a natural extension of Autodesk's Digital Prototyping solution."

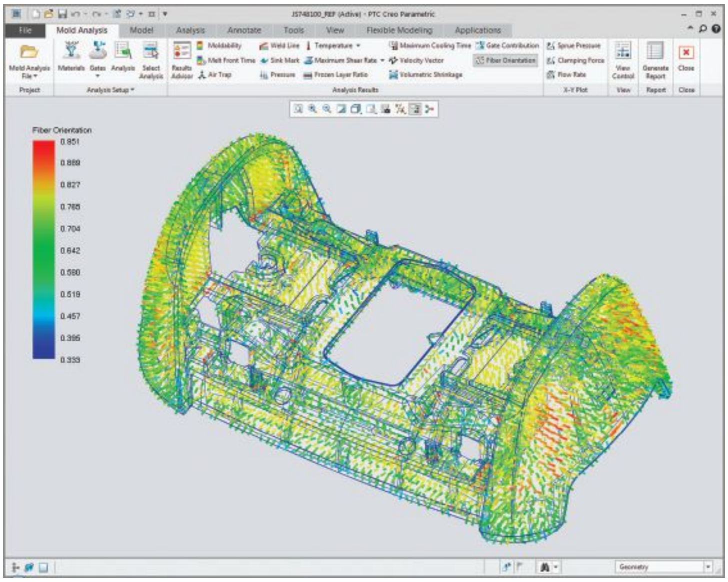
Today, Moldflow software remains the leading plastic analysis package in Autodesk's portfolio. It's offered as Moldflow Design, Moldflow Advisor and Moldflow Insights. Developed to test, modify and verify designs with real-time feedback, Moldflow Design is integrated with CAD packages. Moldflow Advisor helps identify defects, best injection location and simulation and design strategies. Moldflow Insight offers advanced features for in-depth injection studies, Polymer flow, mold cooling, part warpage prediction, model meshing and process parameter controls.

Describing the latest release, Moldflow 2017, Autodesk writes: "Using microcellular injection technology [known as MuCell in the trade] and chemical blowing agents can help you with lightweighting parts without compromising strength. We've improved support for foaming technologies including MuCell with core back."

Automotive, medical and consumer packaging industries rely on MuCell to create lightweight parts with high strength and stability. In Moldflow 2016, the product includes 3D analysis of MuCell making it easier to visualize what happens to parts with complex geometry in the process.

In conducting mold and structural analysis, Moldflow takes into account detailed material information, including fiber direction and orientation. This is a useful feature for those working with manufactured fiber-filled plastics, whose strength and tension are influenced by the fiber layout.

For complex jobs that require more processing power than what's available in your own local machine or network, Moldflow offers the option to send the job to the cloud. The option is available for some of the most compute-intensive phases and operations of Moldflow, such as meshing, solving and design of experiments (DOE). The cost — the estimated number of cloud credits the job will consume — is displayed before the job begins.



The PTC Creo Mold Analysis extension offers plastic mold simulation, including the effects of fiber orientation. ***Image courtesy of PTC.***

SOLIDWORKS, a rival to Autodesk in CAD software, offers plastic analysis in SOLIDWORKS Plastics, part of the company's simulation software lineup. According to the product data sheet, SOLIDWORKS Plastics "predicts how melted plastic flows during the injection molding process [and] part warpage and mold cooling optimization. Users can change part or mold geometry, processing conditions, or the plastic material to eliminate or minimize potential defects, saving energy, natural resources, time and money."

SOLIDWORKS Plastics comes in three different levels: Standard, Professional and Premium. The Standard version is fully integrated with the SOLIDWORKS CAD package, and can simulate the fill stage of cavity domain. Additional features to a single-cavity analysis are available in the Professional version including multi-cavity, family mold layouts, sprues, runners and the capability to simulate the Pack stage. The higher-end Premium version lets you simulate the cavity-to-mold heat transfer during the cooling stage, molded part deformation due to plastics warpage and more.

New Frontiers

Encouraged by advances in metal-based 3D printing, some automotive and aerospace manufacturers are currently exploring additive manufacturing's (AM) potentials for mass-production of end-use parts. If the early initiatives prove successful, what used to be a prototyping and mockup building technology could become a full-scale industrial process.

"The use of 3D printing to produce final parts is going mainstream among the manufacturing industry; this includes plastic or metallic parts. With the development of new materials, the notion of 3D printing the final product is more appealing to many companies. Another aspect of this is that several companies are 3D printing the mold to produce plastic parts," says Jose Coronado, CAD product manager at PTC.

ANSYS' Hocq continues working to make mold simulation more accessible to novices and non-experts. The key, he believes, is in teaching the software "to identify the right convergent strategy or the angle of attack based on user input. Once that's identified, you can apply brute force approach to solve the equations." **DE**

Kenneth Wong *is* Desktop Engineering's *resident blogger and senior editor. Email him at kennethwong@deskeng.com or share your thoughts on this article at deskeng.com/facebook.*

INFO ➜ ANSYS: ANSYS.com

➜ **Autodesk Moldflow:** Autodesk.com/products/moldflow/overview

➜ **PTC Creo Mold Analysis:** PTC.com/cad/creo/simulation-products/mold-analysis

➜ **Polyflow:** PolyflowGlobal.com

➜ **SOLIDWORKS Plastics:** SOLIDWORKS.com/sw/products/simulation/plastics.htm

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New Memory Solutions Could Boost Speed

Storage class memory systems could fundamentally change computing performance.

BY BRIAN ALBRIGHT

As models and data sets continue to get bigger and bigger, the demand for larger memory capacity and faster access has increased. Engineers need more space and faster performance to keep up.

"For engineers, scientists and people creating new technology, it's important to make those people as productive as possible," says Scott Hamilton, Precision specialist at Dell. "When we look at this from a workstation perspective, memory and storage are a big part of that equation."

Now, new memory architectures (referred to as storage-class memory, or SCM) are emerging that could fundamentally change computing speeds. Last year, Intel and Micron unveiled 3D XPoint, memory technology that the companies claim will provide 1,000 times the performance of current solid-state drives (SSDs).

Also last year, HP and SanDisk (now a Western Digital brand) announced their own SCM collaboration, which will combine HP's memristor efforts and Western Digital's non-volatile ReRAM memory technology. The companies claim that their version of SCM will also be 1,000 times faster than flash storage with higher endurance, lower costs and lower power requirements than DRAM. The solution is intended to allow systems to employ tens of terabytes of SCM per server node for in-memory databases, data analytics and high-performance computing.

It could be another year (or more) before these solutions turn up in the data center, and even longer than that before you'll see them in a workstation. In the meantime, computer OEMs (original equipment manufacturers) are addressing this need for faster access and more storage in a variety of ways. In the case of Dell's Precision tower workstations, the company now offers Broadwell EP processors, up to a terabyte of RAM, and Ultra-Speed PCIe drives that the company says are up to four times faster than SATA SSD storage. Later this year, Dell will offer a new SuperSpeed feature on its mobile workstations. The company worked with Intel to provide 2667Mhz bandwidth on its mobile units, a significant increase in clock speed.

Memory, Storage or More?

