Methods

Mouser's technology & solutions eZine

Volume 2, Issue 2

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Welcome from the Editor

When you think about engineering in the context of Industrial Revolution, do you think of innovations and advancements that previous generations made possible, or do you think of the innovations and advancements yet to come? Perhaps both?

"At the tail end of Industry 3.0, we find ourselves a bit whiplashed from the seemingly rapid-fire advances of recent years. We find ourselves connected to everybody and every "thing".... Yet we also find ourselves not truly integrated with the physical and cyber systems around us."

Indeed, engineering innovations belong to eras defined by advancements. In the First Industrial Revolution, engineers harnessed water and steam to advance mechanical production. In the Second Industrial Revolution, engineers harnessed electricity to further advance efficiency in manufacturing and distribution. In the Third, engineers brought information technology to the forefront, connecting resources, companies, and people via the Internet, with technologies, business systems, and manufacturing outgrowths that have taken on lives of their own.

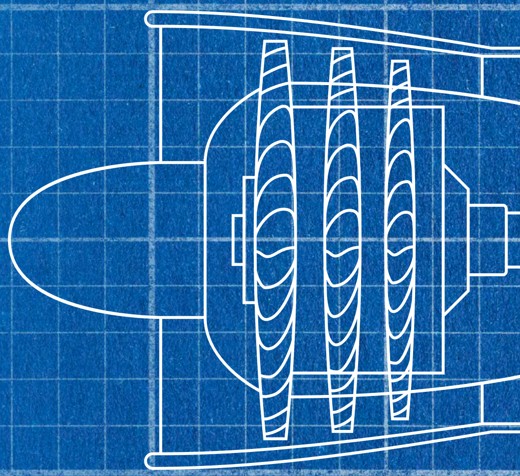
At the tail end of Industry 3.0, we find ourselves a bit whiplashed from the seemingly rapid-fire advances of recent years. We find ourselves connected to everybody and every "thing" through the Internet, mobile devices, and the smart infrastructure around us. Yet we also find ourselves not truly integrated with the physical and cyber systems around us. As a result, we cannot see the larger picture, are limited in the problems we can solve, and are engineering in relative isolation.

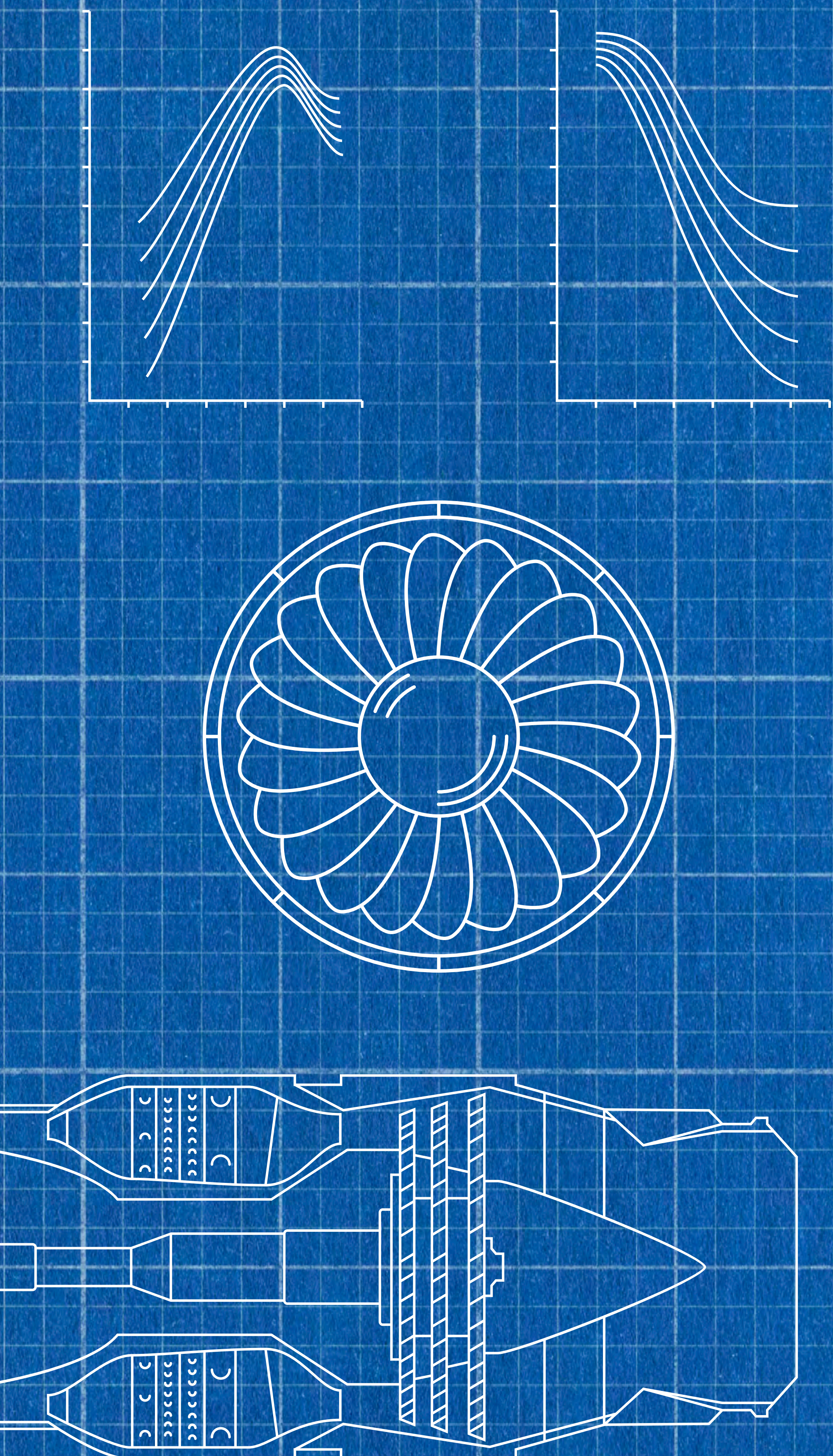
Before we even catch our breath, Industry 4.0 has already begun and has firmly claimed its own identity, purpose, and scope: To combine the physical systems of the early revolutions with the cyber systems of the recent revolution with the people, companies, and industries that have come to rely on them. An era of integrative engineering is upon us. One engineering technique already in use holds tremendous promise in helping us meet these goals. Digital Twinning maps physical assets to a digital platform that can analyze components, products, systems, and processes; provide real-time feedback as to efficiency, health, environmental conditions, maintenance needs, and more; and as a result, enable engineers to create smarter, more efficient, more reliable, more maintainable products, systems, and processes.

In 2018, we are privileged to have the physical and cyber systems that came before us and to be an integral part of shaping Industry 4.0. Mouser Electronics is pleased to be on the leading edge supporting the proliferation of digital twinning as a significant part of the revolution ahead. In this issue of *Methods*, we hear from one of the world's foremost experts on digital twinning; discuss the technology landscape and types of twinning; reveal the many potential benefits; describe the role of sensors, edge-nodes, and communications; and present security and end-user privacy implications and solutions. We also present an interesting paradox of digital twins: They require more sensors and related hardware, yet simultaneously help engineers solve component selection challenges.

As we bring Industry 3.0 to a close and embark on Industry 4.0, we take pause: To acknowledge the engineering innovation that came before us, to fathom the unique juncture we're at, and to marvel at the possibilities to come—the possibilities we will create.

Deborah S. Ray
Executive Editor





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Foreword

By Dr. Michael Grieves, Executive Director, Center for Advanced Manufacturing and Innovative Design (CAMID)

Technologies have advanced and converged to bring digital twinning to the forefront of engineering design. What is the role (or roles) of today's design engineers to maximize the potential of digital twinning?

