White Paper

Engineering the Internet of Things

All around us connected devices are proliferating. New, innovative products are emerging almost daily, and familiar products are benefiting from newer, smarter functionality. These developments come with the promise of making us healthier and safer, as well as more efficient, innovative, competitive and profitable. The Internet of Things, or IoT, which holds great potential, also presents new challenges to the engineers tasked with building the devices. In this paper, we will identify the most critical challenges and describe a platform solution, supported by robust applications, that can help you engineer the best possible IoT products.

According to analysts' estimates, by 2025 there will be 20 to 30 billion connected devices globally, representing a market opportunity approaching $11 trillion [1]. While innovations in factory automation, smart cities, consumer electronics and healthcare stand out, virtually no aspect of the global economy will be left untouched by the "collect-connect-correlate" value of the IoT.

The research firm Gartner points out that digital technologies such as the IoT are changing business models and disrupting every industry, e.g., blurring traditional industry boundaries such as those between cars and smartphones to create the connected car. As a result, market incumbents, seeking to offset the threat posed by technologically savvy startups and new entrants from historically disparate industries, are speeding technology acquisition. In parallel, nimble IoT pioneers are accelerating their investment in digital technology and are gaining a clear competitive advantage. Jeff Immelt, CEO of General Electric, synthesized the impact of IoT when he noted, "If you went to bed last night as an industrial company, you're going to wake up this morning as a software and analytics company."

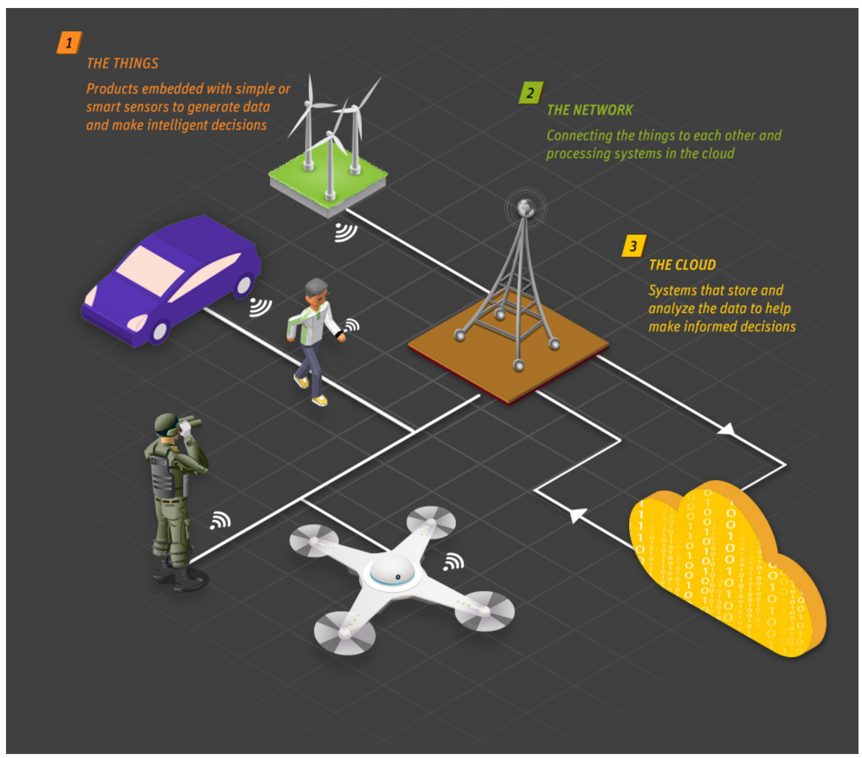
As a technology leader in your organization, it is highly probable that you have or shortly will be tasked with the implementation of an IoT strategy for your products. Like many of your peers you may be wrestling with how to begin the journey from a "product" to a "smart connected product" that requires technology and skills from outside your traditional domain of expertise.

The Three Elements of the Internet of Things

In its simplest form the Internet of Things comprises three elements: the things, the network or gateway, and the cloud, as illustrated below.

The Things

Products, such as cars, phones, robots, industrial equipment, and even homes, are becoming smart and connected. More and more processing power is being added to the things, as are sensors that may be used to measure acceleration, orientation or touch. The things also include communication systems, like Wi-Fi and Bluetooth, that connect them to the network. The main focus of this white paper is on designing the things, using engineering simulation to manage both the opportunity and complexity represented by the IoT.