What the Intel/Micron and HP/SanDisk projects represent, though, is a fundamental change in the way memory operates. Storage class memory is not quite memory or storage, although it will reside in the memory slots on the motherboard. This type of memory is faster and more resilient than flash, and is also persistent.

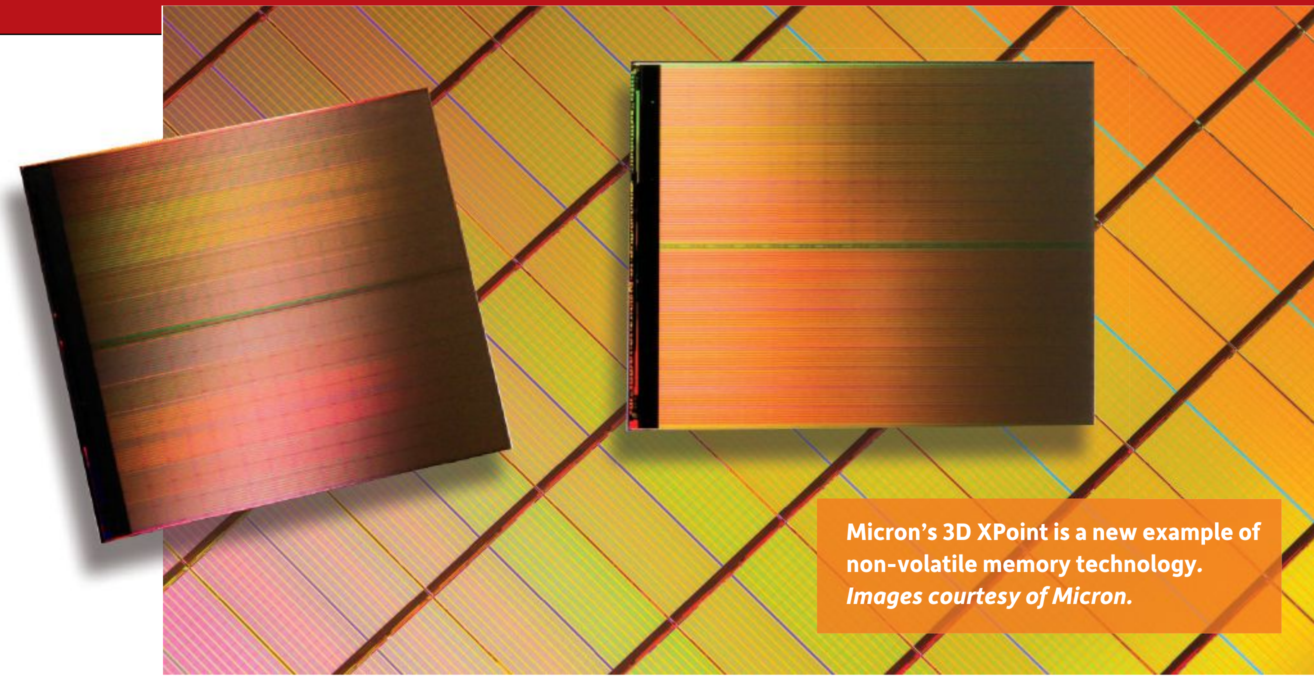
Traditionally, applications store data temporarily in volatile DRAM memory. Persistence is achieved by writing the data and metadata to the disk. With SCM solutions, content remains in memory.

New SSDs have provided significant benefits to engineers when loading models and storing them, and can have a huge impact on productivity. That has helped relieve some of the latency that bogged down operations in the past. "The storage device was the bottleneck, because it can't load the data fast enough," Hamilton says. "With the new SSDs, that bottleneck is not as significant as it used to be."

New NVMe (non-volatile memory express)-based systems use flash memory in the form of an SSD to provide lower latency. "These go on the PCIe bus rather than the data bus, the so the bandwidth is greater. In internal tests, we've seen three to four times performance improvements with NVMe drives," Hamilton says. "For example, when you are doing simulations, those data sets are often more than you can fit in RAM, so you are relegated to this situation where the CPU is waiting for data off of the storage device. Since that's always slower than RAM, you pay a latency penalty. But if you can increase the performance of the storage device, you increase your overall performance."

This is what Intel's 3D XPoint-based Optane SSDs are meant to address. Optane combines 3D XPoint with Intel's system memory controller, interface hardware and software IP. 3D XPoint builds on NVMe and will be mounted on PCIe cards, and will further reduce latency.

Intel and Micron describe the 3D XPoint (pronounced crosspoint) architecture as a "transistor-less cross point architecture" that creates a "three-dimensional checkerboard where memory cells sit at the intersection of word lines and bit lines, allowing the cells to be addressed individually. As a result, data can be written and read in small sizes, leading to fast and efficient read/write processes."



Micron's 3D XPoint is a new example of non-volatile memory technology. ***Images courtesy of Micron.***

DRAM and NAND Flash use electrons to store cell state, and the cell requires sufficient volume to hold those electrons. DRAM loses the electrons when power is removed (which makes it volatile), while NAND Flash retains the electrons (making it non-volatile).

"3D XPoint memory does not use electrons to store cell state, but instead relies on the transition of a bulk material," says Michael Abraham, 3D XPoint business line manager at Micron. "The material's resistance can be either high or low. Because electrons are not required, 3D XPoint memory can scale to smaller lithographies than NAND Flash and DRAM."

NAND Flash has higher capacity per physical area than 3D XPoint, but the Intel/Micron solution is faster to read and write, and can do so in smaller units; it's also 10 times more dense than DRAM.

The resultant Optane SSD is really just a faster version of existing solutions that combine an SSD working in conjunction with a spinning drive to boost the performance of the spinning drive, says Mano Gialusis, product manager for Dell's mobile workstation line.

"What Optane does is provide faster throughput or performance," Gialusis says. "But there is always going to be a bottleneck if you are working with extremely large files. Gigabytes of files would have to be transferred to the Optane device, and that is where it (being non-volatile) could store those or pin those to the device, which would allow you to have faster access."

According to Paolo Faraboschi, fellow and vice president, Systems Research, at Hewlett Packard Labs, the HP/SanDisk version of SCM has a capacity and cost profile similar to storage, with performance characteristics (bandwidth, latency, access methods) similar to memory. Faraboschi says it can be thought of as "byte-addressable non-volatile memory" in that users can access it directly (like memory) without going through a block interface.

"This 'fast-and-cheap' combination allows us to discard today's memory hierarchy, which translates data in small chunks between slow-but-cheap flash and HDDs and fast-but-expensive DRAM," he says. "This busywork of today's memory hierarchy represents something like 90% of everything a computer does today."

Accelerating Applications

So does this help engineers and other end users? Initially, the pay off will be in the data center for large simulation and data analysis applications.

