Cognizant

Digital Systems & Technology

How Cyber-Physical Systems Are Reshaping the Robotics Landscape

The rapid growth of analytics, AI and related intelligent software is merely the first phase of the robotics revolution. Computer algorithms that learn and improve the output of systems over time are now managing and controlling physical systems in ways that enable machines to function autonomously.

May 2019

Executive Summary

The continuously evolving relationship between humans and machines is many centuries old. Humans started to build and use hand tools in prehistoric times, and the advent of more sophisticated implements in the form of machines has played a key role in human development.

The 21st century so far has brought explosive growth in computing power, communication technologies and artificial intelligence (AI) — capabilities that together have delivered what is known as cyber-physical systems (CPS). CPS capabilities include autonomous decision-making, communication with other machines or "assets" connected on the digital thread,[1] and communication with humans in the ecosystem. All these real-time abilities help them fine-tune their courses of action and operate in dynamic situations with high reliability.

A fully evolved CPS can monitor physical processes, and help to define and manage inputs from a "digital twin" — a virtual copy of all the physical aspects of an asset throughout its entire lifecycle — that will enable decentralized decisions. (For more on this concept, read our white paper, "Is Your Organization Ready to Embrace a Digital Twin?")

A CPS is typically designed around a network of interacting entities, with an emphasis on physical inputs and outputs — unlike traditional embedded systems that focus more on computational elements and less on the link between computational and physical elements. The CPS design approach is tightly tied to the concepts of sensor networks and robotics loaded with computational intelligence. CPS deployment calls for a multidisciplinary approach that includes cybernetics, mechatronics, design and process science.

A typical CPS includes the following:

- **Physical components:** Mechatronic, electrical, electronic, mechanical, hydraulic, pneumatic systems, etc.
- **Software components:** Embedded software that hosts the algorithms that make intelligent decisions based on the physical input received by the system.
- **Connectivity:** A communications gateway that helps establish connectivity with other systems as well as the digital thread — an integrated communications highway linking every connected asset that is capable of generating and exchanging useful data over the network.

Ongoing AI research and studies on behavioral patterns of other species like ants, wasps, bees, etc.[2] are helping researchers to optimally configure groups of CPS in "swarms" that can collectively achieve an objective, or to link human senses such as touch and vision to remotely control machines. (See Appendix on page 23 for a look at the research in which we are involved.) Given their wide application potential, CPS are expected to play a leading role in all aspects of the digital revolution that is currently under way.

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Diverse CPS applications

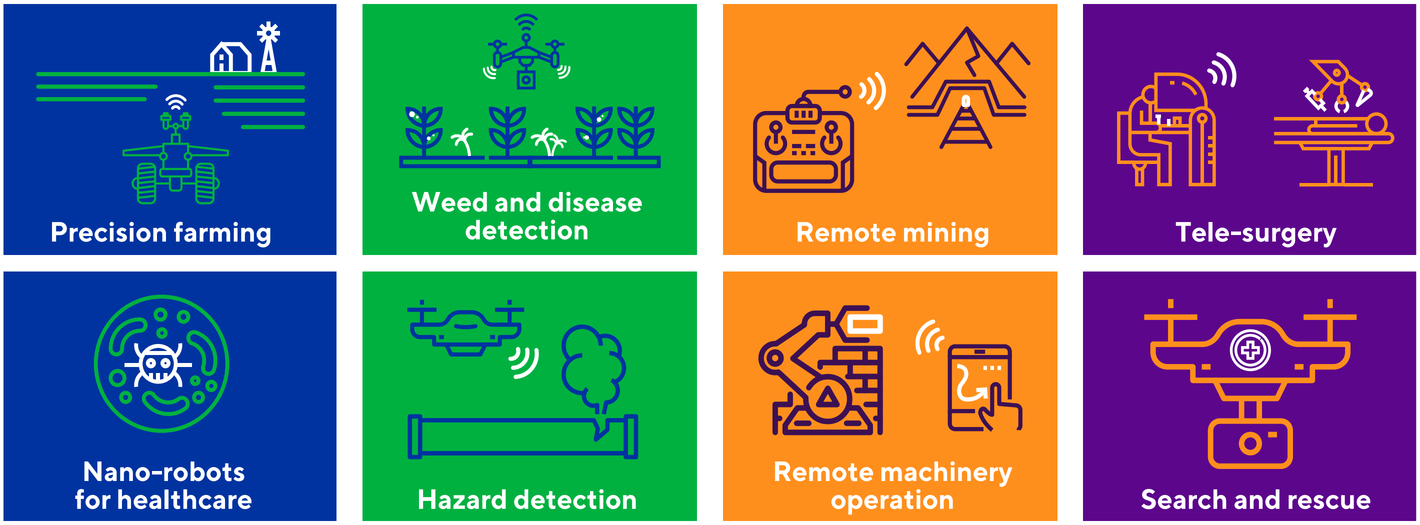

Figure 1

The CPS landscape

CPS are already having an impact through smart appliances, smart vehicles, smart grids, smart robots, biomechanics, etc. One popular example of an existing CPS is the driverless car. Here, a set of 2-D sensors, 3-D sensors such as RADAR/LIDAR,[3] and high-speed cameras, etc. actively scan a dynamic environment, evaluate the best possible path and action for the vehicle using the measured values and data from external data such as traffic and weather, as well as other autonomous systems (e.g., vehicular ad hoc networks, or VANETs [4]),and then instruct the hardware (i.e., the vehicle) to take the best possible action.