The concept of the digital twin was introduced over a decade and a half ago. However, the operationalizing of the digital twin required advances in technologies, primarily computing, communications, and sensing that have only been realized in the middle of this decade. The ability to implement the digital twin promises to change the role of engineering as it is practiced today.

In fact, the argument can be made that the digital twin enables engineers to perform the role that they have needed to do all along: Designing and engineering products that can actually be manufactured and that produce the functionality that engineers think that the product will have and that the product users require. This means that engineers need to be able to do two main things:

- Design the "ilities" into product design: manufacturability, supportability, operability, and disposability.
- Provide a feedback loop from the performance of the product in the usage phase of its life. This is so that the assumptions that engineers make about how a product will actually perform is validated by finding out how the product actually did perform when it was in use.

While there always has been a theoretical concern for the "ilities," the reality is that the different aspects of the product lifecycle were fairly siloed, with engineering, manufacturing, and sustainment/support being isolated from each other. Engineering designed the product and threw it over the wall to manufacturing. Manufacturing figured out how to build the design and sent the finished product on its way from the loading dock. The user of the product figured out how to keep the product operational, with or without support from the product manufacturer.

"Whereas in the past, engineers really didn't have any ability to understand and validate the "ilities," using the digital twin in modeling and simulation allows them now to do so."

The digital twin, with its modeling and simulation capabilities, enables engineers to not only design the product, but also determine how it can be manufactured, how it can be supported, and how it can perform. The ideal here is to design the product virtually, test the product virtually, manufacturer the product virtually, and support the product virtually. Only when the product meets all the requirements that it needs for all phases of the lifecycle is the product physically made. (The ideal, of course, is making the product by 3D printing it! That's a technological discussion for another time.) Where in the past, engineers really didn't have any ability to understand and validate the "ilities," using the digital twin in modeling and simulation allows them now to do so.

The second area that will impact engineering will be reinforcing and, in some cases, creating a feedback loop from product performance in actual use and the engineering phase. With the proliferation of smart connected products made possible by the Internet of things (IoT), products can report back to engineering their actual performance. This can be compared to the predicted performance that drove the development of a specific design. By comparing the actual performance to the predicted performance, engineers can reevaluate their assumptions that they based their designs on. This will allow engineers to modify their designs to better meet the predicted performance in future products. Too often generations of products have the same deficiencies because engineering never obtains feedback on actual products in use.

"The real definition of a quality product is not how well it was designed or how well it was manufactured; the quality product is one where the product user obtains the performance that the product manufacturer promised."

What this means is that engineers will need to determine what data is needed to validate performance assumptions and then design into their products the appropriate sensors to collect that data. The real definition of a quality product is not how well it was designed or how well it was manufactured; the quality product is one where the product user obtains the performance that the product manufacturer promised. Digital twin instances (DTIs) are digital twins of individual instances of the product. DTIs collect performance data of their corresponding physical products in actual use and transfer that data back to the engineering phase. This is a requirement for both understanding and producing quality products.

The two functional roles described here—considering the "ilities" and having a feedback loop from actual product performance—are actually not new roles. They are a "Back to the Future" to when products were much simpler in scale and scope. Then, engineers were involved in all phases of the products lifecycle and had actual experience with their products in operation. The digital twin enables engineers to recapture those roles for modern products.

Dr. Michael W. Grieves

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Digital Twinning: A Look at the Technology Landscape

By Michael Parks, PE, for Mouser Electronics

Digital twins are changing how systems are designed and operated. Understanding the concepts and the enabling technologies is crucial to successfully incorporating digital twins into product development.

The digital twin (DT) represents a manufacturing paradigm shift that is long in the making. The fundamental premise is that for every physical product, there is a virtual counterpart that can perfectly mimic the physical attributes and dynamic performance of its physical twin. The DT exists in a simulated environment, controllable in very exact ways that are not easily duplicable in the real world—e.g., speeding up time so that years of use can be simulated in a fraction of a second.

Thanks to the expansion of companion technologies such as artificial intelligence (AI), ubiquitous wireless Internet access, and inexpensive sensor platforms, DTs are quickly becoming a feasible reality for many companies looking to make better products and more informed business decisions.

Despite all the hype surrounding DTs, the actual concept is rather straightforward. With roots in modeling and simulation, advances in companion technologies, digital thread (to tie it all together), and machine learning (to make sense of it all), digital twinning is on the verge of shifting the landscape of engineering design.

Roots in Modeling and Simulation

DTs can trace their roots back through the history of modeling and simulation:

- A model, not totally unlike a DT, is a physical or mathematical representation of the characteristics and behaviors of an object, system, or process. It dictates how the modeled entity reacts to and impacts its environment and other entities.

- A simulation takes a model or set of models and mimics their operations over time by interjecting artificial inputs (or accepting inputs from a human or an instrumented test object) and monitoring the outputs: This a concept known as "live, virtual, and constructive (LVC)" simulation.

Even before computers made it possible to represent tangible objects virtually in software, physical mockups representing production systems were sometimes used to understand complex systems better: A great example of this is the full-scale simulators built by NASA to train astronauts (throughout the decades) to occupy various spacecraft. In recounting the events of Apollo 13's near-disaster, the 1995 movie, named after the spacecraft, gives viewers an excellent basis for understanding the use cases for DTs. In the film, astronaut Ken Mattingly (portrayed by actor Gary Sinise) spends countless hours in a functional, exact replica of the ill-fated spacecraft. His goal was to solve the various technical hurdles that were thwarting the safe return of fellow astronauts Jim Lovell, Fred Haise, and Jack Swigert. The cost and effort of building exact duplications of the Apollo spacecraft was justified by the enormity of the undertaking and by the amount of planning and practice each mission required.

But what if the cost and effort to create a functional facsimile of a complex system could be made trivial compared to their total lifecycle costs and/or savings? What if, unlike a traditional model, it is possible to use a virtual representation for more than just system design—for instance, using virtual representation to help understand and control supply chain and other business functions associated with product manufacturing? And what if customers could get extremely intelligent predictive maintenance planning based on sharing operational and maintenance data across an entire fleet of systems? This is where the DT could help to

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change everything about design, construction, operations, and maintenance of complex systems. In this context, the Internet of Things (IoT) would be the lifeblood, separating traditional models from next generation DTs.

Advances in Companion Technologies

At the heart of digital twinning is a key concept: The virtual and the physical are inextricably linked. Thus, IoT and the more manufacturing-focused Industrial Internet of Things (IIoT) have become key enablers that allow data to flow between the digital and physical twins. Embedded sensors on a physical object can monitor all aspects of the object's operations as well as the operating environment. This valuable data will feed to the object's DT via IoT for operators and engineers to understand better how a system is operating in real-world conditions.

Reliably enabling a system's teleoperation requires near ubiquitous Internet access. The forthcoming rollout of fifth generation wireless networks, or 5G, will bring many advantages to the wireless market that will be necessary for further proliferation of IoT and IIoT. The advantages include increased reliability, more concurrent users, and greater built-in support for device-to-device communications. A parallel development, multi-access edge computing (MEC), will help ensure network throughput by offloading cloud processing and maintaining it closer to the sensor nodes, which are foundational to IoT. In short, the processing horsepower packed into today's inexpensive embedded systems eliminates the need for raw data transport across networks (and/or the Internet) to activate processing by high-powered servers.

The Digital Thread

A fully effective DT needs a closed data loop, or digital thread, that flows from conceptual design all the way to real-world feedback from fielded systems. Embedded electronic products require multiple disciplines to come together to design and manufacture a finished product. Computer-aided design/engineering (CAD/CAE) software suites enable designers and engineers to build the enclosure and mechanical aspects of a product. Electronic design automation (EDA) applications enable schematic capture and circuit board layouts. Computer-aided manufacturing (CAM) software translates the designs into instructions that manufacturing machinery understands to turn the digital into the physical. Each step along the process adds more data to the DT.

