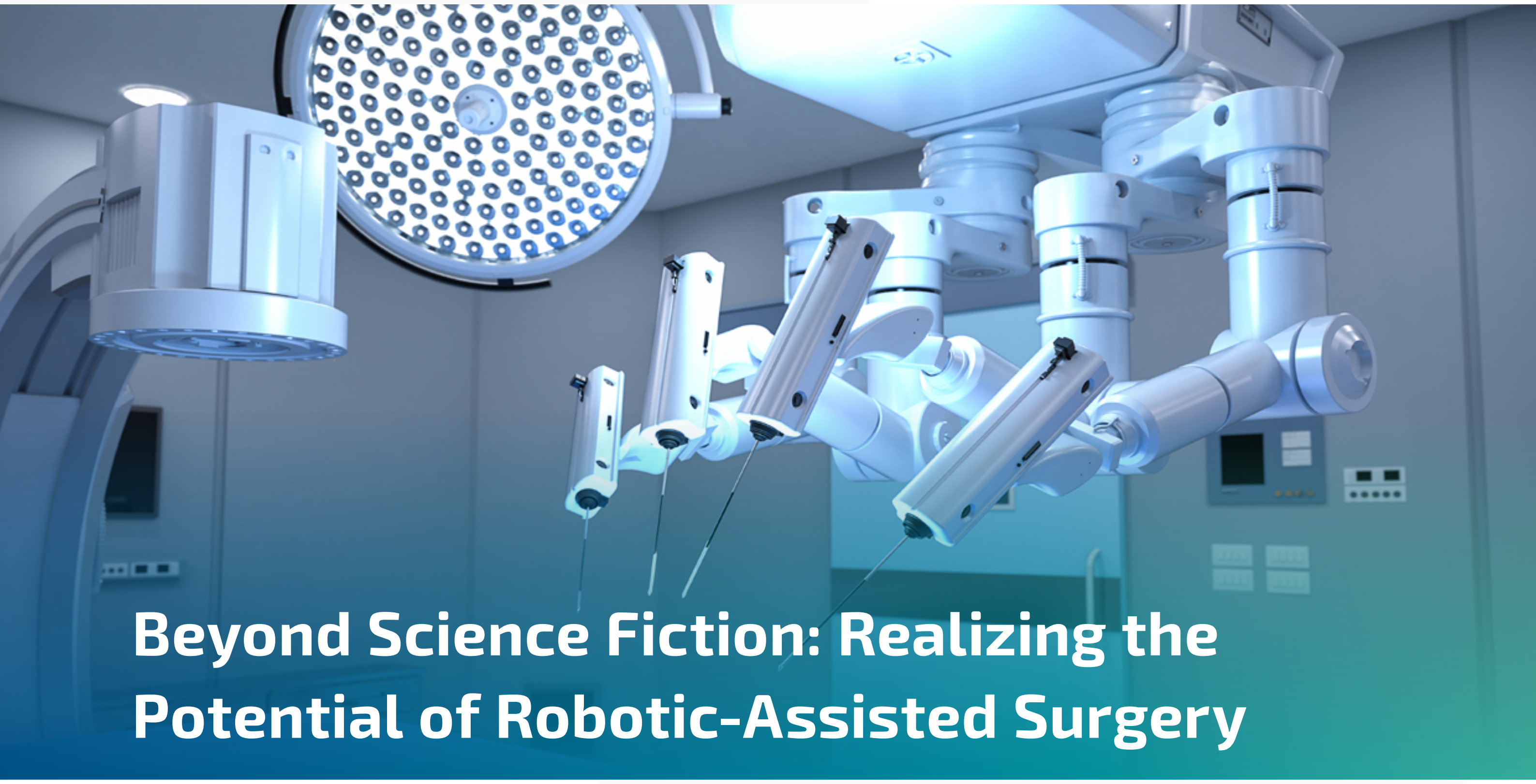
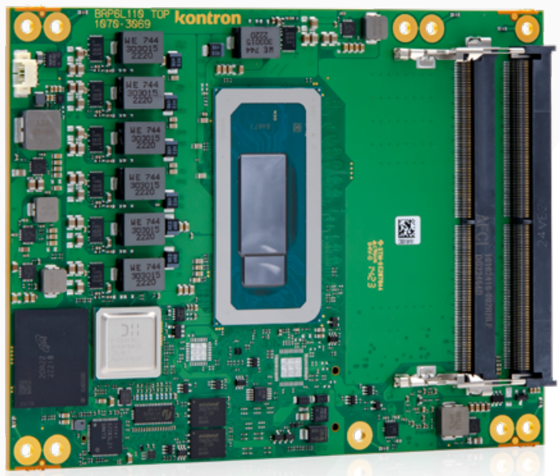