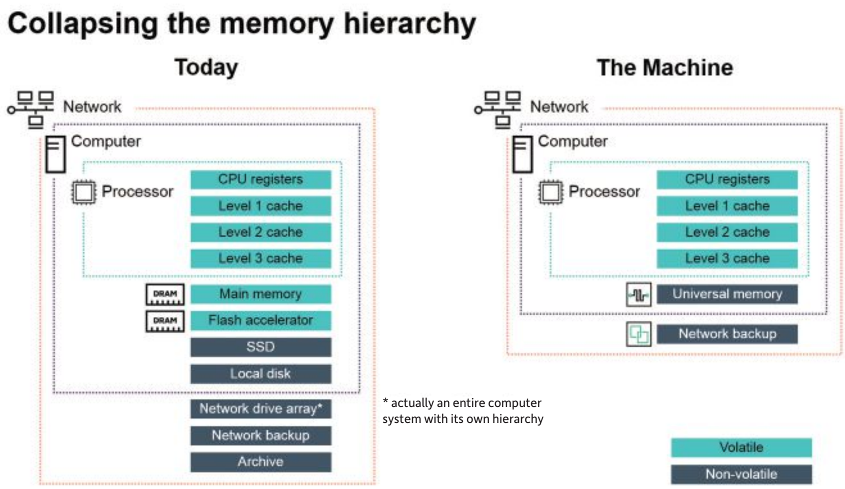
In the case of 3D XPoint, the technology can provide better SSD performance. It could also be placed on a memory module and attached to a memory controller on the CPU. This is potentially more disruptive and allows faster non-volatile accesses.

"Any engineering application that requires more memory per CPU will benefit," Abraham says. "But Micron sees the most immediate benefits for enterprise applications that handle Big Data sets or real-time analytics. Those applications are in lots of different fields, but you see them often in finance and high frequency trading, security/fraud detection and even on-demand content platforms."

"CAD-type applications are both compute- and memory-intensive," adds HP's Faraboschi. "Most people can relate to having to turn off parts of an assembly or disable shading in order to get a decent response time. With enough memory, however, instead of constantly re-computing ray tracing, cross-sections and similar tasks, the application can just look up previous scenarios. The end result is a much more responsive user experience and the ability to work on much larger datasets that are impractical today."

For software developers, these new solutions can provide a faster way to access non-volatile memory. According to Abraham, many of the "hooks" for 3D XPoint and NVDIMM are occurring in a set of libraries defined in PMEM.

"These libraries will make faster block-based access and non-volatile variable access easier to use while bypassing



HP is looking to address fabric limitations with The Machine, its new research project that changes the current memory hierarchy. ***Image courtesy of HP.***

much of the overhead of file systems and drivers," Abraham says. "Much of the plumbing work is happening now to allow middleware applications — like databases, data analytics, etc. — to optimally access 3D XPoint technology, and then end user applications will be able to take advantage of it, too."

That will eventually require a re-architecting of applications to derive the most benefit from the lower latency. As Faraboschi points out, applications are written with existing memory limitations in mind. In order to access a storage device today, programmers have to use storage abstractions that move data in large chunks between the I/O subsystem and DRAM memory.

"This causes serialization and deserialization overheads, and makes in-memory programming very difficult, often impossible," Faraboschi says. "With SCM, you can completely rethink the compute/space balance that the application requires. We understand that in order to achieve maximum performance gains, some recoding is inevitable. However, to ease the transition, companies like HPE (Hewlett Packard Enterprise) are working on new programming tools and models that use familiar languages and constructs as much as possible."

The Impact on the Data Center

Data centers will be the first beneficiaries of storage-class memory. In fact, enterprise data centers are the initial target market for 3D XPoint, because the technology provides new ways to handle data-intensive workload streams.

"The initial enablement work requires careful collaboration between hardware OEMs, software companies and the media experts in our development groups, however — which is why you haven't seen end products yet," Abraham says. "You'll begin to see new architectures developed around 3D XPoint technology emerge in data center environments in 2017 and 2018."

According to Faraboschi at HP, data center performance is limited both by the memory hierarchy, as well as the low bandwidth and latency of the fabric connecting servers.

"SCM, on its own, can't address the fabric limitations," he says. "For that, you need a new fabric architecture such as the one we plan to enable in The Machine, HPE's research project to reinvent computer architecture from the ground up."

The Machine leverages SCM and other technologies to create terabyte- and petabyte-sized pools of universal, non-volatile memory. One key piece of that solution is the memristor, a resistor that stores data after losing power, but HP's commercialization of that technology has been slower than expected.

Coming to a Desktop Near You?

So far, neither of the first two types of SCM are going to be available for at least a year or more. Adoption at the workstation level will be even farther off.

These new memory solutions create fast storage that could provide benefits for professional workstation applications with high storage demands. Abraham, however, thinks workstation users will have better results in the short term with flash-based SSDs for now because of the lower price point. That will change as the technologies mature and prices come down.

Dell plans to adopt the technology as soon as it's available and proven, and the company expects that CAD and simulation users will clamor for it. In the meantime, workstation manufacturers continue to load up on the number of cores available on their machines via Intel's Xeon products.

"CAD applications are memory hungry, and products are just getting more complicated," Dell's Gialusis says. "The amount of analysis work is increasing, and more products are integrating both mechanical and electrical components. Products are more complex. We're all trying to make engineers as productive as possible, and these memory developments are another piece of the puzzle that help us enable that." **DE**

Brian Albright *is a freelance journalist based in Columbus, OH. He is the former managing editor of* Frontline Solutions *magazine, and has been writing about technology topics since the mid-1990s. Send e-mail about this article to DE-Editors@deskeng.com.*

INFO ➜ **Dell:** Dell.com

➜ **Hewlett Packard Enterprise:** HPE.com

➜ **Hewlett Packard Labs:** HPL.HP.com

➜ **Intel:** Intel.com

➜ **Micron:** Micron.com

➜ **Western Digital SanDisk:** SanDisk.com

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Mighty Mouse

The tiny BOXX APEXX 1 1401 workstation delivers a lot of performance.

DAVID COHN

We have reviewed quite a few workstations from BOXX Technologies over the years, most recently the BOXX APEXX 2 2401 (deskeng.com/de/?p=23627) and 2402 (page 52). But we have never reviewed anything like the APEXX 1 1401. In photos, it resembles a typical tower, yet this new system — billed as the world's smallest workstation — is less than 9-in. tall and weighs just 7.6 lbs.

Our BOXX APEXX 1 came housed in a white case with black plastic strips along its four angled corners that serve as feet so it can be positioned horizontally. The system measured a mere 4.7x9.6x8.8 in. (WxDxH), 75% smaller than the APEXX 2. The APEXX 1 requires an external power brick, similar to a laptop computer. The 300-watt power supply included with the APEXX 1 is quite large, however, measuring 7.7x3.9x2 in. and weighing more than 2 lbs. That power supply connects to the rear of the case via a square 6-pin connector similar to those typically used to route power inside a conventional workstation.

An angled panel along the top front edge of the case provides headphone and microphone jacks, a pair of USB 3.0 ports, and a round power button along with a reset switch and indicator lights for power and hard drive activity. In addition to the power connector, the rear panel houses six more USB 3.0 ports, a USB 3.1 Type A port, a USB 3.1 Type C port, an RJ45 network jack, two HDMI ports and a DisplayPort for the CPU's integrated graphics, a PS/2 mouse/keyboard port, S/PDIF out port, and three audio jacks for microphone, line-in, and audio-out.