The interaction of the three elements of the Internet of Things

The Network

Sitting between the cloud and the things, the network is integral to the IoT infrastructure. Without it there are no connected devices. A robust and reliable network includes high-speed routers, switches and gateway technology. Each of these components can be considered things in their own right, and can benefit from engineering simulation. Network design and protocols are important issues of the IoT, but they are not discussed in this white paper.

The Cloud

The cloud consists of data centers and the software that runs much of the business logic of the IoT. Data centers house servers along with infrastructure technology, which includes supporting networking equipment, environmental control systems and a reliable power grid. A lot of attention has been on the cloud infrastructure, but the cloud software that operates and maintains IoT devices is of special interest to engineers designing the things.

Experts agree that the value of the IoT will be fully realized through analysis of data collected from the things. For example, the vibrations of a turbine engine can provide crucial insights to improve operational decisions. Industry leaders like GE and PTC have developed platforms that can connect to simulation tools to optimize the performance of field assets and drive future innovation.

One way of optimizing performance through simulation is to use “digital twins.” The idea of a digital twin [2] begins and ends with simulation: Each physical thing has an accompanying virtual double — a digital twin. Actual performance data collected from the thing is then compared in real-time against the model predictions of the digital twin to identify possible performance issues and take preventative maintenance action. The same data can also be used to drive design and simulation of next-generation products.

While both business and technical data analytics are important to an overall IoT strategy, in this paper we will focus on the design challenges faced by engineers who create the hardware and software components for the things, the network and the cloud. Our discussion will include design of electronic components and embedded software, but exclude discussion of communication protocols and analytics systems and methods.

The Five Critical Challenges for Engineering Smart and Connected Things

Research has shown that best-in-class companies who adopt simulation-based approaches early in their product design cycle “are able to make better decisions throughout the process. This enables these leaders to drive higher quality and lower cost products, as well as deliver the innovations and features that differentiate their products. Ultimately, this pays off in a 15 percent increase in profit margins on new products, three times that achieved by their peers.” [3]

Why is simulation crucial to IoT product development? The transition from mechanical to electronic systems, including millions of lines of software has added layers of complexity. And while this transition to electronic systems has improved product reliability in many ways, the density of wireless connections, transistors, and software has created additional challenges. Simulation has been in use for decades to design components. But companies building the IoT infrastructure are dealing with multi-faceted challenges that require higher level of reliability, precision, robustness and innovation — all at reduced cost. To achieve these goals, companies can neither design in silos nor rely on traditional build-and-test methods, or they will simply be out-innovated.

Simulation has leveled the playing field, enabling smaller companies to compete with large incumbent enterprises. Using simulation, a few engineers can virtually prototype and refine their ideas — going beyond traditional engineering discipline boundaries, resorting to multi-domain and multi-physics analyses. In a recent report, the Boston Consulting Group [4] listed simulation as a critical success factor in the connected economy.

Our work across multiple industry sectors globally, with companies who are addressing the problem of engineering the Internet of Things, has highlighted five engineering challenges. While these challenges are not new to experienced professionals, the sheer size of the IoT opportunity and the competitive forces are leading to one conclusion: The winners and losers in the IoT economy will be separated by their ability to address these challenges consistently and urgently.

Size, Weight, Power and Cooling (SWAP-C)

Whether designing planes, cars or smartphones, engineers need to optimize products for size, weight and energy-efficiency, or the products may lag behind competitors. The addition of IoT technologies, such as pervasive connectivity and sensing, brings with it a higher density of electronic components, leading to additional size, weight, energy and thermal challenges. For example, the modern hearing aid is a smartphone connected device, providing significantly more functionality than previous-generation devices [5]. It includes a flexible printed circuit board, a battery, a receiver, an antenna and, in many cases, a telecoil. The flexible printed circuit board incorporates more than 60 different components and integrated circuits. The designers must manage all these components in a constrained space while optimizing performance — using enough power to deliver reliable wireless connectivity, keeping the device cool, ensuring longer battery life, and minimizing device weight, size and interference with other electronics.