Beyond Science Fiction: Realizing the Potential of Robotic-Assisted Surgery



Harnessing Computer-on-Modules for Enhanced Precision and Flexibility

This white paper discusses the roots of robotic-assisted surgery (RAS), its milestones, how and why RAS is gaining the public trust and five key technologies for its future, which leading industry experts consider to be bright.

The five technologies—artificial intelligence, machine learning, haptic feedback, 5th generation mobile networks and 3D visualization will play important roles as RAS advancements continue their trajectory.

Also playing a vital role is Kontron's COM modules and its ability to provide custom solutions for RAS system providers. To illustrate, a case study involving a Fortune 500 medical device manufacturer looking to launch an RAS platform for multiple procedures, shows how a two-board modular approach integrating the COM Express® modules helped to accomplish scalability, rapid time to market and intellectual property protection.

When it comes to the fast-growing multi-billion-dollar RAS market, the future is here, and Kontron is excited to be a part of it.

kontron
The Power of IoT

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Introduction

Nearly a century ago, science fiction authors began causing us to wonder what a robot-filled world would look like. Today, advancements in artificial intelligence, computing power and machine learning have made possible myriad robotic applications. Industries using robots include aerospace, agriculture, automotive, food and beverage, military, defense and pharmaceutical.

Perhaps the one field with the greatest potential for robotic applications is healthcare, especially robotic-assisted surgery (RAS). Such surgical suites involve small robotic surgical instruments mounted on robotic arms (the number of arms varies depending on the system and its applications), while a separate arm holds a three-dimensional camera for viewing tissues and structures. Using finger and foot controls, the surgeon operates the four arms while looking through a high-definition monitor.

Playing a central role in the advancement of such systems are Kontron computer-on-modules (COMs). COM technology provides the processing brain power for the robotic arms. The modular architecture is flexible yet sophisticated, making it ideal for quick upgrades at lower costs for medical OEMs.

How We Got Here: From Industrial to Medical

The word robot was first coined by a Czech playwright in 1921 and is derived from a Czech word for forced labor, robota. During the next few decades robots remained a favorite subject of science fiction authors such Isaac Asimov, whose classic "I, Robot" short-stories collection (1940-1950) caused readers to wonder what a robot-filled world would entail. However, it was industrial uses, not medical, that were at the forefront of robotic developments in the twentieth century.

The birth of industrial robots[1] began in the 1930s, when the first pick-and-place robotic crane was developed, though it took until the 1960s when the automotive industry began using computer-controlled robots. In 1969 welding robots arrived on the industrial scene. Around the same time, the world's first viable multiaxis robotic arm was introduced, giving robotics a wider envelope of movement[1].

By the 1990s, computer-controlled robots were an industry standard. Today, industry estimates show that industrial robots in use in America grew from about 200 in 1970 to nearly 4,000 just 10 years later—and then jumped to 1.6 million by 2015. Today, there are estimated to be close to three million industrial robots worldwide.

Meanwhile, Fortune Business Insights projects market growth to go from $18.19 billion in 2023 to $41.02 billion by 2030, for a CAGR of 12.3 percent.

The Emergence and Growth of Medical Robots

As for medical uses, robotically assisted surgical (RAS) systems have their roots in the 1970s, when NASA did a deep dive into the potential for telesurgery on astronauts inhabiting the space station. Similarly, the United States Defense Research Advanced Projects Agency researched telesurgery for long-distance battlefield surgery.

Then came the 1980s, when robotic systems were recognized as an effective tool for reducing movement during procedures caused by hand tremors. The first surgical robot, PUMA 560, was used in 1985 for the insertion of a needle, with 0.05 mm accuracy, into a brain for biopsy. Then in 1988, the PROBOT, developed at Imperial College London, was used to make several repetitive incisions during a transurethral prostate surgery.

In 1992, ROBODOC, developed by Integrated Surgical Solutions, Inc. and IBM, was used to prepare femurs for hip replacement procedures. By the late 1990s, three systems combined laparoscopic technology with surgical robots via: the da Vinci AESOP and Zeus.