"At the heart of digital twinning is a key concept: The virtual and the physical are inextricably linked."

The digital thread is the connective tissue that enables the otherwise disparate applications to communicate. Permitting disparate software applications to interoperate, an emerging class of software known as robotic process automation (RPA) enables easily built digital threads. Running at a human user interface (UI) level, RPAs empower disparate applications to interoperate, without expensive software rewrites for each individual application. This capability will prove to be very useful as the digital thread continues to collect data and provide information to the DT from various business systems, such as customer relationship management and supply chain applications. Even after a product has been sold and is in use, the digital thread continues to feed telemetry data to the manufacturer for model refinements on the basis of how a product is actually performing in real-world conditions.

Machine Learning Turns Data into Information

All the data moving along the digital thread are impossible for humans to efficiently process on their own. Machine learning technology will be essential to sift through the mountains of data that feed back from fielded systems. Finding anomalies or trends will allow engineers and designers to refine future product iterations in a more predictive fashion than possible today. Cognitive digital twins, powered by AI technology, will allow products to improve over time without any human intervention. In short, instead of just performing mathematical analyses on raw data, a cognitive digital twin would be able to learn, reason, adapt its logic, and make informed decisions on its own. The result: The ultimate in technology self-help! The implications of a more cost-effective, rapid adaptation and an increasingly intelligent product development lifecycle would seem to make any investment in this technology well worth it.

Conclusion

With DTs, every physical product can have a virtual counterpart that can perfectly mimic the physical attributes and dynamic performance of its physical twin. DTs are quickly becoming a feasible reality for many companies looking to make better products and more informed business decisions. Rooted in modeling and simulation, DT has gained traction due to advances in companion technologies, like wireless communications, sensors, AI, machine learning, and more. Digital twinning may indeed shift the landscape of engineering design as we know it.

Digital Twins vs. Simulations

A false assumption suggests that DTs are just another type of modeling and simulation. If this were the case, DTs wouldn't be useful for electronics engineers. Electronic design automation (EDA) software, which enables circuit capture and simulation, has been around for decades. However, "twin" is the emphasis here. It implies the existence is a physical duplicate: of course, under the consideration that the product doesn't solely live as 1s and 0s in a computer. For product developers who choose to embrace DTs in their design process, this means physical prototypes become even more important. Simulations are only as good as the assumptions a person makes who is running the simulation. However, DTs rely on aggregated real-time feedback from all prototypes being used in various real-world settings. This differentiating philosophy has significant implications for hardware designers.

"Simulations are only as good as the assumptions a person makes who is running the simulation."

Types of Digital Twins

By Michael Parks, PE, for Mouser Electronics

Digital twins are being developed for parts, products, processes, and entire systems. What's more, they're changing how products are developed and impacting how entire systems and processes are engineered and operated.

Good systems engineering tells us that abstraction and hierarchy are two ways to manage the complexity of design when dealing with systems composed of multiple layers of subsystems, assemblies, subassemblies, and so forth. By breaking down complex systems into constituent parts, we can more easily understand the first principles of operation. By taking the lowest level parts and putting them back together, you can build sophisticated yet comprehensible systems.

Digital twins (DTs) work in a similar bottom-up way, where the lowest level is the simplest and yields limited information, with each additional level providing more sophisticated and more diverse types of information. This concept is at the core of an emerging hierarchy of the DT, which includes:

- Parts twinning
- Product twinning
- System twinning
- Process twinning

Parts Twinning

The foundation of digital twinning is the need for robust parts twinning. At this level, the virtual representations of the individual components give engineers the capability to understand the physical, mechanical, and electrical characteristics of a part. For example, many computer-aided design/manufacturing (CAD/CAM) solutions today offer the ability to perform a variety of analyses relating to durability, including static stress and thermal stress. Electronic circuit simulation software, for example, tells us how electronic components will react as various electrical signals are injected into a circuit. It requires a mathematical model of sufficient complexity to be able to best predict real-world behaviors under a variety of scenarios.

Product Twinning

Twinning individual parts offers useful insights but twinning the interoperability of parts as they work together helps to enable product twinning. Being able to understand how parts interact with each other and their environment allows for optimization of the constituent parts, thereby maximizing operating characteristics and minimizing things such as a mean time between failures (MTBF) and mean time to repair (MTTR).

System Twinning

At the next higher level, system twinning allows engineers to operate and maintain entire fleets of disparate products that work together to achieve a result at a system level. Think of an energy grid that can spin up or spin down electrical generation by monitoring the demand. Now imagine this possibility across all types of system families. Groups that build and manage communication systems, traffic control systems, or industrial manufacturing systems will have an unheard-of ability to monitor and experiment with their systems to achieve unparalleled efficiency and effectiveness.

Process Twinning

Digital twinning isn't just limited to physical objects; it can be used to twin processes and workflows as well. Process twinning empowers the optimization of operations involved in refining the raw materials production of finished goods. Purely business-focused workflows, even those that still have humans in the loop, would also benefit from DT modeling, allowing managers to tweak inputs and see how outputs are affected without the risk of upending existing workflows, which would otherwise cause business to grind to a halt. Process twinning will enable senior corporate leadership to monitor key business metrics in a much more data-driven manner than has been previously possible.

Conclusion

Digital twinning is emerging as a hierarchy that includes parts, products, systems, and process twins. The lowest level—the parts twin—is the simplest, with each subsequent level providing more sophisticated and more diverse types of information. By taking the lowest level parts and putting them back together, you can build sophisticated yet comprehensible systems.

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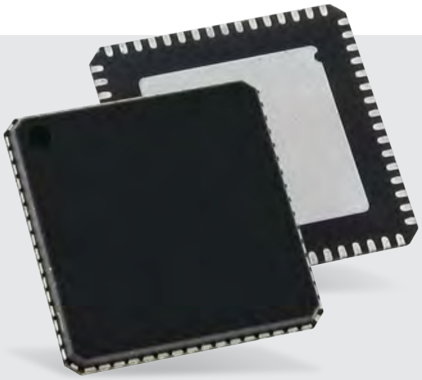

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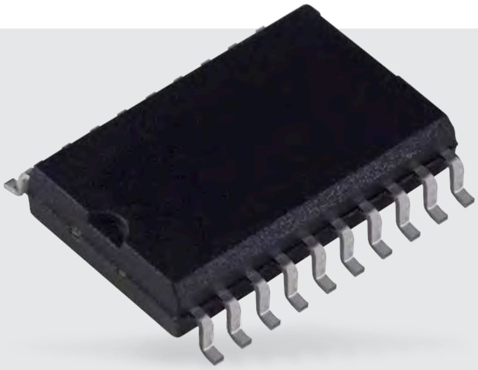

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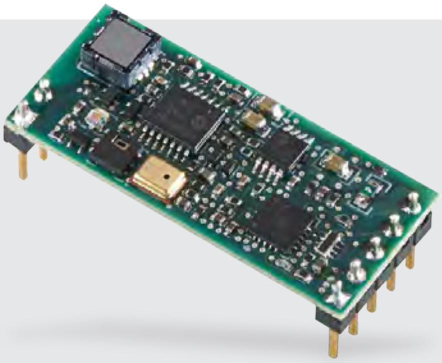

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Real Asset
Digital Twin

New Technologies Pair the Physical with the Digital

By Paul Golata for Mouser Electronics

Digital twinning is one part of the technology road map for Industry 4.0 and the Industrial Internet of Things. A gamut of new technologies must be integrated to work seamlessly together to pair the physical domain with the digital information domain.

Digital twinning seeks to improve the design and maintenance of physical systems by offering data-driven ways to discretely map these physical systems into digital and computerized replicas of themselves. With the arrival of automation and data exchange, digital twinning could be useful in a myriad of industrial applications.