The APEXX 1 includes Wi-Fi and Bluetooth. The rear panel includes two screw-on connectors for a small external antenna. The antenna provided a fast, wireless connection to our LAN on either 2.4 or 5GHz bands in lieu of the gigabit Ethernet port.

Tiny Interior

A system this small obviously requires compromises, especially in expandability. The 6.5x6.5-in. ASRock motherboard only offers two 240-pin memory sockets and a single PCIe x16 expansion port. Although the Intel Core i7 CPU supports up to 64GB of memory, the APEXX 1 can accommodate a maximum of 32GB

The BOXX APEXX 1 workstation from BOXX Technologies is less than 9 in. tall, yet packs plenty of power thanks to an overclocked quad-core CPU. *Image courtesy of BOXX Technologies.*

INFO ➔ BOXX Technologies: BOXXTech.com

BOXX APEXX 1 1401

- **Price:** $3,711 as tested ($3,111 base price)
- **Size:** 4.7x9.6x8.8 in. (WxDxH) micro-tower (plus external power supply)
- **Weight:** 7.6 lbs. (plus external power supply)
- **CPU:** One Intel Core i7-6700K (quad-core) 4.0GHz (over-clocked to 4.4GHz)
- **Memory:** 16GB DDR4 at 2133MHz (up to 32GB supported)
- **Graphics:** NVIDIA Quadro K1200 with four mini DisplayPorts
- **Hard Disk:** Samsung 512GB M.2 PCIe SSD (two internal 2.5-inch SSD drive bays)
- **Floppy:** None
- **Optical:** None
- **Audio:** Onboard integrated 5.1 high-definition audio (microphone and headphone on front panel; microphone, line-in, audio-out and S/PDIF out on rear panel)
- **Network:** Integrated 10/100/1000 LAN with one RJ45 socket
- **Modem:** None
- **Other:** Two USB 3.0 on front panel; six USB 3.0, one USB 3.1 Type A, one USB 3.1 Type C, two HDMI and one DisplayPort video ports on rear panel, 802.11AC wireless and Bluetooth
- **Keyboard:** 104-key Logitech K120 USB keyboard
- **Pointing device:** Logitiech USB Laser Mouse

Single-Socket Workstations Compared

	BOXX APEXX 1 1401 one 4GHz Intel Core i7-6700K 4-core CPU over-clocked to 4.4GHz, NVIDIA Quadro K1200, 16GB RAM	BOXX APEXX 2 2402 one 4GHz Intel Core i7-4790K 4-core CPU over-clocked to 4.5GHz, NVIDIA Quadro K5200, 16GB RAM	Xi MTower CX one 3GHz Intel Xeon E5-1660 v3 8-core CPU over-clocked to 4.1GHz, NVIDIA Quadro M5000, 16GB RAM	Digital Storm Slade PRO one 3.1GHz Intel Xeon E5-2687W v3 10-core CPU, NVIDIA Quadro M4000, 32GB RAM	Computer Direct Volta Pro one 4GHz Intel Core i7-4790K quad-core CPU, NVIDIA Quadro K5200, 16GB RAM	Xi MTower PCIe one 3.7GHz Intel Core i7-5930K 6-core CPU over-clocked to 4.32GHz, NVIDIA Quadro K5200, 16GB RAM
Price as tested	$3,711	$5,806	$4,997	$6,187	$4,441	$4,985
Date tested	1/30/16	1/30/16	1/25/16	10/18/15	7/12/15	12/13/14
Operating System	Windows 7	Windows 7	Windows 7	Windows 10	Windows 7	Windows 8.1
SPECviewperf 12 (higher is better)						
catia-04	34.95	133.05	126.16	78.54	103.66	98.53
creo-01	33.45	108.3	107.44	65.60	91.62	86.66
energy-01	2.56	11.44	11.65	6.31	3.73	3.49
maya-04	31.22	101.53	97.68	63.79	75.92	72.18
medical-01	11.41	45.12	45.78	25.99	31.33	28.84
showcase-01	18.99	60.37	61.65	42.26	49.76	48.98
snx-02	28.47	121.01	219.48	74.62	152.32	150.42
sw-03	70.56	158.22	149.88	110.74	134.67	126.08
SPECapc SOLIDWORKS 2015 (higher is better)						
Graphics Composite	5.17	7.65	5.89	n/a	n/a	n/a
Shaded Graphics Sub-Composite	2.86	4.19	3.16	n/a	n/a	n/a
Shaded with Edges Graphics Sub-Composite	3.92	5.57	4.22	n/a	n/a	n/a
Shaded using RealView Graphics Sub-Composite	3.56	5.45	4.32	n/a	n/a	n/a
Shaded Edges using RealView Graphics Sub-Composite	6.17	9.01	7.20	n/a	n/a	n/a
Shaded using RealView and Shadows Graphics Sub-Composite	4.51	6.77	4.97	n/a	n/a	n/a
Shaded Edges using RealView and Shadows Graphics Sub-Composite	7.20	10.29	7.67	n/a	n/a	n/a
Shaded using RealView and Shadows and Ambient Occlusion Graphics Sub-Composite	7.78	14.87	11.94	n/a	n/a	n/a
Shaded with Edges using RealView and Shadows and Ambient Occlusion Graphics Sub-Composite	11.63	21.17	17.69	n/a	n/a	n/a
Wirefram Graphics Sub-Composite	4.17	4.19	2.98	n/a	n/a	n/a
CPU Composite	6.75	6.09	5.87	n/a	n/a	n/a
Autodesk Render Test						
Time in seconds (lower is better)	46.30	41.70	25.30	47.33	50.83	42.33
SPECwpc v2.0 (higher is better)						
Media and Entertainment	2.84	3.52	3.84	3.67	n/a	n/a
Product Development	2.46	3.06	3.38	3.89	n/a	n/a
Life Sciences	2.96	3.65	4.19	4.46	n/a	n/a
Financial Services	1.53	1.54	2.59	2.55	n/a	n/a
Energy	2.70	3.17	4.37	4.57	n/a	n/a
General Operations	1.93	1.99	1.78	1.47	n/a	n/a

Numbers in blue indicate best recorded results. Numbers in red indicate worst recorded results.

(which adds $521 to the base price). Our unit came with 16GB (included in the base configuration), installed using a pair of 8GB DDR4 2133MHz DIMMs (dual in-line memory modules).

Centered on the motherboard beneath a BOXX-labeled liquid cooling system is an Intel Core i7-6700K quad-core CPU. This Skylake processor, with a rated speed of 4GHz, is overclocked to 4.4GHz. The processor includes an 8MB Smart Cache and Intel HD Graphics 530. A pair of hoses connects the cooling fan to a radiator that takes up half the rear panel.

The small interior space also limits graphics board choices to only half-length, single-slot small form factor GPUs (graphic processing units). While the base configuration comes with an NVIDIA Quadro K620 GPU, our evaluation unit was equipped with a Quadro K1200, a graphics card with 4GB of discrete GDDR5 memory and 512 CUDA (compute unified device architecture) parallel processing cores. The K1200 features a 128-bit memory interface and 80GB/sec memory bandwidth, and provides four mini DisplayPort sockets. That GPU added $211 to the cost of our APEXX 1. Less expensive AMD FirePro W2100 and W4100 graphics cards are also available.