In 1999, the Zeus system was used to perform the world's first RAS closed-chest beating-heart cardiac bypass operation in 1999.

In 2001 RAS truly went global as a French surgeon and a Canadian surgeon while working in New York City remotely removed the gallbladder from a patient in Strasbourg, France. Though the procedure was successful, delays from the control unit to the operating site were cause for concern. Latency time during the tele-procedure was 155 milliseconds; the ideal was 100 milliseconds.

One of the most notable RAS milestones happened in 2010 when the da Vinci Surgical System was used to peel the skin off a grape.

With such a storied past, one might be surprised to learn that RAS accounted for about 4 percent of procedures in 2023, making for huge untapped market potential, says Robert Ingraham, Product Portfolio Manager at Kontron, maker of computer modules, boards and systems for many market segments, including RAS. Artificial Intelligence Index Report 2024, he says, estimate the market[2] to be $4.4 billion in 2022 and as much as $16.5 billion by 2030 as they project a compound annual growth rate (CAGR) of 16 to 18 percent from 2022 to 2030 as dozens of RAS manufacturers, aided by advancing technology continue to drive the market.

Key Considerations: Benefits & Challenges

Benefits of RAS

Implementing robots in the hospital isn't a new concept but a fully automated RAS system comes with key benefits for the patient and hospital. One of the main ones is its dependence on artificial intelligence (AI). AI allows for safer and more accurate procedures using advanced control and manipulation and improved human-robot collaboration.

Another technology used by RAS is machine learning (ML), which enables robots to learn procedures autonomously through expert demonstrations and/or trial-and-error. Once trained, the robotic arms can complete the procedure again and again. RAS also use 5th generation mobile networks (5G). This lightening connectivity could make possible remotely managed cross-border procedures. All of which can result in better health outcomes for patients in cosmopolitan cities or remote areas all over the world.

More to come on how these advanced technologies are making RAS more efficient.

Challenges of RAS

While the benefits are strong, robotic surgery has a major drawback - cost [3]. Surgical systems costing around $2 million and annual maintenance fees totaling about 10 percent of the initial purchase are reasons why cost analyses show robotic surgery to be more expensive than laparoscopy or conventional open surgery.

However, a study involving common gastrointestinal procedures showed that the total hospitalization costs for the robotic approach is less than the laparoscopic or open approach, although procedural costs were higher depending on the type of surgery being performed.

Researchers also considered common robotic urology, gynecology, nephrology, and cardiology procedures, concluding that while robotic procedures cost more, they decreased the length of hospital stays and odds of death when compared to procedures using conventional open methods.

And while analyses show longer operating times for robotic surgeries, as more surgeons become proficient in robotic techniques, operating time is expected to shorten and as more systems are sold, the cost of equipment is expected to decline over time.

Other reasons why RAS will become more prevalent in coming years:

- Robots are tireless and always steady, no shaking hands.
- Robots perform a wider range of precise movements.
- Robots can be programmed to perform lower-level, repetitive tasks.

All of which can result in better health outcomes for the patient.

Five Impactful Technologies

While most surgical robots today perform as tele manipulators without any autonomous activity, relying on human operators to perform, the future of surgery will likely include robots with the ability to work on their own. Their development will involve the effective use of five key technologies: artificial intelligence, machine learning, haptic feedback, 5th generation mobile networks and 3D visualization.

› Rise of Artificial Intelligence

Artificial intelligence (AI) algorithms combined with advanced robotics can aid everything from diagnostic imaging and analysis to remote surgical assistance. The robot will autonomously perform certain repetitive procedures such as cutting tissue to assist with the development of surgical plans.

A current AI-powered surgical video and analytics platform for the OR, Touch Surgery Enterprise by Medtronic, employs AI for the automatic blurring of patient faces and protected information to ensure data-privacy compliance, automatic segmentation of surgical video into key procedural steps, and the ability to compare current and past cases.

Looking toward the future, imagine the potential for robots with situational awareness and the ability to adapt to the surgical workflow in an OR. Cognitive robots of the future are expected to perform such tasks as control of the laparoscopic camera, automatic needle insertion, the stretching of tissue and even certain surgical tasks such as an anastomosis[4].