This new industrial context, where the physical and the digital worlds meet, is known as the fourth industrial revolution—or Industry 4.0. Brought on by the intersection of a host of high-technology electronic and computer systems, the "new way" of Industry 4.0 promises increasing gains, efficiencies, and flexibility. A gamut of new technologies must be integrated to work seamlessly together to pair the physical domain with the digital information domain. Digital twinning is only one part of the technology roadmap for Industry 4.0, as these additional technologies are helping to enable digital twinning for Industry 4.0 to manifest its potential:

- Pairing technologies
- Cyber-physical systems
- Augmented, virtual, and mixed reality
- Artificial intelligence
- Additive manufacturing
  - 3D printing
  - Digital thread

Pairing Technologies

Pairing technologies are critical to digital twinning and the world of Industry 4.0, as these technologies empower a device or system to find, connect, and communicate with other devices and systems. For example, sensors and the Industrial Internet of Things (IIoT) products require the ability to find and connect with other devices successfully. Technologies such as *Bluetooth*®, among others, are employed to make these connections. To accomplish this, connected devices must be able to interrogate other potentially connectable devices successfully. When inquiring other devices, units must be able to ascertain whether they are communicating with a unit that they should be corresponding and exchanging data with. When properly enabled and successful, this accomplishment is called pairing.

Security issues are paramount. Every device should pair only after proper identification has been confirmed to avoid crosstalk or misinformation. Shortcuts may be achieved through programming algorithms that allow the devices to quickly and easily identify other units that they should pair with. Pairing gets accomplished through authentication keys employing cryptography. Pairing works to ensure that the connections stay bonded in a data exchanging relationship between devices and works to prevent an external source from prying into their data exchanges.

Being that flexibility is paramount, units must be able to make and break their pairing quickly and without external, human involvement. Successful pairing may require ongoing communication to keep the pairing active. If one of the units determines that the pairing bond is no longer relevant to its successful operational objectives, it will remove its pairing relationship and present itself available for a different pairing opportunity.

Cyber-Physical Systems

The National Science Foundation (NSF) defines cyber-physical systems (CPS) as, "The tight conjoining of and coordination between computational and physical resources." The critical element in this definition is that it focuses on a system approach—where a set of connected things or parts form a complex whole.

A current example of a CPS is the automated airline flight-control systems. Industry 4.0 requires traffic control, not for airplanes, but for the machines, computers, robots, sensors, and processes

[CONT'D ON NEXT PAGE]

that comprehensively work together for its realization. It represents a system of higher order than IIoT, because it sits one level higher in the complexity chain. Where IIoT is concerned with collecting, handling, and sharing of large amounts of data, CPS is focused on ensuring that this large amount of data, collected from multiple systems, gets properly utilized across multiple disciplines that are relevant to the industry involved. The unique dilemmas of any given industry will require engineering expertise to address these specific challenges.

Augmented, Virtual, and Mixed Reality

New technologies are augmenting our reality. They are providing us with the ability to overlay digital content in front of us physically, merging the real with the virtual, creating a mixed reality that should be considered augmented. This gain is allowing engineers to view things in new ways. For example, rather than viewing a DT on a computer monitor, we could view a DT using an augmented reality (AR) headset that enables the users to engage with digital content or interact with holograms.

The use of such AR empowers viewers to have an immersive experience whereby they engage their bodily senses.

Reality-enhancing headsets can create real-time experiences of actual conditions happening in the physical world, by way of experiencing them through a digitized environment. AR could lead to new insights and understandings. Additionally, a DT display could appear in the user's field of view, making real-time feedback that much more accessible and easy to use.

Artificial Intelligence Technologies

IIoT offers the promise to provide connected data; therefore, useful data must be stored and analyzed. Artificial intelligence (AI) is a solution to how to analyze and successfully handle large amounts of digital data. It helps in allowing digital twinning to become more realized because it promotes value by enabling rapid integration, hybrid integration, investment leverage, and system management and compliance.

Through machine learning, it offers the opportunity to use digital data to model, analyze, train, apply, and infer how best to make decisions. AI is helping to change the traditional perspective of computing, moving it beyond what primarily has been an automating- and scaling-process perspective towards a knowledge-based perspective, via actionable insights. Soon, it will help engineers gather new insights and ways to create value. By using a data-science approach, rapidly powered decisions will enable the generation of further opportunities.

Additive Manufacturing

Additive manufacturing (AM) is a method of production in which 3D objects are built by adding layer-upon-layer of material. AM holds promise because it leads to industries that can address variable demand and produce products that are distributable and flexible. Two areas of AM – 3D printing and digital thread – are advancing to make digital twinning possible.

3D Printing

3D printing is perhaps the most well-known example of AM. In 3D printing, a printer is programmed to print an object using plastics, metals, or other custom materials with virtually zero lead-time. 3D printing is extremely flexible and eliminates the issues involved in producing objects with large economies of scale. What this means for the future is that you will be able to get what you want quickly—as if walking up to the fast food counter.

Digital Thread

With complex systems, however, AM has been confined primarily to the laboratory because all the systems involved do not operate under a unified system and, thus, are hard to scale. Digital thread promises to change that.

A digital thread is a single, seamless strand of data that acts as the constant behind a data-driven digital system. It activates the potential of AM by allowing a unification of disparate applications by way of their adherence to the thread, which is their source of shared information. A digital thread creates an easier process for collecting, managing, and analyzing information from every location involved in the redesigned Industry 4.0. It enables better and more efficient design, production, and utilization throughout the entire process.

Conclusion

Digital twinning will be a hallmark of Industry 4.0, helping to increase gains, efficiencies, and flexibility for existing products and processes. But digital twinning is just one part of the Industry 4.0 road map. Pairing technologies, CPS, AI, and AM are key to seamlessly bringing together the physical realm and the realm of its DT information and insights. While these technologies are bringing their complexities into the digital twinning equation, ultimately, they promise to enable Industry 4.0 to manifest its potential.

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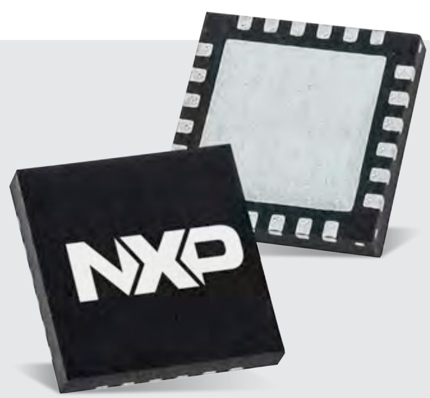
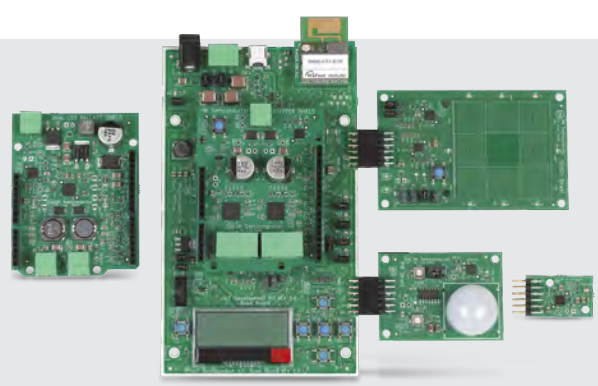




Embracing Interoperability and Deep Sharing Among Applications

By Michael Parks, PE, for Mouser Electronics

Embracing the concept of the digital twin will force product developers to rethink the "islands of applications" approach if they want to remain competitive in a world of ever-shrinking product cycle times and increased competition as manufacturing technologies become more accessible to a broader number of design firms.