Sensing and Connectivity

Smart connected products are “smart” because they can sense their environment, communicate with other electronics, and enable decisions and outcomes. For example, modern cars that contain Advanced Driver Assistance Systems, or ADAS, are equipped with a host of sensing and communication technologies. Over the next four years, the ADAS market could grow from $8.4 billion to $30 billion [6]. The adaptive cruise control function utilizes radar and laser-based sensors embedded in the bumper to keep cars at a safe distance from each other at a given speed. Blind-spot monitors and lane-departure warning systems ensure that drivers stay safely within their lanes. Cars can monitor and report traffic conditions, informing other GPS-equipped cars to alert their drivers and suggest alternate routes. Unlike previous generations of automotive engineers, the engineers designing modern cars — loaded with ADAS — need to pay added attention to reducing electromagnetic interference that may wreak havoc on the electronics. Maintaining signal and power integrity at all times is crucial; with drivers relying on these systems to make decisions, false reporting could lead to bad outcomes.

Reliability and Safety

Given the vast numbers of connected things being projected to emerge in the coming years, reliability is a must if the economic argument for the benefits of connected products is not to be outweighed by the cost of maintenance or lack of uptake by the market. Many products, such as those in the automotive, aerospace and medical industries, will be in safety-critical environments, and will need to meet relevant reliability and safety standards. This is particularly true in the realm of the embedded control and display software that is needed to operate the integrated mechatronic products of the IoT.
In the most complex products, such as connected cars and aircraft systems, validating the tens of millions of lines of safety-critical embedded software code is one of the critical paths.

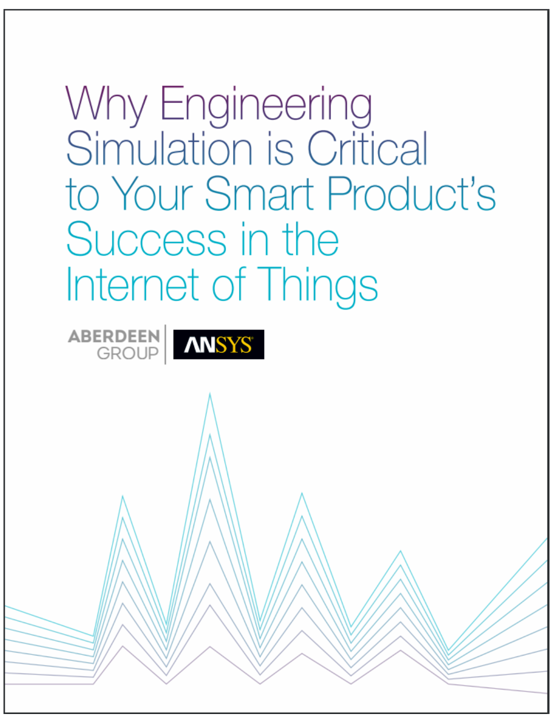
Integration

As the complexity of products has increased over time, engineers have broken down the design process into smaller pieces. While this component-level, bottom-up design methodology allows for very thorough component level verification, significant late-stage issues arise when the components are assembled to create the system. This system and subsystem-level integration effort often leads to over-design, cost-overruns, and even poor design trade-offs to meet product release deadlines. For example, when integrating an antenna in a wireless fitness band, the antenna engineer may find that the antenna isn’t working as expected. The installed performance of the antenna may be different due to the curvature of the wristband, the presence of a biometric sensor antenna, or even the metallic clasp that holds the wristband together. The complexity of IoT devices, the environment in which they will operate, and the need for higher safety and reliability mean that engineers’ late-stage integration challenges have increased significantly.

Durability

One of the attractions of the IoT is that trillions of sensors and communication systems will be deployed to collect and share useful information 24 hours a day, seven days a week. These systems will be expected to perform reliably not just in their intended environment, but also in what are often extreme, harsh environments whose exact conditions are difficult to define in advance. For example, consider a sensing system at the end of a drill bit in the oil and gas industry, or in an unmanned military system operating in a hostile electromagnetic environment. The ambitious Aquila project by Facebook utilizes a drone with a wingspan of a Boeing 737. The drone will use lasers to beam Internet to remote parts of the developing world. The design specifications for this solar-powered drone call for it to fly for up to three months at a time. These design scenarios are incredibly difficult to anticipate or explore using a physical test regime, yet the expectation is that the product must perform in these mission-critical environments.