Over time, CPS developments will open many more avenues and are expected to unlock creative solutions to historically vexing challenges. We see several key themes, covered in the following three subsections.

Swarm intelligence & robotics

Swarm intelligence[5] is an emerging AI field inspired by the behavioral models of social insects (ants, bees, wasps, etc.). A swarm combines the power of many minds into one, allowing the system to be smarter, more insightful and more creative (see Figure 2). This trait is transforming the field of robotics, enabling physical robots to achieve a desired collective behavior based on inter-robot interactions as well as their interactions with the environment.[6]

For example, a swarm of bots can be released in the blood stream to diagnose cancer and can be reprogrammed for targeted drug delivery when anomalies are detected. The key characteristics of the swarm include autonomy, flexibility, cooperation, scalability and decentralized control.

Devices that form part of a swarm must be low-cost and possess the limited communication and computation capabilities needed to operate as part of a collective. The swarm would be operated by individual parts, have the capacity to operate in a fully autonomous mode, and be able to self-repair, self-salvage, etc. Operating in a swarm enables optimal distribution of computational and storage workloads and reduces communication dependencies with base systems. Initial application areas will be plant monitoring, airport surveillance, etc. (To read a brief about our research initiative in this area, please see the Appendix.) These swarms are also positioned to enact tasks deemed impossible now (due to the extensive amount of resources required). A swarm of bots can be sent to areas that are rendered inaccessible to humans for surveillance and rescue missions as well as for locating hazard sources such as toxic gas dispersion, pipe leaks, radioactivity, etc.

Swarm intelligence

- Swarm combines the power of many minds into one.
- Autonomy, flexibility, cooperation, scalability and decentralized control.
- Collective behavior of the swarm for specific problem-solving capabilities.
- Individual bots communicate with others as and when needed.

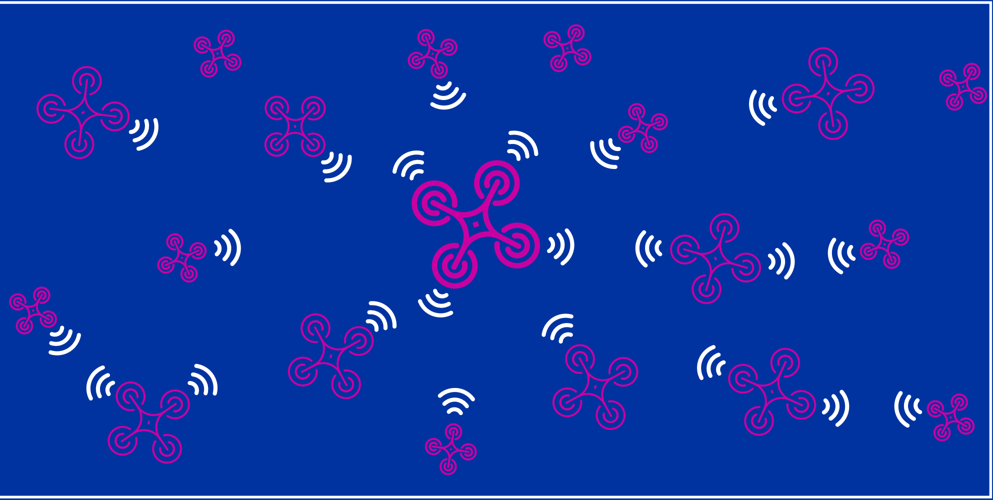

Figure 2

The tactile internet: Distance will be a matter of the mind

The next generation of the internet is expected to extend touch by using CPS to enable human beings separated by space to interact with one another as if they were nearby. The tactile Internet[7] will blur the lines between the physical and virtual worlds, by enabling remote real-time physical interactions online (see Figure 3).

This development will have tremendous impact on society. Access to specialists in healthcare would no longer be location dependent; remote mining and operations would be possible in high-risk areas; and hands-on learning and training would acquire a whole new meaning as the learner and the trainer can interact as if they were co-located (through haptic sensors[8] and actuators[9]).

To make the tactile internet a reality, a multitude of technologies will need to be deployed at both network and application levels:

- 5G networks will boost data transmission at the network level by combining low latency with high resilience while maintaining security and reliability.
- AI and edge analytics will provide real-time information to the user.
- Robotics, augmented and virtual reality, and intelligent automation will function at the application level to enable immersive experiences and human error corrections.

While initial success has been achieved over limited distances using dedicated networks,[10] industry and academia across the world are working together for the complete realization of possibilities.