Companies that design and manufacture mass-produced electronic products must contend with a plethora of different software applications during the entire product development and sustainment lifecycle. These software families include (to name just a few):

- Computer-Aided Design/Engineering/Manufacturing (CAD/CAE/CAM)
- Product Lifecycle Management (PLM)
- Manufacturing Execution System (MES)
- Application Lifecycle Management (ALM)
- Application Performance Management (APM)
- Quality Management Software (QMS)
- Customer Relationship Management (CRM)
- Enterprise Resource Planning (ERP)
- Supply Chain Management (SCM)

Each of these contains a mixture of common and unique data about the product or its associated processes and relationships to business functions. Often, the data isn't natively interoperable between systems without some level of manual effort. Embracing the concept of the digital twin (DT) will force product developers to rethink the "islands of applications" approach if they wish to remain competitive in a world of ever-shrinking product cycle times and increased competition as manufacturing technologies become more accessible to a broader number of design firms.

Iterative Design and Engineering Process

One of the most tantalizing benefits of the emerging DT concept is the nearly seamless capability of real-world data feeds through prototypes and fielded products in the iterative design and engineering process. By incorporating sensors that monitor both the health of the product and its operating environment, engineers can gain an understanding of the nuances involved in a device's functionality within actual operating conditions.

Furthermore, leveraging the ubiquitous Internet as the medium by which to transport data between the fielded product and the DT means that the operational and maintenance history of literally every device becomes helpful in refining both the DT and subsequent product generations. This is encapsulated in a five-step process model:

1 Create

Initially, one should capture a design (mechanical, hardware, and software) in a manner that creates deep sharing between applications. This will require an existing CAD/CAM/CAE that embraces interoperability and appreciates the entire workflow involved in the product design. Vendors that don›t open their applications to others (whether upstream or downstream from their own) may soon find themselves a lonely island.

2 Communicate

Enable a device to report its condition and operations back to its DT so the virtual representation can remain up-to-date based on real-world feedback. IoT and enabling technologies will be crucial in providing the communication infrastructure necessary to connect the digital and the physical.

3 Aggregate

Information about a single object is great but being able to seamlessly collect data points from an entire product line is invaluable. Communication to the equipment manufacturers regarding all data, both performance data and external factors (like ambient temperature), is possible in real time to improve the DT model and simulation variables. New classes of database software are necessary to handle the data volume and complexity that IoT generates and DT consumes.

4 Analyze

DT can then analyze the operational data and predict failures if it sees data points outside of prescribed tolerances. For example, a circuit board might see higher than expected operating temperatures or motors experiencing an unusually high number of stop-start cycles. DT can determine with (some level of confidence) that the part will soon fail and take a series of approved actions, such as placing an order with the company responsible for manufacturing the failing part and alerting a technician to brush up on the process for replacing the component. Thus, any downtime will be minimal and relatively predictable.

5 Adjust

Lessons learned from analyzing fielded systems could be helpful in refining future iterations of a product by providing real-world data points. Access to unadulterated data, free from an end user's subjective perceptions, enables faster development cycles, significant reductions in product defect-detection time, and/or an identification of useful tweaks. This access also reduces waste by allowing manufacturers to make real-time improvements to products still coming off the assembly line. DTs allow designers to test different "what-if" alternatives, as the cost is negligible, and the risk of failure is low. This can translate into huge savings by omitting costly rework.

"DTs will force shifts in business priorities such as investment in telecommunication infrastructure and/or cloud-based services."

Other Valuable Insights

DT abilities go beyond tweak assessments of the physical properties of a design. DTs can also make it easier to study software and firmware revision impacts on performance. Various configurations and settings can undergo rapid testing and assessment to determine which ones will deliver optimum performance. Firmware could seamlessly push out updates to all relevant devices by leveraging the same Internet connection that initially sends the data out to identify improvements.

Coupling DTs with other emerging technologies that possess product design implications, such as augmented reality (AR) goggles, could empower engineers and designers to experiment with near-endless design alternatives before they commit to a final solution. DTs will allow assembly-line technicians to create a construction-schematics virtual overlay on top of the physical construction in progress. This will help to identify potential defects far earlier and more efficiently during production, than otherwise possible. If any issues arise, the DT model's rich, visual experience (unencumbered by fumbling through of paper drawings) will translate into significant efficiency gains on the production line.

Desktop manufacturing tools, such 3D printers, laser cutters, and milling machines, are continuing to evolve as well. Soon, these machines will be able to leverage DTs to empower Global Development teams to collaborate virtually and produce (at least) prototype-like physical objects by clicking a button.

Conclusion

DTs will force shifts in business priorities such as investment in telecommunication infrastructure and/or cloud-based services. Soon, designing with applications software in mind will no longer be sufficient; instead, engineers and technicians will need to become more tech savvy for the benefit of their designs, especially in industries that don't traditionally shift as quickly as consumer-oriented industries do. By seamlessly bringing what's virtual and physical together, DTs are positioned to change almost everything about how the world's industries build and sustain physical products.

Enhancing the Bottom Line: Digital Twins Provide Business Insights

By Ed Baca, Technical Marketing Manager, TTI, for Mouser Electronics

Many companies struggle to determine what they should be doing to drive and deliver real value, both operationally and strategically. Digital twins can provide business insights.

IoT and Industry 4.0 are the topics leading the conversation this year, and advances in connected devices have exceeded many experts' estimates. New efficiencies based on intelligent sensors, real time communications, automation, and robotics will optimize industries ranging from mining, agriculture, and shipping to manufacturing verticals including electronics, automotive, and petrochemical products. As this trend continues, many companies struggle to determine what they should be doing to drive and deliver real value, both operationally and strategically.

The connected digital system embedded in every IoT implementation has the promise of bringing value to an organization's bottom line with enhancements in efficiency and productivity. Once this system is operational, how does a company know if they are achieving the greatest possible benefit? Can they decrease waste, shorten production time, and improve their value to the end customer?

One way to determine if a company is maximizing efficiency and productivity is to create a digital copy of the system, process, and physical objects. This replica—the digital twin—responds to stimulus like a physical system does.

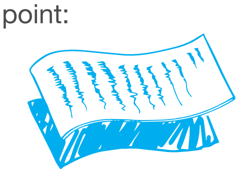
Gaining Business Insights

Until recently, digital twinning was cost prohibitive because of the massive compute power, bandwidth, and storage requirements necessary to model an active process in real time; however, reductions in hardware and storage costs, as well as increased software performance, have led to affordable process modeling with great results. This is not an easy task to accomplish, but the benefits outweigh the cost when implemented correctly. A digital twin that evolves along with the physical object offers several potential business benefits. For example, it can:

- Allow companies to have a complete digital framework of their manufacturing process and products
- Help companies better understand how products are used in the field
- Enable a view of the product life cycle, from introduction to adoption and, eventually, obsolescence
- Realize value in shortened time-to-market by improving operations and reducing defects
- Discover new business models to drive revenue

Identifying and Prioritizing Processes

A fundamental challenge in starting a digital twin process is understanding the ideal level of features or detail in each aspect of the digital twin system. A simple system with broad characteristics may not have the desired outcome, while trying to model thousands of sensors, actuators, and complex circuits will almost guarantee failure because the task is too overwhelming. As a starting point:



1. **Create** a list of processes in your system that could benefit from having a digital twin, including all organizations in your company such as operations, engineering, research, sales, and product management.

2. **Visualize** the benefits of having a predictive model that may reveal process improvements or cost savings.

3. **Prioritize** the list to undertake the most beneficial process first.

Then, identify data from sensors, encoders, and actuators:

- How do these physical objects respond to conditions?
- How can the actions and responses be represented using as few assumptions as possible?
- How do these devices respond to ambient temperature, humidity, and barometric pressure changes?
- Should the data be collected and processed at the edge of the network, or can it be done in the cloud or central location? The process response time of the digital twin should mirror that of the physical system to truly have a digital replica of the actual process.