And while not all products need to endure these extreme conditions, they need to be tested for durability. Consumer electronics users, like smartphone and tablet consumers, for example, expect their devices to withstand minor drops and impacts. Exploring and ensuring performance in a variety of operating environments is a core engineering challenge.



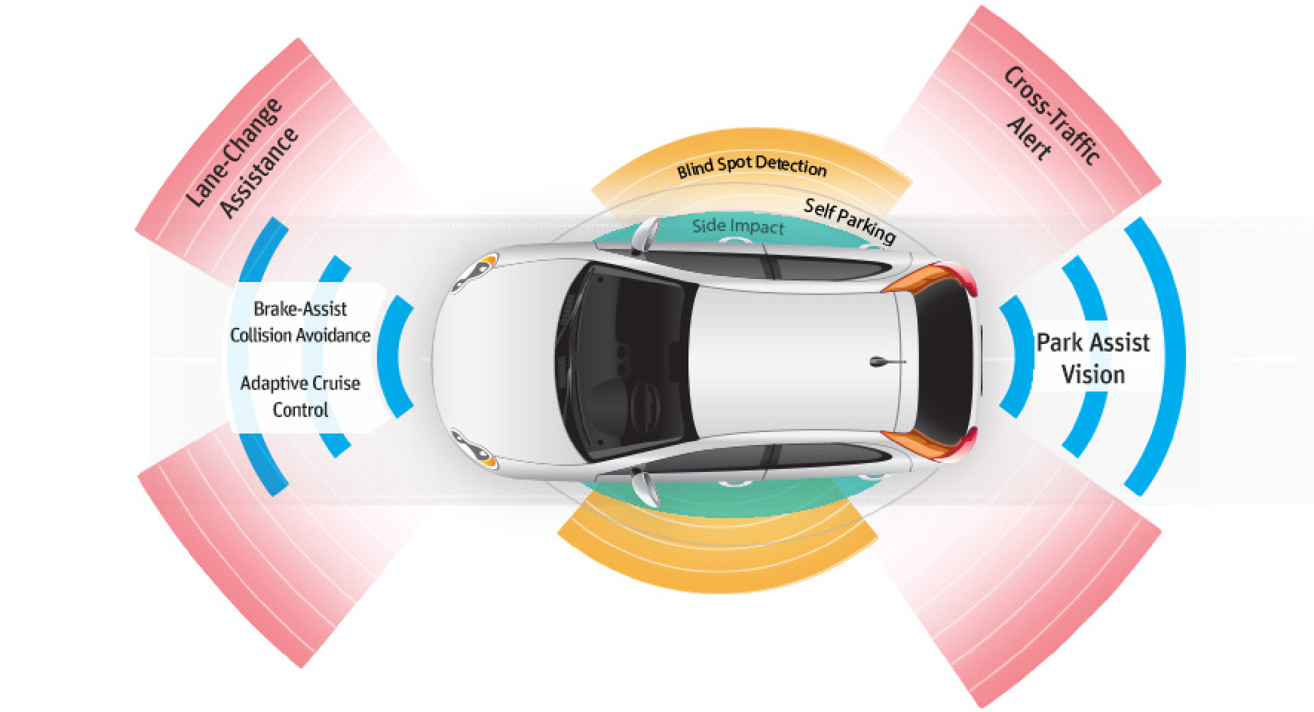
A Consolidated Simulation Platform as a Solution

Quickly developing cost-effective solutions for highly complex IoT-enabled products requires changes to engineering product development processes. We are seeing IoT product pioneers break down the barriers between traditional engineering silos and use engineering simulation tools that can connect a series of discrete functional application areas in a common working environment, or simulation platform. Research has shown that product development teams that consolidate their simulation-driven product development capabilities on a single platform are 24 percent more likely to meet product launch targets and 37 percent more likely to decrease the length of their product development time compared to those who have not consolidated. These are critical metrics that can define whether your IoT product development efforts succeed or fail in this highly disruptive and competitive business environment. ANSYS provides both the discrete application simulation capabilities and the consolidated platform to deliver an integrated IoT product development solution.