› Importance of Machine Learning

An important branch of AI is machine learning (ML). In industry, ML is used for quality control, automation and customization. In the RAS world, ML enables robots to be trained in such things as tissue removal patterns. Once trained, such robots will detect tissue deformations during the surgery and make alterations to the surgical plan accordingly. ML also figures prominently in RAS training. Future integration of multimodal input with ML algorithms and haptic feedback will allow for robust and multifaceted training and skills assessment[5].

› Impact of Haptic Feedback

As for how haptic feedback impacts RAS, here's an example: motorized master controllers reflect the impedance, or effective resistance, detected by sensors in the robot's end effectors during a task such as suturing. Haptic feedback via vibrations of the master device or actuators felt by the user's fingertips creates the illusion of holding a physical object.

› Growth of 5th Generation Mobile Networks

Also driving RAS growth is the proliferation of 5th generation mobile networks (5G). Whereas remote robotic surgeries performed in the 2000s experienced latency and reliability issues, today's 5G networks provide sustained high-speed performance, reducing minimum latency to milliseconds while providing reliable network connection during the entire procedure.

› Advancement of 3D Visualization

Another key element in advancing robotic assisted surgery are advancements in 3D visualization, which provide surgeons with spatial understanding, enabling them to perform procedures with improved precision. While commandeering the system's console, the surgeon sees a magnified view of the surgical area streamed from the high-definition camera. Much like the viewing advancements in home theater, this technology continues to be refined in the RAS space.

Module Integration and Processor Technologies

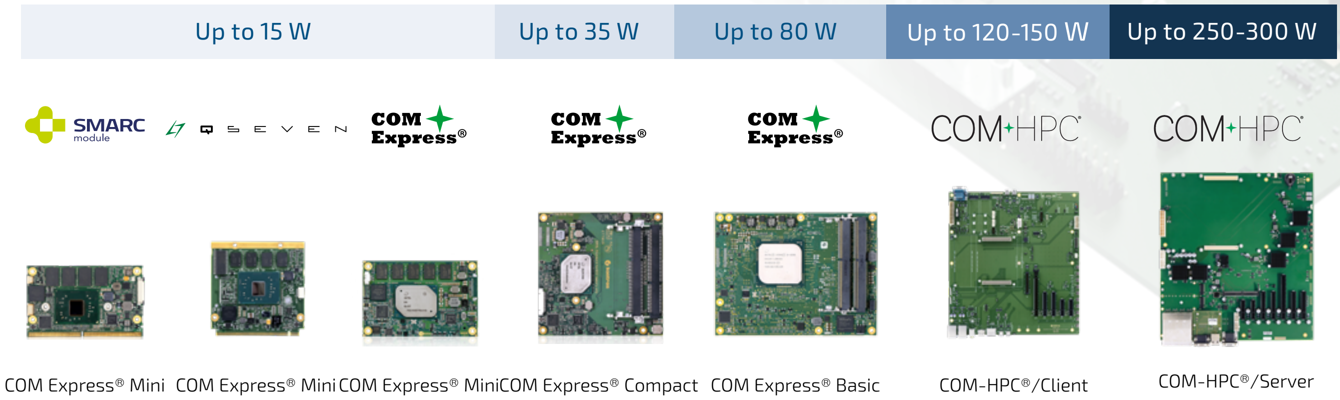
As we saw earlier, the future of RAS depends on the successful integration of AI into computer modules and increasing 5G connectivity. Computer modules employing new processor technologies such as Intel's Raptor Lake and AMD EPYC™ processors are providing the building blocks for such advancements.

Kontron's COM Express® modules, based on 13 and 14 Gen Intel® Core™ technology support up to 24 cores (up to eight performance cores and up to 16 efficient cores), as many as 32 threads, and as much as 128 GB of memory, making the technology especially good for model imaging.

Scalable system-on-a-chip (SoC) and performance range options are seen in three COM Express® form factors: Basic and Compact (pin-out Type 6/7 compliant); Mini (pin-out Type 10 compliant), allowing for high performance in a small form factor, just 125 x 95 mm.

Kontron's comprehensive COMe offerings allow the medical OEM the exact right module for their project. Modules, on a whole, allow for scalable flexibility without having to change the entire design. In the end, this reduces the total cost of ownership (TCO).