Conclusion

The digital twin promises to help organizations realize a bigger bottom line by helping them understand—and maximize—efficiency and productivity. Recent reductions in hardware and storage costs, as well as increased software performance, have made digital twinning possible for more companies than in recent years.

Although many companies struggle to identify the right level of detail for the twin, creating and prioritizing a list of processes is the first step, followed by understanding data provided by sensors, encoders, and actuators. For best results, the digital twin should mirror the physical process in every aspect and use as few assumptions as possible.

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Digital Twinning Raises the Bar for Edge-Node and Sensor Designs

By Paul Pickering for Mouser Electronics

Digital twins impose stringent demands on sensor installations, especially for legacy applications. Implementing a digital twin system requires that designers pay careful attention to sensor performance and bandwidth limitations to arrive at an optimum solution.

Spurred by the ubiquitous connectivity of the Internet of Things (IoT) and low-cost sensors, the digital twin (DT) model is quickly becoming a part of manufacturing and other industries. But implementing a DT program imposes stiff requirements at all levels of the signal chain, particularly at the edge node located close to or on the machines being twinned. This article will outline sensors and edge-node architecture, discuss the importance of the edge node, and discuss edge-node communications, all lending themselves to maximizing a DT's full potential.

Sensor and Edge-Node Architecture

Digital twinning architecture closely resembles three-level IoT architecture (**Figure 1**):

- Sensors at the edge node gather real-time information about the operation of a functional unit (such as an industrial robot, aircraft engine, or wind turbine) and transmit this information over a wired or wireless local area network (LAN).
- A gateway node communicates with multiple edge nodes (possibly using a variety of protocols) and combines this information into a wide area network (WAN).
- An enterprise node receives gateway data, applies it to the digital model, and communicates the results.

With a sufficiently accurate model and high-quality data, a DT can predict failures, boost efficiency, and even make changes in real-world operations.

The Importance of the Edge Node

DTs require a constant stream of high-quality, real-world data to validate the performance of a virtual machine against its physical counterpart. Otherwise, the real and virtual worlds will gradually diverge, and the calculations and predictions of a DT will be of little value.

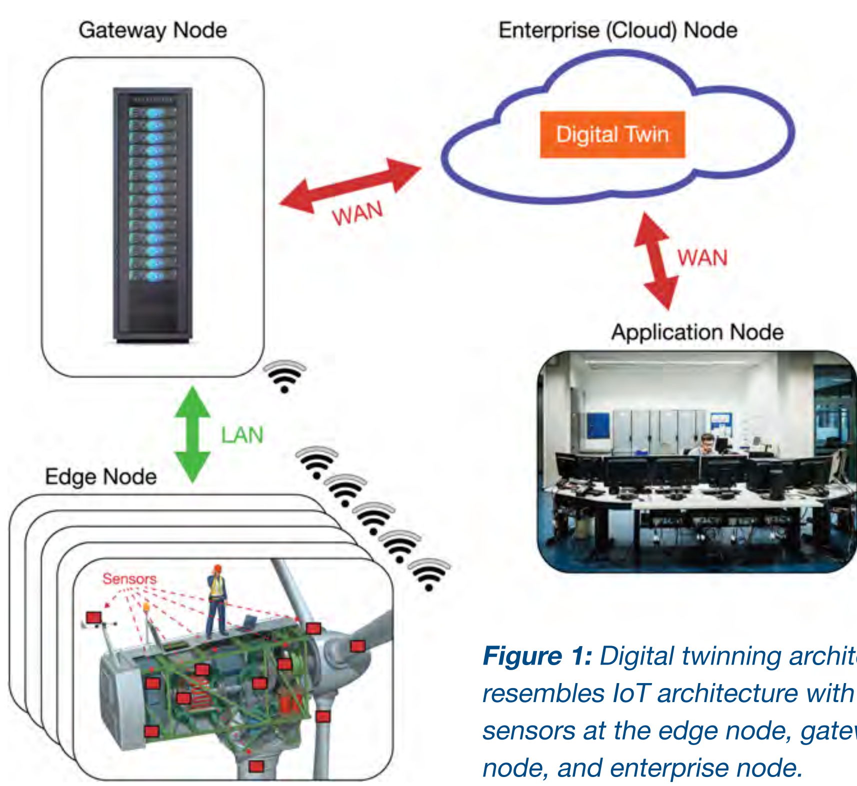

Figure 1: *Digital twinning architecture resembles IoT architecture with sensors at the edge node, gateway node, and enterprise node.*

An edge node is fundamental to this data-gathering process because it contains sensors that gather real-world, operational and environmental data and contains communication links that send this information upstream. If a DT can make changes to the physical process, an edge node contains actuators that allow this process to happen.

"An edge node is fundamental to this data-gathering process because it contains sensors that gather real-world, operational and environmental data and contains communication links that send this information upstream."

Sensor measurements fall into two categories:

- Operational measurements (relating to the physical performance of a machine or device), such as tensile strength, speed, flow, displacement, torque, operating temperature, or vibration
- Environmental or external data (affecting the operations of the physical process), such as ambient temperature, barometric pressure, and humidity

Edge-node sensors can take many forms. Devices such as temperature sensors, pressure sensors, load cells, and accelerometers measure real-world characteristics and generate numerical information. Sensor fusion systems combine the results of multiple sensors to generate insights that are not possible from any single device. Cameras and microphones create streams of video and audio using complex, unstructured information that requires extensive processing to interpret.

Legacy Machines Pose Challenges

Ideally, DT design begins with a digital design that serves as a model for the real-world installation so the sensors providing the real-time data can be included in the model and carry over to the final version. This is certainly the case in many high-technology applications in the oil and gas, nuclear energy, aerospace, and automotive industries. But problems can arise if a machine design predates the implementation of a virtual model. Upgrading an edge node to activate digital twinning brings a new set of challenges.

Designers in more traditional industries rarely have the opportunity to design a DT's real-world counterpart from the ground up. Instead, they must work with an existing factory infrastructure that may have been operating quite well for years, if not decades. If so, the DT infrastructure must be "grafted" onto the existing system. Although an underlying system may be a good candidate for digital twinning, the integration process becomes exponentially more complex if an existing machine has few or no sensors monitoring its performance. In this case, dozens to hundreds of sensors must be grafted onto a machine that was never designed to accommodate such technology.

Even if an original machine has sensors already in place, the sensors accuracy may not be sufficient to provide useful data to a digital model. An installed temperature sensor, for example, may function only to detect an over-temperature fault but not to provide the quality of data necessary to identify a pattern of temperature overstress, which might help predict an early failure.

The capacity of an installed communications network is another potential issue. A traditional IoT installation uses many different wired and wireless standards to connect edge nodes to their respective gateways. These include such industry standards as:

- Zigbee®—for low-power mesh applications
- Sub-1GHz—for low power and long range
- Wi-Fi—for a direct internet connection with high speed
- *Bluetooth*®—for the lowest power
- And many more

Each standard must undergo a careful evaluation to decipher if it can handle burden increases by digital twinning data.

Specialized Sensors Are Common Thread in Existing DT Applications

Although digital twinning is in its infancy in many industries, many technology products undergo design, testing, and validation in the virtual world long before the first prototype ever sees daylight; these products also tend to gather large numbers of data from specialized,

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real-time sensors. Aircraft engines and Formula 1® racing cars are two good examples:

Aircraft Engines

Aircraft engines are already highly instrumented. A traditional turbofan engine (**Figure 2**) contains sensors to measure pressure, temperature, flow, vibration, and speed. Multiple specialized sensors exist within each category: For example, for pressure there are turbine pressure, oil pressure, oil- or fuel-filter differential pressure, stall detect pressure, engine control pressure, bearing compartment pressure, and more sensors types.