Let's consider an example. Advanced Driver Assistance Systems (ADAS) are a key technology challenge on the journey to the IoT-ready connected car. Integration of this system requires sensors, safety-critical embedded software, data processing and a complete systems engineering view. These are traditionally segregated engineering disciplines, yet the tightly coupled behavior of this system demands an integrated engineering approach and a simulation platform that supports the overall solution from the advanced physics at the component and system levels.

Take a radar system as an example. First we need to understand its stand-alone performance using simulation tools.

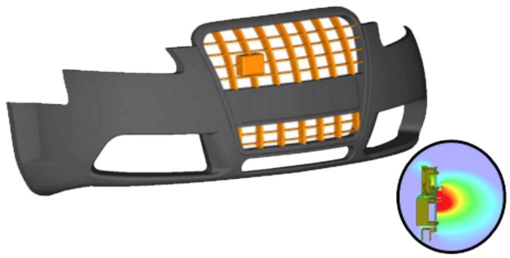
But the radar system needs to operate successfully when installed on the vehicle, and is subject to the elements such as rain and ice. Simulation of the whole radar and fascia assembly solves such integration issues upfront.



Examples of Sensor Complexity in an Advanced Driver Assistance System

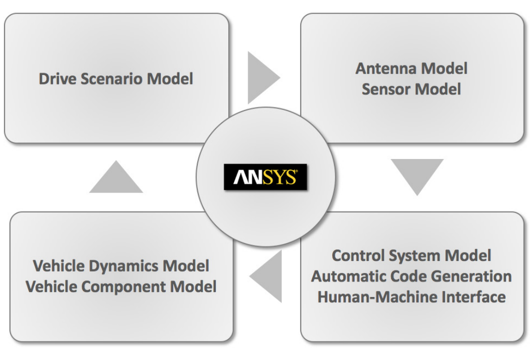
The behavior and response of the vehicle to inputs from the radar system is to a large extent determined by the vehicle's onboard control software. Verifying and validating the hundreds of thousands, and sometimes millions, of lines of embedded software, and their interaction with the physical components, is a critical path design work package. ANSYS' consolidated simulation platform enables virtual hardware-in-the-loop testing of ADAS, and automatically generates safety-critical embedded software that conforms to industry standards such as AUTOSAR and ISO 26262.

ADAS is a classic example of a large, complex system encompassing the entire vehicle. To virtually validate ADAS design, all other major vehicle systems, such as control systems, human-machine interfaces, brakes and vehicle dynamics need to be modeled in a comprehensive system simulation. Then that comprehensive vehicle and ADAS model needs to be run through a real-world model of roads, buildings, pedestrians, etc., to test the ADAS'



Integrating the radar into the vehicle

Understanding the performance of the RADAR system in the real world



Dynamic collaboration brings together multiple systems

behavior in simulated driving scenarios. The ANSYS consolidated platform provides capabilities to model most of these aspects, but also is open and collaborative, so that other third party partner software can be used in parts of the ADAS simulation loop.

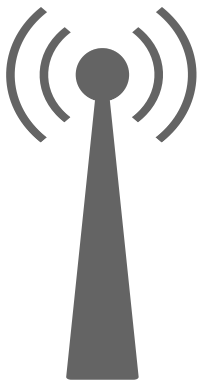
So whatever IoT device you are developing, from a wearable medical device to a drone to a connected soldier, ANSYS has a simulation-driven product development solution that enables you to realize the benefits of a consolidated simulation platform.

The Seven Crucial Applications for Engineering the Internet of Things
Of course, an integrated solution developed on a consolidated simulation platform, such as the ADAS described above, can only be successful if the underlying discrete simulation applications are in place. With over four decades of experience working with product development teams, ANSYS has identified seven applications that are crucial to designing successful IoT-enabled products, and which make up the discrete components of the consolidated platform-based solution. In the following section, we identify and explain the seven applications crucial to designing products for the Internet of Things. If IoT product development is your business, it is imperative that you and your engineers understand and apply these applications to maximize your chances of success. To illustrate these applications more clearly, we're also sharing examples from industry leaders who are using the applications to develop innovative solutions to gain market advantage.

Antenna Design and Placement
The performance of wireless systems can be very different in the real world when compared with the prototype testing environment of an anechoic chamber. Multipath signal propagation and fading are just some of the issues created by the presence of complex real-world structures, mobility, and even human beings. Additionally, modern devices use multiple wireless technologies and frequency bands, requiring multiple antennas. As a result, antenna coupling and co-site issues can degrade performance.