The base configuration also includes a 256GB SSD M.2 PCIe drive. For our evaluation unit, BOXX increased this to a 512GB M.2 drive, adding $390 to the cost. Removing the left side panel reveals an additional pair of 2.5-inch drive bays that can accommodate SSD SATA drives and BOXX offers choices ranging from 120GB ($139) to 1.2TB ($1,871).

BOXX offers an optional external USB DVD/RW drive for $45, but similar drives are available for less.

The Mouse That Roared

As we have come to expect from BOXX, the APEXX 1 1401 performed extremely well, although its mid-range GPU resulted in somewhat compromised graphics performance. On the SPECviewperf tests, the APEXX 1 simply could not match the results of other tower workstations equipped with higher-end GPUs and even lagged behind mobile workstations using the latest NVIDIA mobile graphics cards.

For our SOLIDWORKS tests, we have recently begun using the SPEC SOLIDWORKS 2015 benchmark. This new evaluation performs nine graphics tests and two CPU tests. The BOXX APEXX 1 is only the second workstation on which we have run this new benchmark, although we have also used it for recent reviews of several mobile workstations. With its overclocked CPU, the APEXX 1 turned in very good results, even surpassing the Xi MTower CX on the CPU-specific tests.

On the AutoCAD rendering test, which shows the advantages of fast CPUs with multiple cores, the BOXX APEXX 1 completed the test rendering in an average of 46.3 seconds, equal or better than many other quad-core systems we have tested.

We also ran the SPECwpc workstation performance benchmark. The APEXX 1 held its own well against more conventional workstations, even garnering top scores on test components that favor fast disk I/O thanks to its M.2 PCIe drive.

BOXX Technologies backs the system with a three-year warranty featuring next business day on-site service with 24/7 phone support during the first year and depot repair service with weekday daytime phone support during years two and three.

The BOXX APEXX 1 delivers excellent performance. With a cost as configured of $3,711, our evaluation unit was also attractively priced. BOXX says that the APEXX 1 is perfect for space constrained production environments and we agree, with one caveat. During our testing, when subjected to heavy compute loads, the sound level of the APEXX 1 went from barely audible to 52dB — about equivalent to a large electrical transformer at 100 ft. While not as loud as some systems we have tested, those were more likely to be placed beneath as desk whereas the APEXX 1 might very well be positioned closer to ear level. That concern aside, the BOXX APEXX 1 delivers a lot of bang for the buck. If space in your engineering office is at a premium, the BOXX APEXX 1 just might save the day. **DE**

David Cohn *is the technical publishing manager at 4D Technologies. He also does consulting and technical writing from his home in Bellingham, WA, and has been benchmarking PCs since 1984. He's a Contributing Editor to* DE *and the author of more than a dozen books. You can contact him via e-mail at david@dscohn.com or visit his website at dscohn.com.*

A New Peak Performer

BOXX adds updated technologies to the APEXX 2.

DAVID COHN

After testing the diminutive APEXX 1 (see page 49) from BOXX Technologies, it seemed only fitting that we follow up with a look at an updated version of the more conventional BOXX APEXX 2. When we reviewed the original APEXX 2 last year (deskeng.com/de/?p=23627), it proved to be one of the fastest single-socket workstations we had ever reviewed — not a big surprise because the company has consistently delivered some of the fastest over-clocked workstations.

Our original APEXX 2 2401 came with a 4th generation Intel "Devil's Canyon" CPU, a processor featuring 22nm lithography and improvements in thermal efficiency compared to the previous Haswell and Broadwell processors. The new APEXX 2 2402 is based on a 6th generation Skylake CPU. The new APEXX 2 gave us a chance to compare two nearly identical workstations to see for ourselves whether Skylake lived up to Intel's performance improvement claims.

The BOXX APEXX 2 2402 came housed in a custom-designed aluminum chassis measuring 6.85x16.6x14.6 in. (WxDxH) and weighing 19.75 lbs. As in previous BOXX workstations, the front grille conceals a pair of 4-in. diameter cooling fans and holds a filter to trap dust before it can enter the interior of the case. On the APEXX 2, one of those fans is actually part of the CPU liquid cooling system.

A single 5.25-in. drive bay above the front grille housed a 20x dual-layer DVD+/-RW optical drive as well as a panel containing two USB 3.0 ports, two USB 2.0 ports, audio jacks for headphone and microphone, a round power button with bright-white LED power indicator, a blue hard drive activity light, and a small reset button. A Blu-Ray R/W drive is a $212 option.

The rear panel provides four additional USB 3.0 ports, a USB 3.1 Type A port, a USB 3.1 Type C port, an RJ45 network jack, HDMI and DVI ports for the CPU's integrated graphics, a PS/2 mouse/keyboard port, an S/PDIF out port and five audio connectors (microphone, line-in, line-out/front speaker, center/subwoofer, and rear speaker).

Updated Interior

Loosening a pair of captive screws and removing the right side panel reveals a compact but well-organized interior. In addition to the single drive bay with front panel access, there are also three internal drive bays — two 3.5-in. bays with quick-release drive mounts and a 2.5-in. bay.

The new APEXX 2 2402 uses an ASRock Z170M Extreme4 motherboard, with the CPU beneath a BOXX-labeled liquid cooling system. The only CPU BOXX offers in the APEXX 2 2402 is the Intel Core i7-6700K quad-core CPU. Although this processor has a base frequency of 4.0GHz, the "K" designation indicates an unlocked CPU multiplier, meaning that it can be overclocked. In the new APEXX 2, BOXX overclocks the CPU to 4.4GHz.

The motherboard provides four memory sockets supporting 288-pin DDR4 DIMMs (dual in-line memory modules), and can accommodate up to 64GB of non-ECC unbuffered RAM. The $2,997 base configuration includes 16GB using a pair of 2133MHz 8GB modules. Opting for just 8GB would reduce the cost by $209, while maxing out the memory would add $1,422.

The motherboard also provides four expansion slots — three PCIe 3.0 x16 slots and a PCIe 3.0 x1 slot — and supports both NVIDIA SLI and AMD CrossfireX technologies. Although the CPU includes Intel HD Graphics 530, the base configuration comes with an NVIDIA Quadro K620 discrete GPU (graphics processing unit). BOXX also offers other graphics options from both NVIDIA and AMD as well as NVIDIA Telsa boards. Our system came with an NVIDIA Quadro M5000 graphics accelerator, the successor to the K5200 included in last year's APEXX 2. This high-end GPU, which includes 2048 CUDA (compute unified device architecture) parallel processing cores, added $1,886 to the overall system price and provides four DisplayPorts as well as a DVI port and stereo connection. As installed in PCIe slot 1, the thickness of the M5000 blocked access to the adjacent PCIe x1 slot, leaving just the other two PCIe x16 slots accessible.

Updated Technologies

Unlike the original APEXX 2, which used a SATA-based SSD (solid-state drive) for its primary storage, the updated APEXX 2 comes standard with a 256GB SSD M.2 PCIe drive. A 512GB M.2 drive is a $390 option. The PCIe interface improves bandwidth and reduces latency, enabling SSD drives to exceed the I/O capabilities of drives using the older SATA interface.