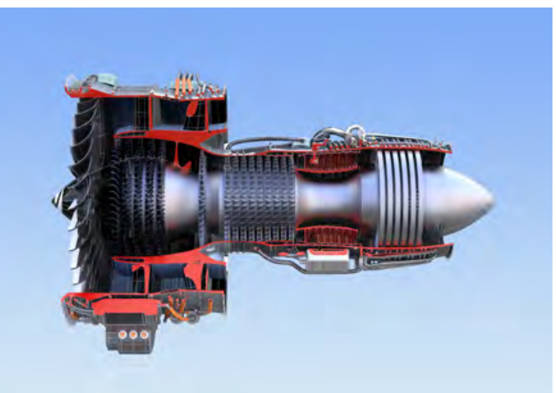
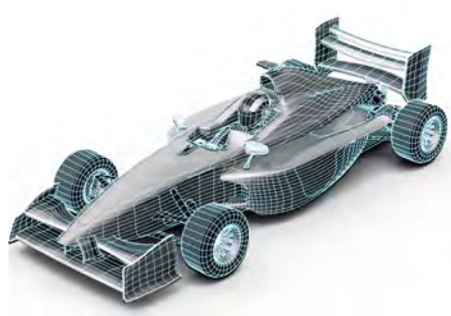


Figure 2: *An edge node, like that in an airplane turbofan, contains hundreds of sensors, so adding a DT requires an order-of-magnitude increase.*

A DT requires much more data than a traditional monitoring application, so its sensor design must accommodate the increased requirements. Although most airplane engines in service today contain fewer than 250 sensors, manufacturers are demonstrating next-generation, DT-compatible products containing more than 5,000 sensors. Additional data comes from sensors monitoring fuel flow, fuel and oil pressure, altitude, airspeed, electrical load, and outside air temperature. Rolls-Royce, GE, and Pratt & Whitney are already using DTs to increase reliability, boost efficiency, and reduce maintenance costs.



Formula 1 Racing

DT technology helps improve driver and car performance in the high-pressure world of Formula 1. The McLaren-Honda team, for example, uses over 200 sensors to transmit real-time data relative to the engine, gearbox, brakes, tires, suspension, and aerodynamics. During a race, the sensors transmit up to 100GB of data to the McLaren Technology Centre in Woking, UK, where analysts study the data and use the DT to relay optimal race strategies back to the driver. The DT virtually drives in the same race as the physical car, even adjusting itself to the same road conditions, weather, and temperature.

The Future of DT Edge-Node Architectures

If a DT model is to undergo full implementation, several issues with the existing edge-node architecture must be solved:

Smart Sensors and Edge-Node Processing

As sensors gather ever-increasing amounts of data, it's important to have a clear understanding of how to use the data in a digital model and where to process the data, whether at the node, at the gateway, or in the cloud. Processing at the node reduces network bandwidth but risks losing information that would reduce DT performance.

The type of sensor has a bearing on the decision. Although many sensors transmit information in a structured format that's easy to use (like the digital transmission that denotes pressure, for example), those such as microphones and image sensors produce massive volumes of raw data that's unstructured and useless without extensive processing, no matter where it's performance occurs.

Enhanced Communication Interfaces

Despite increasing edge-node processing, vastly increased data flow will require system designers to perform network bandwidth increases at all levels. Aircraft engines, for example, generate up to 5GB per engine per second and up to 844TB per day for a twin-engine airplane in commercial service.

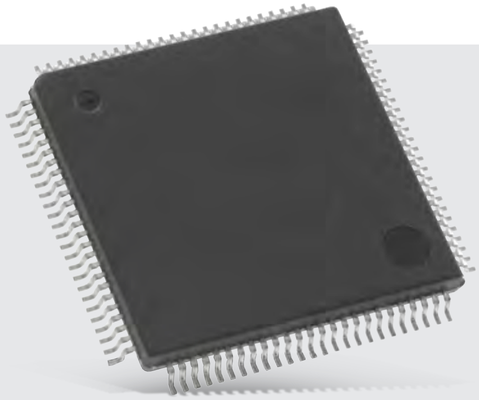
Traditional industries produce large volumes of data, with an additional complication: Many remotely located edge nodes in traditional, industrial IoT applications use battery-power and low-performance wireless protocols for low-power consumption optimization. The existing design tradeoffs may need a re-evaluation to detect communication bottlenecks.

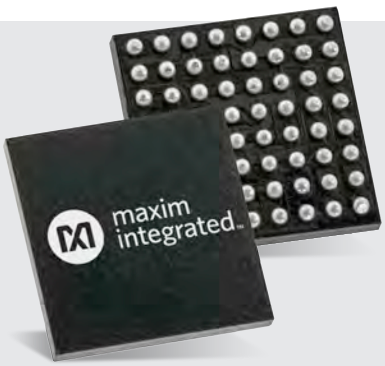
Robust Edge-Node Security

Existing IoT installations have created new security issues in edge-node devices, and security measures such as encryption, secure hardware designs, application keys, and device certificates are becoming more common. Increases in DT adoption will raise the importance of these technologies, especially in nodes that add Internet Protocol (IP) connectivity—which opens an entry point for would-be hackers.

Conclusion

Implementing a DT program imposes stiff requirements at all levels of the signal chain, particularly at the edge node located close to or on the machines being twinned. The edge node is fundamental to digital twinning because it contains the sensors that gather real-world, operational and environmental data and contains the communication links that send this information upstream. Digital twinning is currently being used in industries like aerospace and automotive, where there are many kinds of specialized sensors that are essential for digital twinning. In retrofitting equipment for digital twinning, dozens to hundreds of sensors must be grafted onto a machine that was never designed to accommodate them. For digital twinning can continue gaining traction, several solutions are vital and must live within sensors as well as in edge-node processing, communication processing, and edge-node security.





Digital Twins Help Solve Component Selection Challenges

By Michael Parks, PE, for Mouser Electronics

Innovation often—perhaps always, some would argue—brings additional engineering problems to solve, but it's not every day that the innovation itself helps solve them, too. Digital twinning has the potential to do both.

Digital twins (DTs) create a bit of a paradox: On one hand, they can dramatically increase the need for sensors and other components, as well as increase the need for fast, seamless, and reliable connectivity. Yet on the other hand, DTs can also solve challenges that engineers face in addressing these increases and help them more quickly and confidently select components. Innovation often—perhaps always, some would argue—brings additional engineering problems to solve, but it's not every day that the innovation itself helps solve them, too.

DTs Require More Components, Seamless Connectivity…

Embracing DTs means embracing data—lots of data from as many physical twins as possible, which means including additional hardware beyond what is essential for core functionality of whatever is being built. It also means embracing additional sensors that capture ambient conditions, product health, and user interactions so that the DT can better understand the experience of its physical counterpart.

Correspondingly, connectivity becomes more crucial under this new paradigm: The telemetry that sensors place onboard a physical twin is useless if it cannot provide feeds back to the DT as part of a product's digital thread. To be useful, communication must be fast and seamless. For most products, this means using wireless connectivity to pass data on to the Internet and back to a design team—Wi-Fi (802.11) or cellular-based (4G or the upcoming 5G) solutions being the most popular route for consumer-oriented devices. Low-power wide-area network (LPWAN), 5G cellular, and various mesh-network topologies are among the potential options for industrial applications. Wireless connectivity and multiple sensors inclusion have implications regarding energy management, especially if a product is battery powered.

…But DTs Also Help Solve Those Additional Challenges

Often in engineering, a job's completion is reduced to design tradeoffs. Sometimes, a component choice is purely driven by technical need. Other times, tradeoffs stem from real-world issues, such as cost targets or component availability. Regardless of why tradeoffs occur, there are often consequences for poor choices, such as product recalls. In the era of agile development, "fail early and fail often" is a mantra for getting a product built fast. DTs give engineers a safe sandbox to do just that and, in doing so, DTs help to reshape product engineering and development.