Consider a scenario where a wireless sensor network is deployed in a factory. Each sensor uses a dipole antenna to communicate with other sensors. The ideal radiation pattern of a dipole antenna resembles a donut, but, when deployed in an industrial setting, the complex structures and the interference from other antennas distort the radiation pattern, reducing antenna efficiency, increasing power consumption and leading to unreliable performance and failure.

So, how can engineers ensure reliable wireless connectivity within an industrial setting, or on a car, plane or smartphone without having to resort to time-consuming build-and-test methodology?



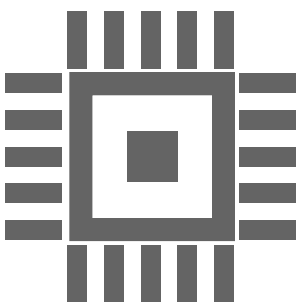
Using ANSYS solutions, engineers can perform a near-field analysis to predict the effects of the entire industrial environment on the performance of antennas and wireless devices. The finite element domain decomposition, 3-D method of moment, hybrid, and shooting and bouncing ray (SBR) techniques can also be used to quickly solve electrically large and complex full-wave electromagnetic models. This approach provides greater insight, improves accuracy and increases reliability.

As an example, engineers at Synapse Product Development — a leader in wearable electronics — have used ANSYS tools to increase antenna range by a factor of five, while reducing their overall design cycle by 25 percent.

Chip-Package-System Design

Designing high-speed printed circuit boards (PCBs) and semiconductor integrated circuits (ICs) poses significant challenges due to design complexity in the form of lower operating voltages, circuit density and faster data rates. In addition, many IoT product design teams need to address size, weight, power and cooling considerations.

Whether designing a PCB or an IC, engineers must balance the requirements of three broad areas that affect product reliability — electrical, thermal and mechanical performance. Engineers also need to simulate the interactions between the semiconductor die or the IC, the IC package and the PCB. Power integrity analysis is necessary to ensure a proper power delivery network, and signal-integrity analysis is needed to minimize crosstalk and increase design robustness. Addressing thermal reliability calls for simulation to evaluate the impact of temperatures of the board and associated components, ensuring that the devices operate reliably over the specified temperature range. And mechanical reliability requires a thermal stress simulation to evaluate thermal and mechanical stresses in the board, along with solder joints between the board and its components.



In addition to performing individual physics simulations, engineers must consider the interaction between physics disciplines, coupling signal integrity analysis with thermal simulations and connecting thermal simulations with structural analysis. This method provides a holistic view of the overall reliability of PCB design.

The chip-package-system workflow, unique to ANSYS, enables engineers to improve electronic system performance. The workflow enables PCB designers to simulate their designs, including crucial information from IC and package models. Conversely, the workflow allows IC designers to include the impact of package and PCB when verifying their IC designs. With all relevant system-level considerations modeled and simulated, engineers can reduce electromagnetic interference, increase electrostatic discharge (ESD) protection, and improve the electronic systems to power the IoT economy. Telecommunications leader Alcatel-Lucent leveraged ANSYS solutions to design high-speed networking technology, reducing costs by more than 67 percent.

Power Management

Anyone whose smartphone battery has run out understands the essential role of power management. But power management isn't just about smartphones or Wi-Fi. Energy harvesting, wireless power transfer and low power IC design are the building blocks on which many IoT devices will be built.

Energy from mechanical motion, heat, piezoelectric material and electromagnetic emissions can be captured and converted directly into electricity. When designing energy harvesting systems, engineers need to consider several parameters, including energy source, transducer type, power efficiency, required power levels and energy storage.

Importantly, when designing wireless systems, safety is a key consideration. Standards and regulatory agencies limit the amount of electromagnetic energy that can be delivered to living tissue. ANSYS simulation tools, including human body models, can be used to design and analyze a variety of power delivery systems and their impact on the human body.

At Vortis Technologies, engineers are applying ANSYS software to solve the problem of wasted RF energy in cell phones, which not only reduces battery life but also creates acoustic noise. The company's innovative phased-array antenna system delivers 125 percent improvement in battery life, resulting in 2.25 times additional talk time in a smartphone. The new antennas can be designed in one-tenth the time required using a build-and-test method.