Tactile internet

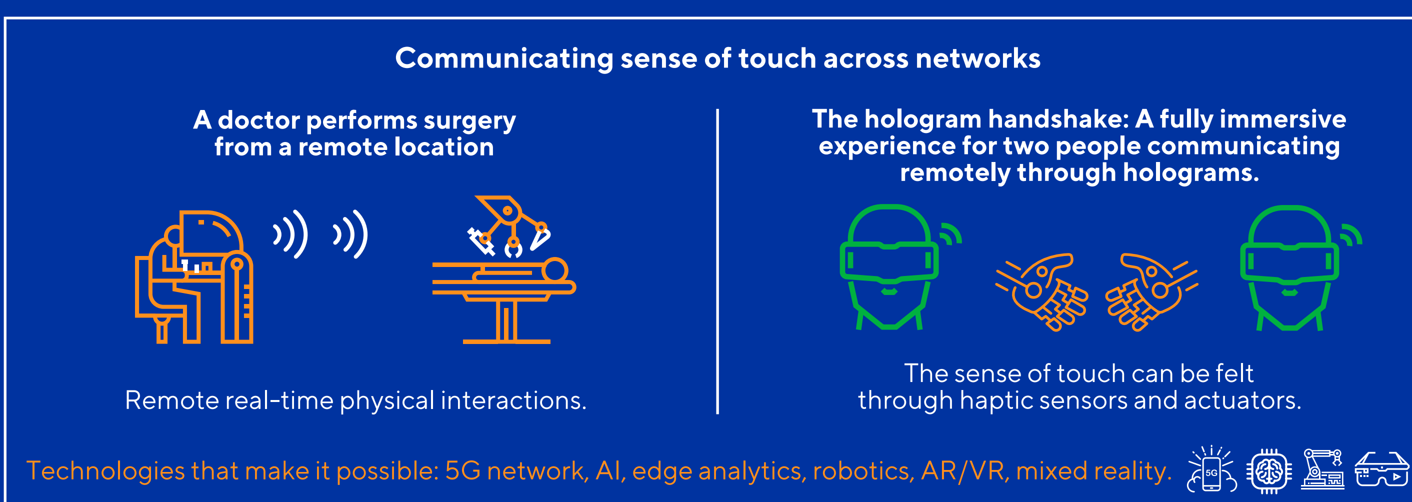

Figure 3

Federated edge-based systems: Bringing AI closer to the point of action

The ever-increasing computational power of peripheral devices has increased the opportunity to bring AI/ML and real-time decision-making closer to where data is produced — "at the edge." This involves best-in-class geo-distributed machine learning (GDML)[11] models that are privacy-aware and adapt decision-making algorithms to the context. (To read a brief about our research initiative in this area, please see the Appendix.)

Realization of this capability could significantly transform the sophistication of CPS-driven solutions. Intelligence at the edge will enable smart, local and real-time information to be made available to the components within the CPS as well as to users of such devices, in order to function with the freshest insights.

Edge-based systems will form the basis for the smooth functioning of CPS, especially with time-critical tasks where even milliseconds matter, such as:

- Remote robotic surgery where vital data need not be transferred to a cloud or data-center for processing insights but can be displayed or communicated immediately.
- Rescue operations, where swarms can map unknown areas while they are moving if the visual and sensor inputs about the surroundings are processed at the network's edge. (To read a brief about our research initiative in this area, please see the Appendix.)
- Self-driving cars, where traffic signs can be read and interpreted in real time by on-board computers.

These systems provide much-needed real-time insights to these systems so that they can operate and adapt to current scenarios.

Edge-based systems will enable better optimization of embedded software design models, as well as reduce power needs in edge devices and device security. Training data will be available right at the edge to fine-tune the models. Privacy-aware, contextual information collected at the edge will ensure the CPS learns to improve over time.

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How CPS will ignite Industry 4.0

The construct of the Fourth Industrial Revolution,[12] known to some as Industry 4.0, posits that game-changing opportunities will result from the emergence of advanced automation and data exchange that leverages technologies such as CPS, the Internet of Things (IoT), cloud computing, data analytics, AI and additive manufacturing. The transition from concept to reality will require autonomous and real-time interaction between machines, processes and people tapping new and improved information and communication technologies.

Information technology has been a key enabler for business since the mid 1900s. Mainframes, midrange computers, desktops, computer-aided design, and enterprise and office software were key to the exponential increase in operational productivity. With Industry 4.0, a manufacturing industry euphemism, the internet is the core technology, not the computer. The idea is to digitize all aspects of manufacturing and interlink all machines, processes and people through a common digital thread. This integration is not limited internally just to the organization but spans the entire value chain, linking suppliers, customers and partners into a digital ecosystem. Its design is based on the principles of information transparency, interconnectivity, technical assistance and decentralized decision-making.

Industry 4.0 could change all facets of manufacturing, and thereby take productivity, efficiency and safety to the next level. Digitally networked factories can coordinate production steps better and plan optimum usage of machines and resources. Factories can take a modular approach and quickly align their assets and resources according to production requirements, advancing a more cost-effective way of producing mass-customized products.

In an Industry 4.0 world, production environments are self-configuring, self-optimizing and self-adjusting to real-time operating parameters. This will drive greater flexibility, agility, safety, cost-effectiveness and productivity improvements. Machines can independently inform the system when the raw material is needed and algorithms can determine ideal delivery routes.