Using the M.2 slot on the motherboard means that PCIe storage does need to consume an expansion slot. That was not true for the system we received, however. Instead of an M.2 drive, our APEXX 2 included an 800GB Intel 750 Series SSD (a $1,284 add-on) installed in PCIe slot 4. Other PCIe SSDs ranging from 400GB to 1.2TB are also available. Eliminating the base-configuration PCIe M.2 drive did reduce the system cost by $361. Customers looking for even more storage can still use the available internal drive bays to add SSDs or HD SATA drives ranging from 120GB to 4TB, and the integrated drive controller supports RAID 0, 1, 5 and 10 configurations.

A 550-watt 80 Plus Gold power supply is tucked into the bottom rear of the case, mounted to a hinged support system that pivots out of the way after removing two screws.

Improved Performance

So how did this updated BOXX workstation perform? On the SPECviewperf tests, the new APEXX 2 2402 surpassed the performance of every other single-socket workstation we have ever tested, including last year's first generation APEXX 2.

For our SOLIDWORKS test, we have recently begun using the new SPEC SolidWorks benchmark and could therefore not compare the new system to its predecessor. But again, the APEXX 2 beat all of the other workstations we have evaluated thus far using this new benchmark.

On the AutoCAD rendering test, which clearly shows the advantages of fast CPUs with multiple cores, the new APEXX 2 beat last year's model in spite of having a slightly slower quad-core CPU, leading us to believe Intel's performance claims for its new Skylake CPU. In fact, only the recently reviewed Xi MTower CX, with double the number of CPU cores, could beat the rendering performance of the new APEXX 2.

Perhaps the most telling results, however, were those we obtained using the SPECwpc workstation performance benchmark, which includes six test suites representing vertical markets, which often have very different computing demands. While the new APEXX 2 lagged behind some systems equipped with more powerful CPUs, it outperformed the previous generation APEXX 2 in every suite and on every workload, with improvements as much as 50% on some verticals. On tests that focused on disk performance, however, the new APEXX 2 beat the previous generation by as much as 4x. Clearly, the new Skylake CPU and PCIe-based drives deliver significant improvements.

BOXX Technologies backs the system with a three-year warranty featuring premium next business day on-site service with 24/7 phone support during the first year and depot repair service with weekday daytime phone support during the second and third years. Premium support during the second and third years is available for an additional charge.

As equipped, the new APEXX 2 2402 we reviewed priced out at $5,806, nearly $700 more than the first generation APEXX 2 we received last year. Had we opted for the standard 256GB PCIe M.2 drive, however — which would nearly match the capacity of the SATA-based SSD in the system we tested last April — the new APEXX 2 would cost $4,883, $228 less than its predecessor. Either way, the new BOXX APEXX 2 delivers even better performance than before, continuing to make it a perfect choice for CAD and 3D modeling applications. **DE**

The BOXX APEXX 2 2402 from BOXX Technologies houses a 6th generation Intel Core i7-6700K quad-core CPU overclocked to 4.4GHz. *Image courtesy of BOXX*

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INFO ➜ BOXX Technologies: BoxxTech.com

BOXX APEXX 2 2402

- **Price:** $5,806 as tested ($2,997 base price)
- **Size:** 6.85x16.6x14.6 in. (WxDxH) tower
- **Weight:** 19.75 lbs.
- **CPU:** One Intel Core i7-6700K (quad-core) 4.0GHz (overclocked to 4.4GHz)
- **Memory:** 16GB DDR3 at 2133MHz (up to 64GB supported)
- **Graphics:** NVIDIA Quadro M5000
- **Hard Disk:** Intel 800GB PCIe SSD (two 3.5" and one 2.5" internal drive bays)
- **Floppy:** None
- **Optical:** 20X dual-layer DVD+/-RW
- **Audio:** Onboard integrated 7.1 high-definition audio
- **Network:** Integrated 10/100/1000 LAN with one RJ45 socket
- **Modem:** None
- **Other:** Two USB 2.0 and two USB 3.0 on front panel; four USB 3.0, one USB 3.1 Type A, one USB 3.1 Type C on rear panel; integrated DVI and HDMI video ports

WHATEVER HAPPENED TO CLOUD RENDERING?

Images courtesy of Thinkstock

Five years ago, cloud rendering seemed poised to explode. Now, it seems to have made little progress. What went wrong?

BY MARK CLARKSON

Why hasn't cloud-based rendering taken off the way it was predicted? There are certainly more options than ever. Application support is growing, albeit slowly. Both Amazon and Microsoft recently added systems with GPU (graphics processing unit) acceleration in their cloud offerings. But cloud-based rendering has been held back by a combination of technology, security worries and simple inertia.

"We actually tried cloud rendering with Bunkspeed back in 2007," says Brian Hilner, product manager for SOLIDWORKS Visualize (formerly Bunkspeed). "We tried it for a few years, then we tried it again in 2010. We had a service for it, we had machines on Amazon, we also had our own cluster machines in our office that people could tap into. It just wasn't getting any traction. I think we were about 10 years too early," he concludes.

Security

One major hurdle facing cloud rendering are persistent worries about data security says Hilner. Companies have been reluctant to upload their proprietary data to the cloud. "In my opinion," says Hilner, "one of the biggest reasons why cloud rendering didn't take off like people thought it would is that the data can't leave the insides of these proprietary networks. That's what I've heard talking to previous Bunkspeed – now Visualize – customers. These are Fortune 500 and Fortune 100 companies, major players in the automotive industry, aerospace industry, medical industry and in product design. They can't upload data that hasn't been released yet — of their newest car or new airplane interior or new product. That stuff literally can't leave their servers. IT guys won't let them. Admins won't let them."

Some big companies, he says, actually disable the USB ports on their computers to prevent data from being downloaded, transferred or, even worse, taken home.

"If they're disabling USB ports, cloud rendering is going to be a hard sell," Hilner adds.

Companies, understandably, want to keep their proprietary data safe, but how best to do that?

Bye-Bye Data Center

"A couple years ago," says Justin Boitano, VP of Marketing at Frame, "a lot of businesses thought that their private cloud — because it was private — would be more secure. But look at the data breaches that have happened. Sony had a big security breach where they lost core intellectual property from their own data center."

And Sony is certainly not alone in that.

"Over the past few years," says Boitano, "a lot of IT organizations have come to the realization that they underinvest in the security of their data center, and that their core competency as a business isn't really in data center security. Almost every executive that we talk to says: 'You know, you're right. We do underinvest in data security and, frankly, I'd rather outsource [the data center] to Amazon or Microsoft and let them manage the security aspects so we can focus on what we do best, which is creating great content or products or buildings.'"

And there is indeed a change underway. More and more large companies are using Google Drive, Amazon Web Services and other cloud offerings. More than half of all Fortune 500 companies use Azure for at least some data. Many are getting out of the data center business completely — or nearly so. General Electric is closing down all but three of its 30-plus global data centers, shifting most of that data to the cloud. Yamaha America is shutting down all of their data centers. Manufacturers, banks and insurance companies are following suit.

"A lot of global engineering firms want to move all their customer data to the cloud," says Boitano. "They provide people access for the time [they're] doing a certain phase of work, and then remove that access when they've completed their work. You're not moving the data around; you're just providing application access to the data as needed."