Innovative IoT Platforms to match different Performance, Space & Thermal Requirements



The COM modules also can be configured with AMD EPYC™ 3000 processors for applications requiring high processing power for medical imaging. The technology supports up to 16 cores, provides for 5 LAN interfaces, and addresses the needs of 5G workloads with its high compute density.

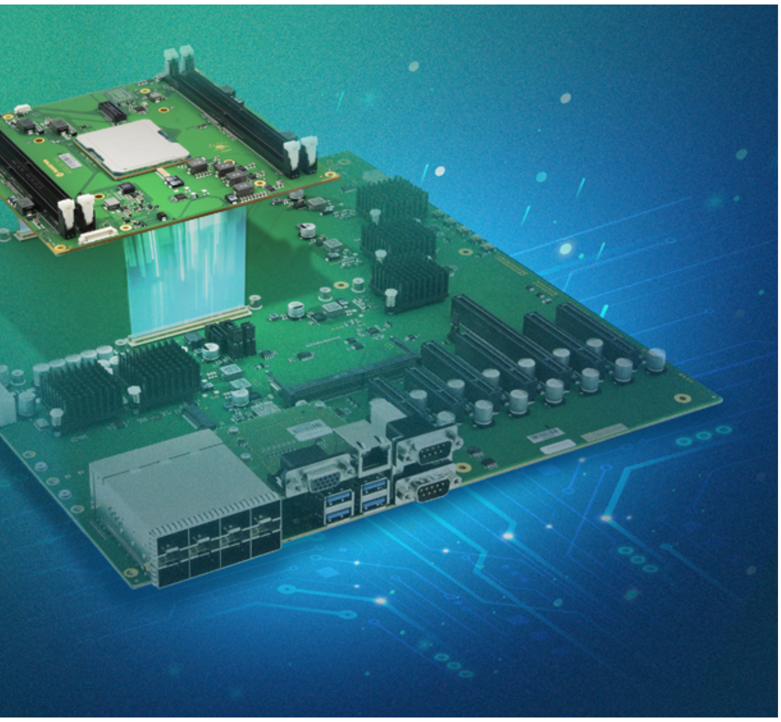
To ensure computer-on-modules continue meeting RAS requirements as systems continue to advance, a new high-performance computing standard, which Kontron helped define, for modules has been defined by the PCI Industrial Computer Manufacturers Group (PICMG): COM-HPC®, allowing for greater computing power, faster processing, improved digital management and crisper images. Kontron's comprehensive line of COM technology allows the OEM fluid flexibility and the ability to upgrade to the latest tech easily.

COM-HPC® - COMPARISON TO COM EXPRESS®			
COM-HPC®/Client	COM Express® Type 6	COM-HPC®/Server	COM Express® Type 7
2x 400 pin connector	2x 220 pin connector	2x 400 pin connector	2x 220 pin connector
2x NBase-T (max. 10 Gbit/s)	1x NBase-T (max. 10 Gbit/s)	2x NBase-T (max. 10 Gbit/s)	1x NBase-T (max. 10 Gbit/s)
48x PCIe + 1x PCIe (dedicated for BMC)	24x PCIe	64x PCIe + 1x PCIe (dedicated for BMC)	32x PCIe
2x SATA	4x SATA	2x SATA	2x SATA
4x USB 4.0, 4x USB 2.0	2x USB4 (instead of DDI) 4x USB 3.2, 4x USB 2.0	2x USB 4.0, 2x USB 3.2, 4x USB 2.0	4x USB 3.2
2x 25 GbE KR	LVDS 2x24/eDP/MIPI DSI	8x 25 GbE KR	4x 10 GbE KR
3x DDI + 1x eDP/DSI + HDA/SoundWire	3x DDI + 1xLVDS or 1x eDP + HDA/SoundWire		
1x IPMI + 1x PCIe (BMC on carrier) for remote management		1x IPMI + 1x PCIe (BMC on carrier) for remote management	1x IPMI + 1x NSCI
„Low Speed" (IPMI, eSPI, SPI (BIOS), GPP SPI, SMB, 2x I2C, 2x UART, 12x GPIO, MIPI CSI, MISC)	„Low Speed" (eSPI/LPC, SPI (BIOS), SMB, I2C, HDA, UART, 8x GPIO/SDIO, MISC)	„Low Speed" (IPMB, eSPI, SPI (BIOS), GPP SPI, SMB, 2x I2C, 2x UART, 12x GPIO, MISC)	„Low Speed" (eSPI/LPC, SPI (BIOS), SMB, I2C, UART, 8x GPIO/SDIO, MISC)