Critical assets can be monitored remotely using data generated by plant sensors. Low-latency CPS at the network's edge — located near the monitored machine — can quickly respond to anomalies and ensure safe operations. Industry 4.0 will bring producer and consumer closer together, as consumers provide design inputs via their preferences and behaviors (i.e., a customized bicycle handle bar or sneakers) and producers

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build the final product. Their interaction doesn't end here but rather is ongoing. Smart products embedded with data gathering and transmission capabilities are already helping cutting-edge industrial companies to continuously share the data with the producer who can in turn remotely monitor the product's condition and predict maintenance needs. This will give rise to a whole new set of business models that are capable of generating additional revenues from data-based bespoke offerings.

The unique characteristics of CPS place it in a sweet spot for Industry 4.0. Its autonomous decision-making and machine to machine (M2M) communication make it highly flexible to operate in an Industry 4.0 environment. CPS can autonomously monitor production processes, collaborate with other machines, take commands from them and issue its own to others as needed.

CPS can prove to be extremely helpful by performing tasks that are unpleasant, dangerous or too physically daunting for humans. CPS can be programmed to work collaboratively with humans without any protective fences in between. They would be intelligent enough to sense human presence and consciously collaborate with them safely and securely. (To read a brief about our research initiative in this area, please see the Appendix.) In this way, they would help augment human capabilities by taking over error-prone tasks and letting humans focus on value-added ones (see Figure 4).

CPS and human collaboration

In the event fire alarms go off in an indoor setting, a team of swarm robots plus one human supervisor will perform the following activities:

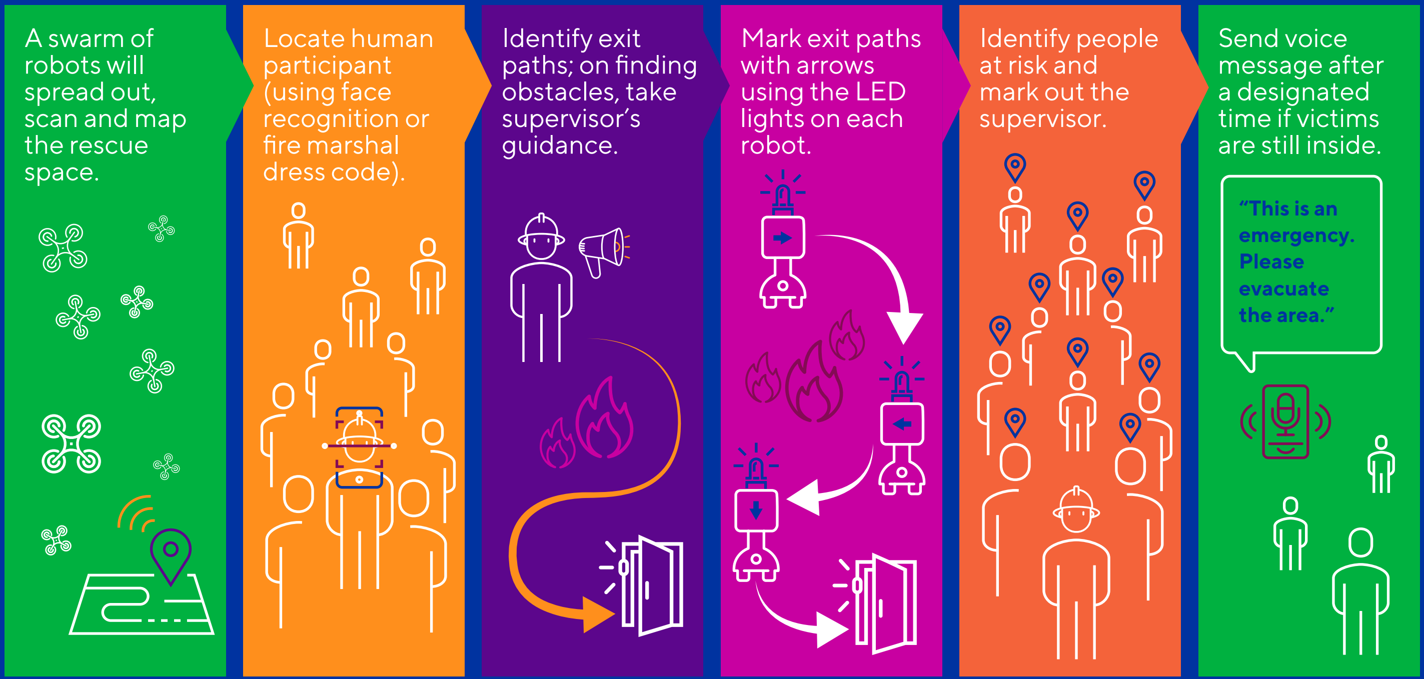

Figure 4

Applications across industries

CPS components feature advanced communication and computation capabilities. This enables them to interact with one another, as well as with the physical world. CPS offer capabilities such as swarm intelligence, tactile internet and edge computing. When working in tandem, they can unleash disruptions across industries, which can lead to productivity, safety and quality-of-life improvements. From here, we will examine CPS applications across key industries.

Healthcare

CPS have the potential to reorder the fields of medical care, diagnosis and treatment.