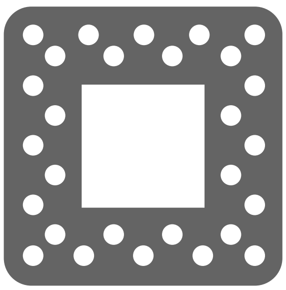
Sensors and MEMS Design

Sensor and MEMS (microelectromechanical systems) designers face business and technology challenges when designing, prototyping and creating compelling products that can mean the difference between success and failure. To gain a competitive advantage, sensor manufacturers need to develop their products as fast and efficiently as possible.

MEMS and sensors are complex because of their special functions, challenging manufacturing processes, and tiny size. MEMS are so small that performance measurement equipment can impact device function, making it difficult to obtain reliable performance data. Simulation provides accurate insight into the performance of these devices beyond what physical prototyping provides.

ANSYS simulation solutions allow a wide range of sensors, actuators and other MEMS devices to be simulated, from RF sensors dependent on electromagnetic fields to gyroscopes dependent on mechanical motion to piezoelectric devices dependent on both. Proven solvers and coupling solutions enable the high-fidelity analysis of device designs. Once an initial design is created and simulated, ANSYS enables the entire device to be optimized before building, including the interaction of the components. For example, an initial design may be optimized to minimize power use and temperature spikes by varying physical size and examining performance tradeoffs.

ANSYS has a long history working with MEMS designers that has positioned its customers to deliver better MEMS products. Engineers at KSR international used ANSYS solutions to optimize inductance sensor designs, reducing development time from three months to two weeks.



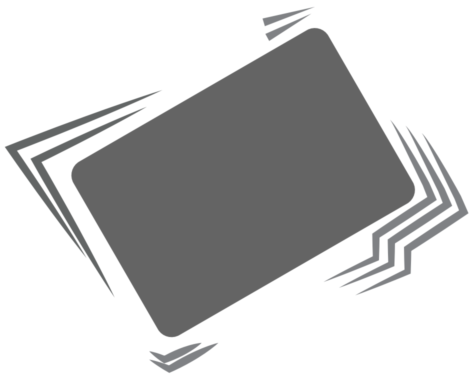
Embedded Software Development

The modern car can contain 50 million to 100 million lines of code. With autonomous vehicles on the way, we can expect software content to rapidly increase. But embedded software is not just for cars: It is essential to add richness and smart functionality to many IoT devices, including industrial equipment, robotics, planes and drones. Because many of these products and systems are safety- or mission-critical — for example, braking systems on cars and planes — the control software must operate flawlessly. When systems fail, they must fail in a predictable way to minimize damage.

Often, there are industry regulations, certifications and qualifications that govern the reliability and performance of software. Software development is no longer just about writing the code: It is also about verification and validation. For each line of implementation code, software engineers often find themselves writing many more lines of verification code. Despite the amount of effort expended, software code bugs continue to persist, leading to safety recall, security breaches and sometimes tragic outcomes.

ANSYS has created a model-based embedded software development and simulation environment with a built-in automatic code generator that significantly accelerates the pace of embedded software development projects. Engineers can use ANSYS solutions to model complex systems, understand the interaction of various subsystems, and generate high-integrity software code that complies with many industry standards. The ability to generate millions of lines of code at the push of a button not only removes human coding errors, but also increases productivity, quality and traceability of code. Moreover, this capability shifts engineering effort from code to system, further improving engineering productivity, innovation and end product

Piaggio has been using automatic code generation, noting that ANSYS software modeling tools enable their engineers to express the design specification in a formal manner. As a result, Piaggio can produce software quickly, remove functional bugs, and reduce the number of expensive test demonstrations. Software modeling and simulation has accelerated Piaggio's development process by a factor of three.



Designing for Harsh Environments

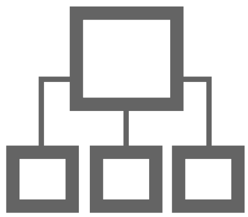
IoT devices must operate in the real world, which can be an unforgiving place. Fast-growing applications such as drones, wearables, self-driving automobiles and smart industrial equipment must operate reliably in harsh environments, where they may be subject to vibrations and physical impact. Despite these conditions, IoT devices must be robust and stay active for extended periods and across great distances without maintenance. A malfunction can result in mission failure, significant investment to repair or replace the system, and even risk to human lives.