Case Study: Multi Procedure RAS Platform

A Fortune 500 medical device manufacturer, looking to launch an RAS platform for multiple procedures recently sought a partner known for its longevity, stability, reliability; its world-class quality and brand reputation; and for being a trusted advisor. Moreover, the partner-to-be needed to be ISO 13485 certified and equipped to provide excellent customer support and services. After considering all these criteria, the OEM selected Kontron as its partner and together they identified three high-level requirements common to many such projects:

- **Design in scalability,** the ability to create adjacent products with varying levels of capabilities. Examples could include less expensive robotic surgical devices with fewer features for deployment in developing nations. Simply put, scalability and the flexibility it brings to a project affords users the ability to replace modules without having to implement a full redesign.
- **Achieve rapid time to market,** a critical element for the fast-growing medical market. To achieve this, noncore design time was minimized using proven modules and processor technologies resulting in reduced development time and the costs associated with these efforts.
- **Future-proof the introduction and protect the manufacturer's intellectual property (IP)** by readying it for next-generation designs with minimal changes, thereby avoiding the risks and added costs that often accompany changes in the medical-device world.



Kontron's Robert Ingraham notes that the case study involves distributive network architecture calling for multiple computers within the system's control tower, surgical arms and surgeon console. A two-board modular approach integrating the COM Express® modules helped to accomplish the above-mentioned requirements, allowing for cost-effective solution that streamlines operations and enables seamless integration in medical environments.

> "Usage of standard computer modules across form factors is what the customer was looking for," says Ingraham. "The design solution involved the use of standard computer modules across form factors, creating an environment where change isn't a requirement until the customer identifies a need for modifications."
>
> Robert Ingraham, Director Business Development at Kontron

Further, a two-board approach enables some 'heavy lifting,' with the selected SKUs for the project being compliant to use conditions of 100 percent operation over 10 years for best-in-class durability.

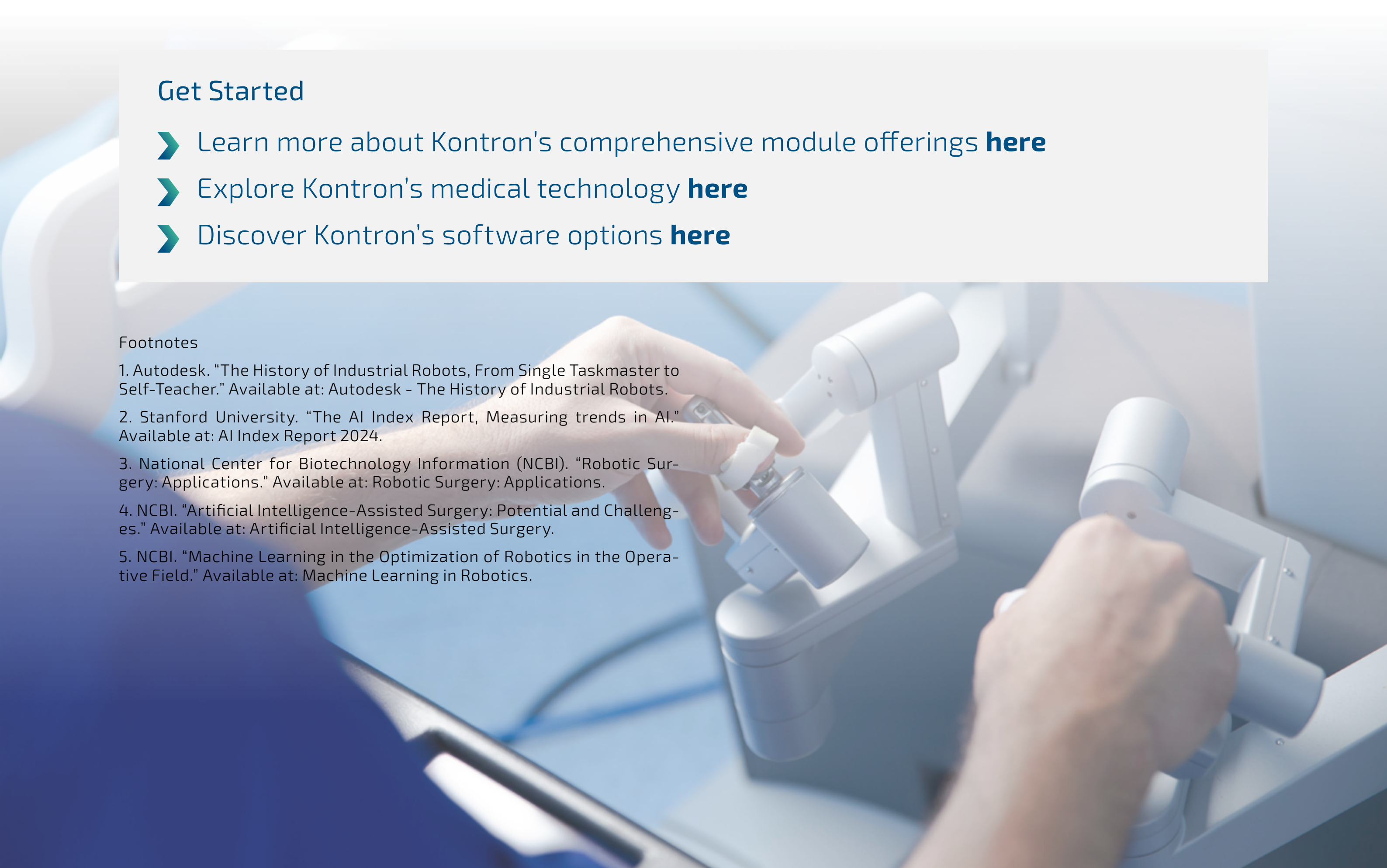
It's also easy to extend the life of the application by switching to a new generation module when available, even those from second sources, since all suppliers must adhere to PICMG standards. Finally, IoT differentiation also guarantees long-life availability.