- **Swarm robotics can enhance robotic endoscopy, by releasing a swarm of micro-bots into the bloodstream to detect anomalies.** Thereafter, they can be reprogrammed for various treatments such as sewing tissues, targeted drug delivery, etc.
- **Swarm intelligence also potentially could treat cancer[13] through targeted drug delivery and personalized therapies.** A swarm of robots can be used to inject medicine directly into cancerous tissues, thereby minimizing the possibility of damage to adjoining healthy tissues by the drug.
- **With the emergence of 5G-enabled tactile internet services, remote surgeries will soon become an everyday reality with the help of tele-surgery robots powered by AI.** For example, the world's first robotic heart surgery[14] was recently performed by a doctor from a remote location using robotically controlled instruments. CPS will enable further applications like this where network capabilities overcome geographical boundaries in enabling expert availability for treatment.

Smart factories

CPS are expected to impact and transform manufacturing, engineering and supply chain management. Flexible and self-organized factories are becoming a reality as real-time data is combined with human-like decision-making made possible by advances in machine- and deep-learning AI algorithms. This blend of capabilities that allow control over physical machines on the move is a hallmark of CPS.

- **Swarm robots can continuously scan and monitor the physical environment.** In conjunction with federated edge-based systems, they can quickly inspect, repair and mitigate hazards such as gas spills, pipe leaks, radioactivity, etc. They can also cover large areas for inspection and monitoring.

- **Repair and maintenance can be conducted remotely by using the tactile internet when circumstances are too complex for robots.** Humans can work on equipment and machinery from remote locations making use of real-time information and analytics transmitted over the edge.
- **Decentralized intelligent and coordinated structures built on federated edge systems can smartly monitor and track shipments, route and re-route based on real-time information,** and help control and coordinate autonomous transportation vehicles.

Smart homes & living spaces

CPS are expected to make major strides in strengthening personal safety and security, especially for the elderly, infants and those needing special care.

- **Smart devices and sensors collaborating in the cyber and physical spaces can help retrieve information from the environment, and share that information instantaneously with other devices and users.** For example, wearable sensors or detectors installed in a home can monitor movements of people and other environmental conditions, and sound alarms in case of emergencies or accidents, thus ensuring more timely help and support.
- **CPS can also enable efficient energy consumption by monitoring temperature, humidity and other parameters.** They can help maintain optimum and comfortable temperatures inside the home based on real-time sensor data.

Military & surveillance

Military operations and surveillance are critical areas, where applications of CPS can be a game-changer. The swarm behavior of drones can be used for intelligence gathering, targeted missile attacks and enhanced decision-making. Recently, the U.S. Department of Defense[15] successfully carried out a demonstration of miniature drones.

Drone-ware is expected to be economical to build and could be dispersed over vast geographies, ensuring maximum area coverage. Their self-healing qualities would enable smooth and efficient functioning in the event of injuries. Further, based on the real-time intelligence gathered, they would be capable of adapting and taking decentralized and collaborative decisions. These intelligent systems would arm humans with insights to speed time-sensitive decision-making.

Precision farming

The various components of CPS can contribute to an integrated and intelligent agricultural management system. These devices will have the potential to communicate with the physical environment, monitor conditions and execute tasks accordingly.[16]

- **Remote sensors and coordinated unmanned aerial vehicles can be deployed in large expanses of farmlands to provide real-time information about soil quality, plant health and other environmental conditions.** These insights will enable farms to provide water, fertilizers and pesticides to targeted areas, leading to more efficient resource use.
- **Swarms of autonomous drones with cameras (infrared and visual light) to scan and monitor crops using image analytics can help identify diseases or other problems that can destroy complete yields.** These drones could coordinate with another swarm capable of delivering targeted remedies to improve farming productivity and increase yields.
- **On the ground, autonomous farm equipment such as tractors, tillers and harvesters, and irrigation equipment can consume CPS information and make intelligent decisions.** For example, John Deere's precision farming solution FarmSight[17] leverages these technologies.

Rescue operations & crisis management

Rescue operations and crisis management is another area where applying CPS is gaining significant momentum as these systems can be sent to crisis-struck areas that are inaccessible to humans.

- **Drone swarms can be spread out over a large area to gather real-time information about the source of calamity, analyze the impact, and locate the affected population and area.** These swarms can be scaled up or down depending on real-time requirements.
- **Haptic devices can play a crucial role here, as it would be possible to extend immediate and remote help in such areas rendered inaccessible to humans.** CPS can also be used to create a managed transportation system[18] by coordinating various transportation modes and tracking the movement of people and vehicles. The outcome: In case of emergencies, people can be evacuated through the most efficient routes. This can help contain transportation chaos in times of natural disasters such as hurricanes, cyclones, etc.

Starting with a big bang approach — migrating the existing asset ecosystem all at once — can be overwhelming due to its complexity, cost and operational risks. To overcome this, a step-by-step approach would be beneficial. To start the process, identify a business case that will have the highest potential for improvement.

Challenges & potential solutions

Such unique opportunities bring a distinct set of challenges to CPS deployment. The challenges are complex and diverse, and solutions vary as well.

Adaptation

Adaptation is a two-fold challenge: one is to make all assets compliant, and the other is to onboard a CPS to the ecosystem. Seamless M2M communication is the key to success for any CPS that is added to an ecosystem. Most facilities are upgraded over the years, which results in a heterogeneous mix of machines and equipment. Legacy systems typically do not have data interfaces, and when they do, they are rudimentary and store information in a proprietary format.