Whether they are used in industrial, aerospace or consumer applications, IoT devices are subjected to harsh environments, including vibrations, impact and fatigue. NASA has shown that 45 percent of first-day spacecraft electronics failures were due to damage caused by vibrations and stress during launch. According to SquareTrade, dropped iPhones have cost American consumers $6 billion in recent years.

Engineers must consider these potentially harsh environments very early in the development process when design choices can be made at the lowest cost — and with the least impact on the project schedule. Physical prototyping is simply not a viable option for many obvious reasons. Not only is it difficult to create all the possible test scenarios given the constraints of time, budget, location, and resources, but the measurement results can vary greatly and lack the fidelity needed for IoT and many other critical applications. ANSYS simulation tools can account for all the relevant physical forces, including fluid flows, structural forces, thermal effects and electromagnetic environments.

Astrobotic Technology, a pioneer in commercial spaceflight, used ANSYS solutions to design the structural components of the Tranquility Trek spacecraft. Chief Engineer John Thornton said, “Using design and simulation tools from ANSYS, Astrobotic quickly designed and refined a lightweight aluminum and composite spacecraft able to withstand static acceleration and dynamic random vibration loads of launch while maintaining an acceptable level of safety. Simulation helps reduce costs related to prototypes and physical testing.”

One leading supplier in the aerospace and defense sector used ANSYS Mechanical as part of a major redesign of an IoT-like component. They modeled harsh environmental conditions, including vibration, to eliminate many rounds of expensive dynamic and highly destructive testing. As a result, they were able to save over $1 million by reducing the development time, eliminating outsourced FEA consultant fees, reducing testing, and improving product capabilities for accuracy, while maintaining safety.



Virtual System Prototyping
As product complexity grows, so does the need for enhanced simulation capabilities. The hottest innovation areas require system simulation to work. The complexity within systems arises from the challenges of connecting the individual pieces to ensure they work together as designed and expected. Coupling physical attributes of a product with the systems and embedded software, companies can greatly minimize integration issues, reduce costs, increase the likelihood of first-pass success, and ensure that products perform as expected.

While it is easier to visualize the IoT in terms of individual devices or components — a smartphone, a thermostat, or a wind-turbine — the complex and invisible networks that connect them, as well as the cloud that stores and delivers data on demand, require sophisticated modeling and simulation. The smart wind turbine, for example, needs to adjust its behavior according to wind patterns, the amount of energy on the grid, and the behavior of other smart wind turbines.

The interactions of the software, the electronics hardware, and the multi-domain nature of the problems significantly increase the complexity of the engineering challenge. Simulation software from ANSYS can help by providing validation results that include systems-level qualities, properties, characteristics, functions, behaviors and performance insight. Based on this high-level perspective, system designers can make informed design choices that optimize the performance of not only each individual component, but also the entire system.

Andrew Cresci, General Manager of Strategic Alliances at NVIDIA, notes: “It’s a virtual cycle: NVIDIA is an industry leader in the design of GPUs; we use ANSYS simulations running on current-generation GPUs to design the next generation of GPUs.”

ANSYS: Your Trusted Partner
Whatever your industry or product focus, the IoT is poised to impact your business in significant and often unexpected ways. At ANSYS, we’ve developed an expanded range of capabilities, including electronic and embedded software modeling, to help you thrive in the IoT era.

Engineers designing the Internet of Things technologies face considerable challenges, including SWAP-C, sensing and connectivity, safety and reliability, integration, and durability. Platform-based engineering simulation, supported by seven applications — antenna design and placement, chip-package-system design, sensors and MEMS design, power management, embedded code generation, harsh environment design, and virtual system prototyping — is crucial to maximizing the IoT opportunities for your organization.

Many of the world's leading companies are already using ANSYS solutions to deliver the most innovative products spanning smartphones to spacecraft, autonomous vehicles to drones, and robots to wind turbines.

As the IoT continues to evolve, ANSYS will remain your trusted partner — delivering the proven simulation capabilities you've come to rely on, along with new capabilities that support your continued product development success in a transformed world. We can help you engineer, design and test the best possible products for the Internet of Things.

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