The Future of RAS and Module Technology

As advancements in AI, ML, 5G, 3D imaging and haptics continue to address RAS challenges such as scalability, flexibility, security and faster time to market, and component companies such as Kontron partner with OEMs for comprehensive solutions, including system integration, industry experts predict steady growth for the RAS market. Though cited earlier in the paper these industry projections are worth another mention: from $4.4 billion in 2022 to as much as $16.5 billion by the next decade, and a projected 16 to 18 percent CAGR through 2030.

Also well worth mentioning are the ethical and legal considerations associated with RAS. Companies and organizations need to take steps toward developing standardized training of surgeons to mitigate security risks using components such as Kontron's SecureGuard® USB blocker, Secure Boot software security mechanism and Trusted Platform Module (TPM) security chips, while providers establish consent processes ensuring that patients are fully aware of RAS capabilities and potential risks.

Despite the many challenges facing component companies, system integrators and healthcare providers, RAS represents a burgeoning market, says Ingraham, who offers this summation: "*The growing acceptance and demand for surgical robots will drive technological innovation up, while driving costs down. What was once science fiction has become reality.*"



Get Started

- Learn more about Kontron's comprehensive module offerings **here**
- Explore Kontron's medical technology **here**
- Discover Kontron's software options **here**

Footnotes

1. Autodesk. "The History of Industrial Robots, From Single Taskmaster to Self-Teacher." Available at: Autodesk - The History of Industrial Robots.

2. Stanford University. "The AI Index Report, Measuring trends in AI." Available at: AI Index Report 2024.

3. National Center for Biotechnology Information (NCBI). "Robotic Surgery: Applications." Available at: Robotic Surgery: Applications.

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About Kontron

Kontron is a global leader in IoT/Embedded Computing Technology (ECT) and offers individual solutions in the areas of Internet of Things (IoT) and Industry 4.0 through a combined portfolio of hardware, software and services. With its standard and customized products based on highly reliable state-of-the-art technologies, Kontron provides secure and innovative applications for a wide variety of industries. As a result, customers benefit from accelerated time-to-market, lower total cost of ownership, extended product lifecycles and the best fully integrated applications.

For more information, please visit: **www.kontron.com**

About the Intel® Partner Alliance

From modular components to market-ready systems, Intel and the over 1,000+ global member companies of the Intel® Partner Alliance provide scalable, interoperable solutions that accelerate deployment of intelligent devices and end-to-end analytics. Close collaboration with Intel and each other enables Alliance members to innovate with the latest IoT technologies, helping developers deliver first-in-market solutions.

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