Effective adaptation can be achieved by selecting a universal and standardized data exchange specification (ISO, for example), which can then be used to map all data fields from legacy assets to the CPS. Data adaptors might also be needed to fetch information from a proprietary format to the standard format for each asset. Based on open data standards, CPS can connect to a universal communication bus using standard communication and data exchange protocols.

Starting with a big bang approach — migrating the existing asset ecosystem all at once — can be overwhelming due to its complexity, cost and operational risks. To overcome this, a step-by-step approach would be beneficial. To start the process, identify a business case that will have the highest potential for improvement. Once the assets are identified for the given use case, a pilot project should be planned that includes onboarding a CPS that can interact with existing assets. Note its interactions across other departments, as these can help to assess its true organizational potential. Once the teething troubles are addressed, a wider program within the enterprise can be planned.

Culture

Organizations of any size may face a cultural challenge in transitioning to a human-machine based ecosystem in which machines play a prominent role in decision-making and work alongside humans. Factories have been predominantly run by humans with machines following their instructions, but this master-slave equation will gradually change to more of an equal partnership. Technology throughout the generations has brought fears of job loss, redundancy, etc. – and the advent of CPS is no different.

In response, managers must first reinforce the value of human beings in the digital ecosystem, assure people that machines are not a threat but rather extensions of their capabilities, and define the collaboration protocols between people and machines.

In order to promote a digital culture, decision-makers and stakeholders need to clearly understand the changing environment, know the current state of their operations and promote a culture of innovation. They need to embrace the benefits that CPS would bring and consider how the technology will align to their long-term digital strategy.

Implementing CPS cannot happen in isolation, where its true capabilities are siloed. This would defeat the whole purpose of creating an M2M ecosystem. A holistic approach is needed to define the digital strategy and clearly understand how, when and where using a CPS could deliver the greatest business value.

Security

Cybersecurity is one of the toughest challenges from an implementation standpoint. As machines and processes become more connected, they are also exposed to vulnerabilities and pose a significant threat to critical industrial infrastructure. Moreover, stringent safety norms may prevent modifications from being made to legacy equipment to patch security holes and to comply with regulations in which sensitive data can only be shared with approved third parties.

CPS would be the core of the operating ecosystems that empower critical infrastructure, and exploitation of vulnerabilities in them can lead to catastrophic effects across these ecosystems. In the Stuxnet worm attack,[19] for example, over 15 Iranian facilities were attacked and infiltrated by the worm, causing irreparable damage to critical machines/hardware that were specifically targeted.

With the integration of IoT and CPS devices into existing enterprise networks, it is important to ensure that existing systems are programmed to accommodate the expected benefits and that the technology does not create a significant liability risk. As devices will now be connected outside of organizational silos, the exposed attack surface and the associated risk for a cyber-incident increase greatly. Securing against such vulnerabilities would involve building middleware that facilitates secure integration of legacy and IoT systems in enterprise networks that learn automatically over time.

Such middleware will transform the way threat is perceived and handled in enterprise networks as the wear-your-own-devices (WYOD) trend continues to grow. We are collaborating with TU Delft to advance the state of the art in this domain.

A well-defined security strategy is required to proactively handle potential catastrophic events, especially given the vulnerabilities posed by a hyper-connected CPS ecosystem that could potentially allow infiltrators to cause damage. The strategy should encompass an integrated security solution that provides end-to-end visibility of network traffic and includes clearly defined security policies that ensure the safety of machines, processes and devices used by people. A combination of vigilant monitoring and enforcement of rules and alerts would support the safe and efficient operations of the digital infrastructure.

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Security management needs to be well considered while designing a CPS. Its design should be independently capable of securing its data, intelligence logic and interactions with other systems. Importantly, it must be empowered to take necessary actions (i.e., a mandatory shutdown or lockout) in the event of a security breach.

Talent & skill development

As CPS become mainstream over the coming years, the shift will not only produce various opportunities in the form of new offerings, business/service models, etc. but will also automate jobs that are currently handled manually. If not managed well, it might lead to social inequality where low-skilled people are sidelined by intelligent CPS systems.

The key is to strike a balance between finding and allocating value-added tasks to humans and repetitive jobs taken on by CPS.

A re-skilling strategy needs to be established for the existing workforce so they can utilize their core skills as well as learn new ones to stay relevant with the evolving digital ecosystem where humans and machines work in a collaborative and harmonious environment.