That may not seem central to the idea of cloud rendering, but it is. To begin with, it represents an increased willingness by companies to entrust at least some of their data to the cloud — a necessary first step. In addition, cloud rendering solutions have wrestled with the problem of packaging your data and uploading it to the cloud renderer without breaking your workflow. If the data is already sitting in the cloud, you get to skip that step. And it opens up other, intriguing possibilities.

Data Gravity

"At Frame, we talk about the concept of 'data gravity,'" says Boitano. The idea is to move your applications closer to the data they act on. If your CAD program and your CAD data are both sitting on your desktop workstation, the workflow is seamless. But when your CAD program is running on your desktop and your CAD data is sitting on the other side of the internet, the user experience can grow awkward.

Many of the problems surrounding the cloud rendering user experience center around the problem of moving data between your local PC and the cloud-based rendering application. But what if you moved your applications to the cloud where your data lives, and ran them there? Now, there are no slow offline transfers, no packaging the data for movement to a different part of the workflow.

Frame lets you install Windows applications on the cloud and then run them from a browser. Your local workstation just plays a video stream and relays keystrokes and mouse clicks. In fact, because so little is asked of your local PC, it doesn't have to be a powerful workstation at all. It can be any kind of device capable of running a browser.

Frame's fastest system — a Quad NVIDIA GRID GPU system with 16 CPU cores and 64GB of system memory — will cost you about $3.60 an hour to use. "If you do interactive rendering only a few times per week," says Boitano, "it's much cheaper to rent that time in the cloud than buy a $15K workstation that sits idle a good part of the day." In fact, even at 40 hours per week, it'll take two years to reach $15K. And, by that time, the machines in the cloud will probably have been upgraded.

Overcoming Inertia

In large part, the slow adoption of cloud-based rendering — like the adoption of any new technology— comes down to inertia. People like to do things the way they've always done them and that thus far has not included the cloud. But there are new technology companies starting up all the time. Those new, younger companies have less inertia to contend with and are more likely to already host everything on the cloud. As they find the need for 3D visualization — or any heavy computation task — they're likely to turn directly to cloud-based services. And as we've seen, even the biggest of companies are moving their data to the cloud. It's up to the application developers to streamline access to it.

"The winners in the cloud rendering space," says SOLIDWORKS' Hilner, "will become winners by having direct access to services like Google Drive, Dropbox and [Amazon Web Services] within their cloud rendering infrastructure, providing their users with a seamless workflow."

Cloud rendering does seem poised to break through into the mainstream. Of course, you may have heard that before. **DE**

Contributing Editor **Mark Clarkson** *is* DE's *expert in visualization, computer animation and graphics. Visit him at MarkClarkson.com or send e-mail about this article to DE-Editors@deskeng.com.*

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Commentary

by Denny Scher

3D Printing vs. Injection Molding

Some observers of the plastics manufacturing industry, especially those with a vested interest, would like to have you believe that 3D printing is going to be the demise of injection molding. While there are certainly cases where 3D printing makes sense, the reports of the death of injection molding have been greatly exaggerated.

Plastic injection molding is a tried-and-true method of production that is in no danger of going away anytime soon. It is a basic, dependable method of producing high-quality plastic parts. Despite recent improvements in the technology of 3D printing and those likely to emerge in the future, the fact is that more than 80% of plastic parts used in products today have to be injection molded.

The answer to the question, "Which manufacturing method is best for my part?" is: "It depends." It depends on variables like quantity, quality and cost.

The preferred method can be determined by investigating quantity, quality and cost.

Quantity

David Kazmer, professor of Plastics Engineering at the University of Massachusetts, Lowell, said in a published paper that 3D printing currently makes sense for the most rapid "procurement time to quantity" for a small quantity of 50 or fewer units.

So for larger production runs, injection molding is still the best manufacturing method, especially considering the long production time involved for 3D printing compared to injection molding.

There is an emerging hybrid practice of 3D printing the mold tooling inserts only, then producing the parts with injection molding. For certain limited applications, 3D printed inserts can be employed as a test mold for product development and very limited quantities. A 3D-printed mold may last for typically just 60 to 180 pieces.

Kazmer's study looked at where 3D-printed tooling inserts may fit into the big picture, and concluded that there were still significant issues with both metal inserts (surface finish and machine cost) and polymer inserts (surface finish as well as poor strength and heat transfer).

Quality

One of the key limitations of 3D printing is the inability to make parts with the same physical properties as conventional injection molded parts. Although the number of various materials available for 3D printing seems to be constantly increasing, it is still limited compared to all the various plastic materials that can be injection molded. While a 3D-printed prototype might be acceptable for evaluating its shape, there is no way to test the material characteristics if your prototype is not the same material as the production part will be.

Another issue cited in Kazmer's study was surface finish. While the surface finish of the part may vary according to how good (expensive) the 3D printer is, it is still no match for the smooth surfaces attainable with polished steel injection molds.

Last, but certainly not least, is the issue of tolerances. Although the ability of 3D printing to hold tighter part tolerances is expected to improve with advanced process designs like parallel printing and optimization, today the part quality achieved in 3D printing is inferior compared to injection molding.

Cost

The overall cost of a 3D-printed part compared to an injection molded part is tied to the quantity being produced, assuming the aforementioned quality issues do not preclude 3D printing as an option out of the gate. In Kazmer's research, the cost of 3D printing 300 of a certain size part was $20 each. The piece price of injection molding a million such units with a steel mold was just $1.13 each.

Another cost factor to consider is any design change in the prototyping stage. In 3D printing, there is no cost of modifying a mold for a prototype iteration. Design changes are simply made to the CAD model.

Within injection molding, design changes with a steel mold are typically easy to make and relatively inexpensive, but with aluminum molding tools, a design change may require the expense of all new tooling.

Additionally, new simulation software is now available to help resolve injection molding challenges in software — rather than through costly, time-consuming prototyping iterations. Testing molds in a virtual simulation environment cuts across communication barriers and allows designers, mold makers and manufacturing professionals to collaborate more efficiently and effectively, while eliminating the need for costly prototype and mold cycles.