Embedded systems designers, perhaps more so than others, recognize the many challenges in selecting a component. A quick search for resistors on Mouser's website translates into 17,961 pages (at the time of this writing), and each page contains 25 line items (meaning a lot of options!). Even modest circuit designs contain a combination of resistors, capacitors, transistors, LEDs, voltage regulators, and perhaps even an integrated circuit (IC) or two. With that level of complexity, even seasoned engineers sometimes rely on a trial-and-error process in certain aspects of the prototyping phase of product development.

The DT can aggregate all data and help the engineer make informed decisions on design factors such as component selection. With insights gained from real-world data, engineers can more accurately test the impact of components swapping in a design. For example, what would happen to overall product failure rates if a certain switch were replaced by one similar in in every way except for having a shorter mean time between failures (MTBF)? The frequency of end-user-switch presses, data that can be collected from the physical twin, can feed to the DT via the digital thread. That's when it becomes a straightforward pairing process of various DT versions with potential switches until a pair is found that balances cost with technical performance. Ultimately, DTs can help from not only a technical perspective but also a business perspective.

Conclusion

While innovation often brings additional engineering challenges, it's not every day that the innovation itself helps solve them, too. The DT is one such innovation that increases requirements for components and connectivity, yet helps solve these problems as well. A paradox or just plain genius? The answer is yet to be seen as the potential of DTs unfolds in the years to come.

Addressing Data Security and End-User Privacy in Digital Twinning

By Stephen Evanczuk for Mouser Electronics

The same qualities that make digital twins high-value targets also make them invaluable aids for identifying possible threats and understanding the impact of these threats on a physical device, its immediate environment, its users, and its enterprise.

Digital twinning holds great promise for revealing deep details about product functionality, but it may reveal much more. In providing a faithful, virtual replica of its physical counterpart, a digital twin (DT) exacerbates any weakness in a real product›s ability to ensure security and privacy. At the same time, digital twinning offers unique opportunities for enhancing both focal points of protection.

Cyber threats are a fact of life for any connected product. By simply connecting a device to a network, users expose their products to a great number of additional attack surfaces, and new zero-day vulnerabilities continue to emerge. The industry finds itself awash in security alerts for hardware and software components that have been trusted at the most fundamental levels of product functionality and network operation.

A true DT faces exactly the same threats and operates with the same security policies intended to safeguard the physical device. At a deeper level, the DT ideally implements those policies using the same cybersecurity mechanisms employed in the physical device. The net effect is that interactions with external entities are seen to be secured in the same way, relying on the same authentication methods to confirm the identity of those entities and the same encryption methods to protect their interactions. As seen through their public interfaces, the virtual and physical devices are considered indistinguishable—and do suffer from the same vulnerabilities.

New Vulnerabilities

Digital twinning means that engineers can strengthen shared vulnerabilities by applying the same policy and mechanism to both the physical and the virtual devices. Yet, digital twinning can expose a different, potentially more damaging kind of vulnerability.

A fundamental opportunity associated with digital twinning is its ability to engage a wide body of resources both inside and outside the enterprise with the product. By working with the twin, each participant across the entire product life cycle can apply their own expertise for the mutual benefit of all stakeholders and their mutual customers. To serve its role in this analytical process, the DT gathers and encapsulates vital, intellectual property and exposes interfaces more extensively than even the physical product itself does. Indeed, virtual devices need to offer deeper visibility into internal operations and more instrumentation for monitoring those operations than the physical product would ever provide.

These factors alone add to concerns for maintaining security and privacy. For example, a DT (by definition) lacks hardware-level features such as secure-key storage needed for effective security. Similarly, a highly instrumented DT may inherently result in a preservation of actual private user data that might be ephemeral at best in a data aggregator.

By its nature, a DT may preserve intellectual property, secure assets, or private user data in embedded instruments or in "side-channels" used to monitor or even control the virtual device. Proprietary algorithms and data spread across circuits and software or locked deeply in the physical device may probably

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"Digital twinning provides the ultimate side-channel for monitoring a system's behavior, detecting an attack, and employing mitigations sophisticated enough to fool attackers—keeping them unaware of their own exposure."

DTs—becoming ripe plums for a dark harvest. In providing a convenient assemblage of so many secrets, DTs are likely to emerge as higher value targets than the physical devices they mimic. Why acquire a physical device when a much more valuable target is a few keystrokes away, wrapped only in security layers ridden with zero-day defects?

New Answers

Of course, engineers can address each of these concerns with more stringent safeguards. In doing so, however, development organizations may find that locking down the DT's security becomes a project of its own, even at the risk of defeating DT›s purpose as an accessible asset. At the same time, legitimate concerns will emerge about the loss of fidelity between the virtual and physical in deploying increasingly severe measures for security and privacy. Ultimately, stakeholders will wonder to what extent the cure is worse than the disease.

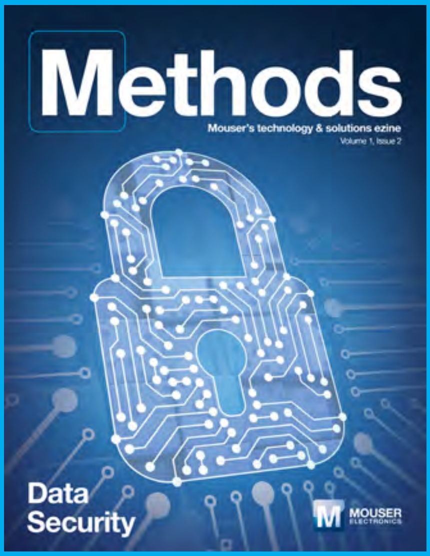
Yet, in these very symptoms lay the answer for the cure. The same qualities that make DTs high-value targets also make them invaluable aids for identifying possible threats and understanding the impact of these threats on a physical device, its immediate environment, its users, and its enterprise. In fact, DTs offer several possibilities for enhancing security and privacy through existing and emerging approaches.

For example, threat and risk assessment methodologies require a deep understanding of design details as well as a broad perspective of functional objectives. Identifying all reasonable threats requires a comprehensive catalog of the components, interactions, and processes that reach across the atomic trust boundaries in a device or system. In assessing risk, one must understand the device or system at a broader level that is consistent with user requirements and enterprise objectives. Few assets can provide the kind of evidence-based assessments that become possible with a DT. What could be a better environment for developing effective threat models than a model-based, virtual environment? Similarly, engineers can virtually prod each component to understand risk in a way that is simply too costly for or even impossible with the physical device. Emerging tools are already beginning to automate threat analysis through identifying vulnerable components—an approach that can be further energized with the details inherent in a DT.

Besides cataloging potential threats, security-conscious organizations maintain constant vigilance to identify early signs of an attack. Although active security depends on the successful orchestration of a number of methods, digital twinning offers a powerful tool in this effort. Enterprises can use a DT to identify potential behavioral anomalies in physical devices that suggest a potential compromise or active attack. Although this approach already forms the basis of high-security detection environments, application of this technique using DTs presents a significant challenge because of the amount of data involved. Yet, emerging and accessible machine-learning tools promise a likely solution, even to this problem.

The struggle between white hats and black hats will continue as sure as the tide that ebbs and flows—one surging ahead to later fall behind the other. Even in a perfect world of bug-free code, human nature would inevitably expose systems to attacks so sophisticated that their users would remain unaware until too late. Digital twinning, however, provides the ultimate side-channel for monitoring a system's behavior, detecting an attack, and employing mitigations sophisticated enough to fool attackers—keeping them unaware of their own exposure.

Digital twinning certainly brings new challenges to security and privacy. Yet, the solution to those challenges lay in digital twinning itself. For organizations willing to accept the challenges and explore the solutions, digital twinning offers a significant capability to implement critical improvements in product security and user data privacy.



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