Key considerations & recommendations

Organizations that move to implement CPS for their operations should consider the following points to help maximize benefits and avoid pitfalls (see Figure 5):

- **Create strong ecosystem mapping and monitoring.** In line with the target operating model, organizations need a strong ecosystem mapping and monitoring system/framework to help identify and monitor all IoT devices and sensors, data flows, data management processes and various data protocols for devices to communicate. This becomes increasingly important since CPS, when implemented, will need access to various ambient and situational data. Making sure ecosystem monitoring is robust will ensure CPS performance is optimal.
- **Enact use-case-driven rather than big bang deployments.** Organizations must thoroughly analyze and prioritize beneficial use cases and trial-test them incrementally. This is advisable compared to a big-bang approach since the associated challenges and risks of implementing such systems can be carefully mitigated. As such, it becomes important to build a roadmap of CPS over a period of time starting with less complex implementations and graduating to higher complexities and AI-driven systems.
- **Apply modeling, simulation and piloting discipline.** When organizations complete planning and design, it is advisable to model and simulate CPS functioning by running pilots in controlled environments. As these systems become more autonomous and work in swarms, challenges concerning the collaborative aspects of different systems should be identified early on. This will reduce the risks and uncertainties during actual deployments, including the major risk of downtime.
- **Build a scalable architecture with guaranteed performance.** A consistent architecture that is scalable at a meta level as well as at a physical device level is important when adapting to CPS-induced changes. This approach offers a loose coupling of the cyber and physical parts to ensure that maintenance is more easily accommodated, while the software base (control loops of the CPS) with performance guarantees is maintained at all times.
- **Design for human interventions and overrides.** It is important when designing CPS to build in human interventions and overrides. This will help in situations where the self-controlled environments do not function as planned. Also, embedding human interventions and overrides will provide a sense of trustworthiness to the system.
- **Proactively consider robustness, safety, security and privacy considerations.** A critical aspect of the CPS is robustness against uncertainties in the operational environment, security attacks and malfunctions. Deployments must guarantee safety to human beings at all times. Last but not least, it is critical for CPS implementations to include privacy controls established in compliance with the corresponding regulations (e.g., GDPR). This will help the CPS flourish while remaining compliant with regulatory requirements.

Key CPS considerations and recommendations

Figure 5

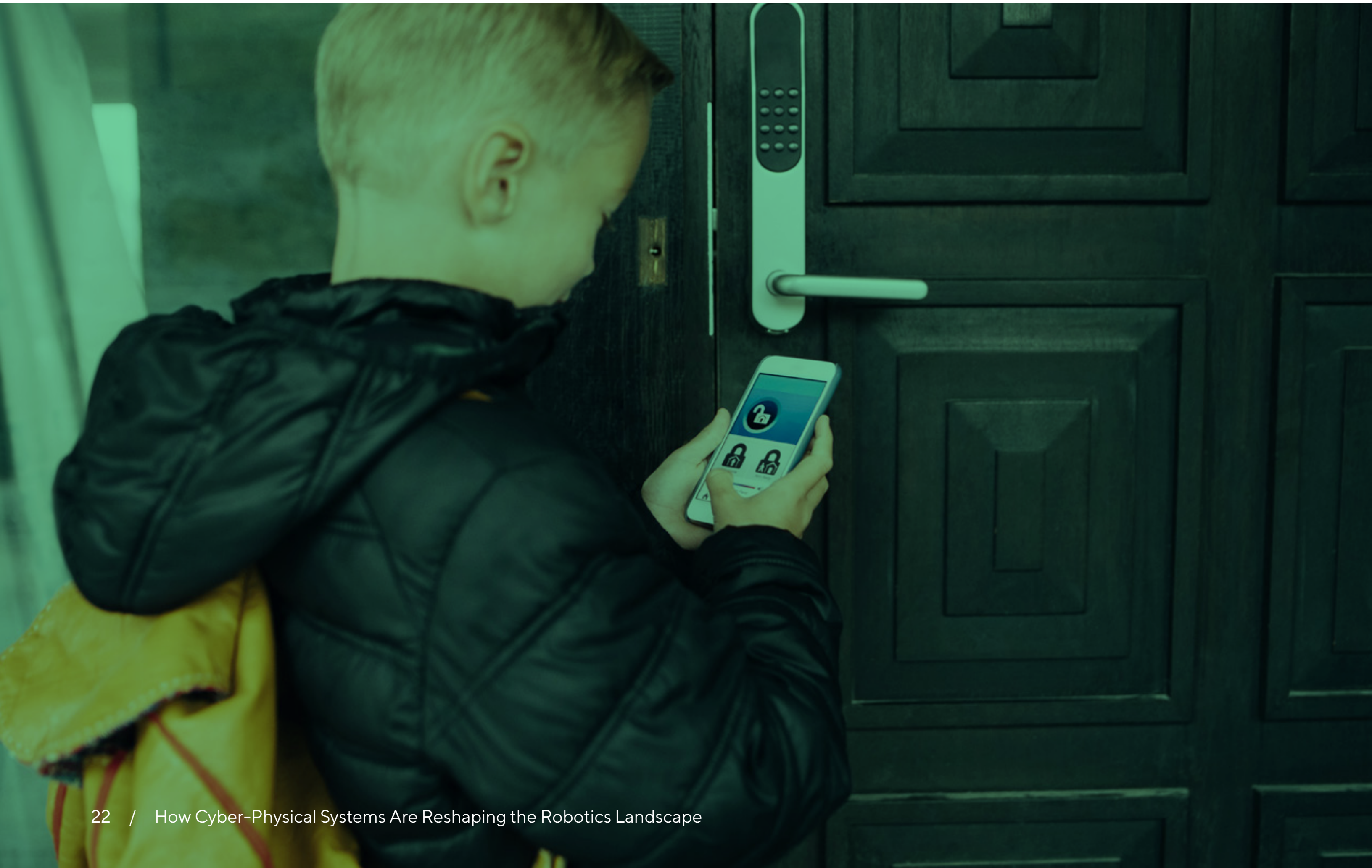
It is important when designing CPS to build in human interventions and overrides. This will help in situations where the self-controlled environments do not function as planned. Also, embedding human interventions and overrides will provide a sense of trustworthiness to the system.