When it comes to 3D printing vs. injection molding, the best production method for your parts will become clear when you answer questions regarding your desired quantity, quality and cost. **DE**

Denny Scher *is the marketing manager for ICOMold (ICOMold.com). Send email about this commentary to de-editors@deskeng.com*

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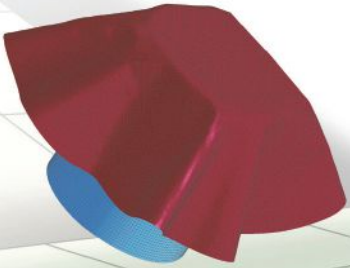
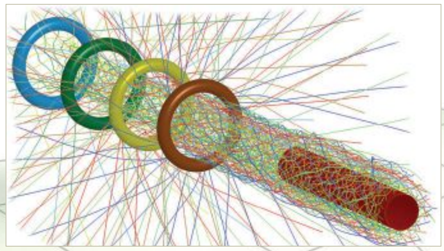
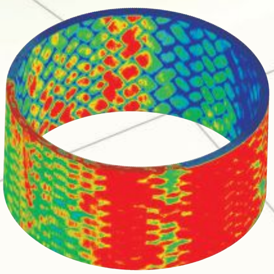
Multiple manufacturing processes can be simulated including draping, weaving, braiding, infiltration, Resin Transfer Molding (RTM)

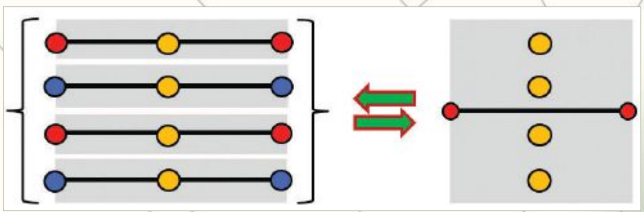




MAPPING

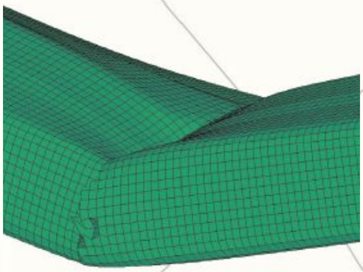
Tools are available to map between different scales

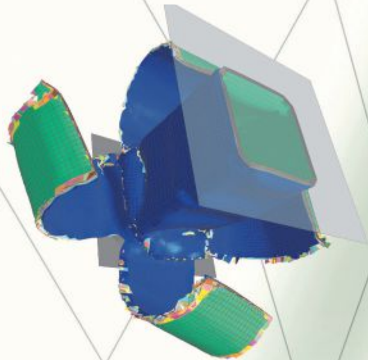




CRASH ANALYSIS

Various failure modes are available to predict crash behavior of composite structures





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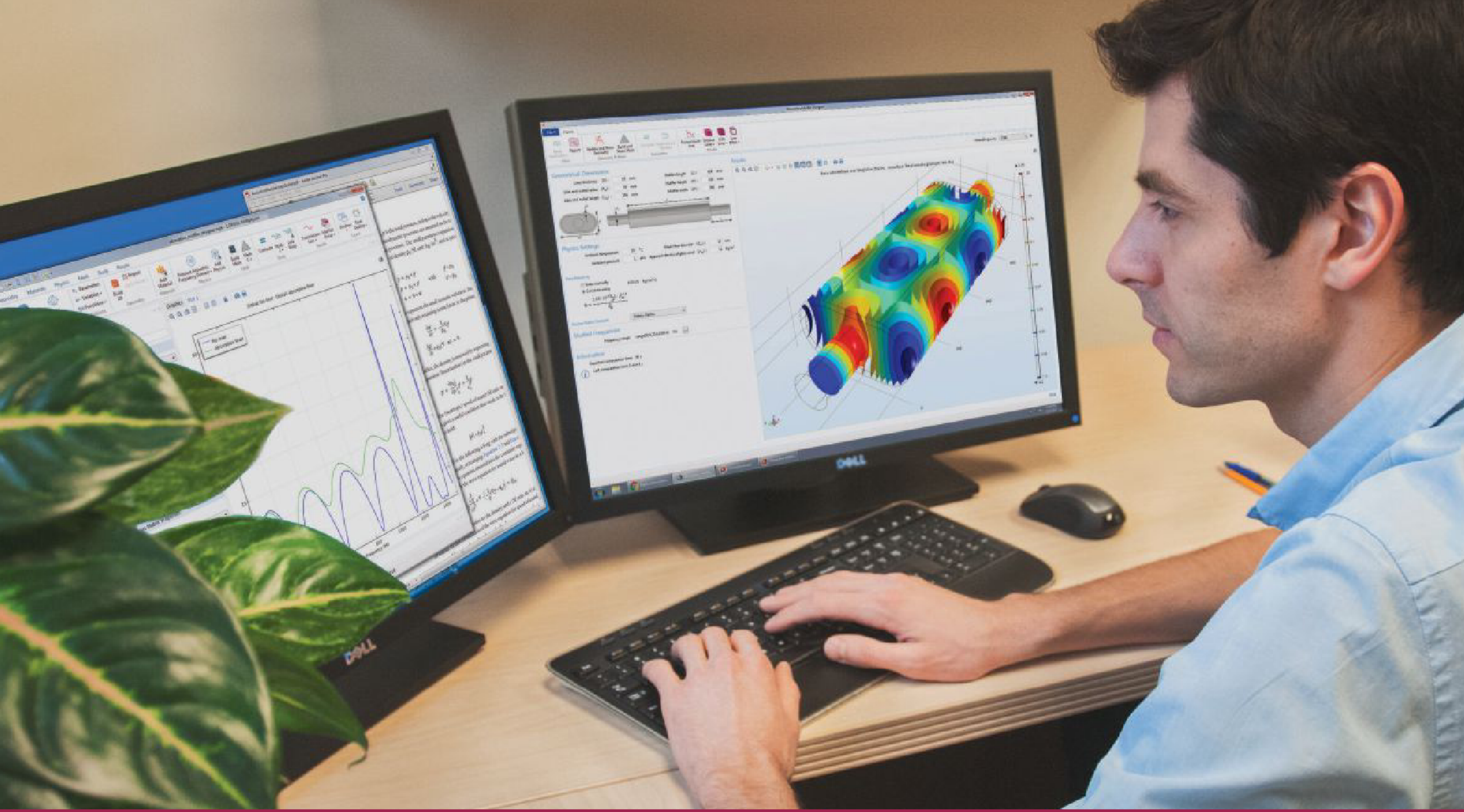

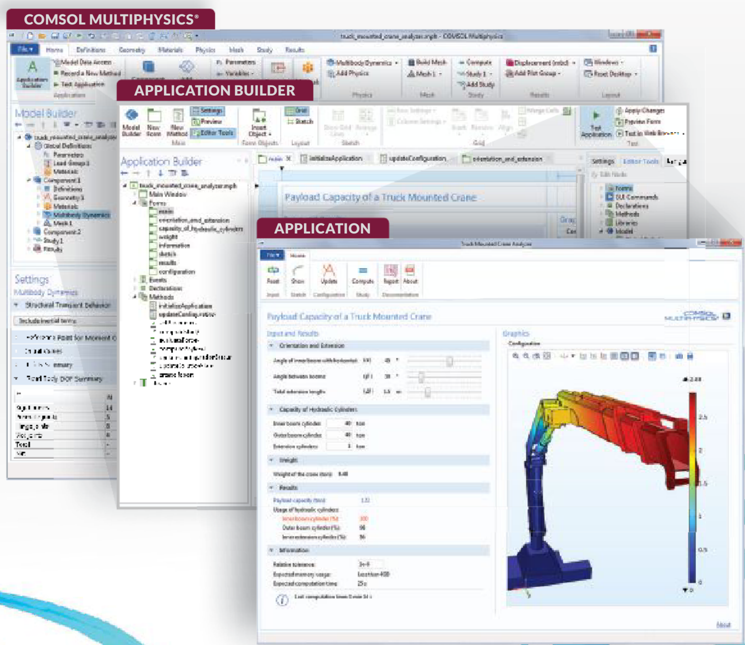

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