Looking forward

Smart devices have become an inseparable part of everyday life. From operating independently, devices are now being visualized to work in tandem with other smart devices and also enable the functioning of autonomous physical systems in the form of CPS.

This phenomenon, combined with advanced capabilities in computation, storage and analytics, will create a range of new business and social interaction models. While the possibilities are endless, industry and policymakers will have to focus on the twin agenda of delivering transformational products and services while ensuring adherence to ethical and security considerations.

As a result, organizations planning to move forward with CPS implementations will need to ensure that their programs consider the key six parameters outlined (see Figure 5) with special emphasis on security. This will help them deploy CPS that will create intelligent ecosystems of machines which coexist with and enhance human capabilities.



Appendix

As a company that believes in being ahead of the digital technology curve, we collaborate with leading academic institutions worldwide in R&D initiatives to drive impactful application of leading-edge digital technology. We are working with multiple prestigious institutions, such as Delft University of Technology, the Netherlands, and the Indian Institute of Technology, Madras (among others) across various use cases that will help us activate CPS of the future. Key use cases include:

- **Use case one:** Consider an airport where people move freely around, with no queues for security checks. This can be made possible through a swarm of autonomous robots moving around in public places such as airports. These robots can sense threats as they walk by. When an unusual event occurs, the segment of the swarm closest to the event decides on the next action. While each robot is autonomous, the experience gained by one robot is transformed into swarm intelligence so that the airport is safe. We are researching this in our "Internet of Robots" project, with the goal of developing a foundation platform that incorporates swarm intelligence supported by low-latency communications and distributed decision-making.
- **Use case two:** Most commercial voice assistants, such as Alexa and Google home assistant, today transfer every word spoken to a central cloud for speech/command recognition as they require heavy computation. Such transfer of data causes response latency as well as potential privacy issues, which is far from ideal. In one of our university research engagements, an edge AI/ML system is being developed to address the latency issues. We will also construct privacy-aware, geo-distributed ML models in order to build enhanced models at a central cloud.
- **Use case three:** Human in the loop (HIL) techniques use human-swarm mixed-initiative interactions (HSI) to form teams comprising robots and humans that collaborate in a peer-to-peer setting to accomplish shared common goals. Including humans in the mix helps the swarm robots respond to unforeseen situations by learning from the people as they improvise to overcome adverse ground conditions.
- **Use case four:** Autonomous vehicles (including cars, drones, underwater vehicles, bots, etc.) are heavily dependent on GPS technologies to locate their positions both when stationary and in motion. However, there may be various environments that are denied/unavailable/unreliable for GPS, such as underground caverns, remote areas where satellites are inaccessible and underwater environments. Our research project looks at advanced image processing and simultaneous localization and mapping (SLAM) algorithms in order to enable such vehicles to find their way with minimal external system dependency.

Endnotes

1 https://en.wikipedia.org/wiki/Digital_thread.

2 www.ijitee.org/wp-content/uploads/Souvenir_IJITEE_v8i4_February_2019.pdf.

3 RADAR is a detection system that uses radio waves to determine the range, angle, or velocity of objects. It can be used to detect aircraft, ships, spacecraft, guided missiles, motor vehicles, weather formations, and terrain.
LIDAR, which stands for Light Detection and Ranging, is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the earth.

4 Vehicular ad-hoc networks are created by applying the principles of mobile ad hoc networks — the spontaneous creation of a wireless network for vehicle-to-vehicle data exchange — to the domain of vehicles.
A mobile ad hoc network or MANET is a decentralized type of wireless network. The network is ad hoc because it does not rely on a preexisting infrastructure, such as routers in wired networks or access points in managed wireless networks.

5 https://en.wikipedia.org/wiki/Swarm_intelligence.

6 https://wyss.harvard.edu/technology/programmable-robot-swarms/.

7 Tactile internet or the internet of touch can enable remote real-time physical interactions over the internet where individuals can feel the sense of touch over networks.

8 Haptic technology recreates the sense of touch by applying forces, vibrations or motions to the user.

9 An actuator is a component of a machine that is responsible for moving and controlling a mechanism or system.

10 www.bbc.com/future/story/20140516-i-operate-on-people-400km-away.

11 In the GDML technique, each compute node runs a local component of the algorithm on the data available and calculates interim results - local values of objective function, gradient and direction. www.cognizant.com/whitepapers/making-actionable-decisions-at-the-networks-edge-codex2938.pdf.

12 The term "Industry 4.0", shortened to I4.0 or simply I4, originates from a project in the high-tech strategy of the German government, which promotes the computerization of manufacturing, https://en.wikipedia.org/wiki/Industry_4.0. www.weforum.org/about/the-fourth-industrial-revolution-by-klaus-schwab.

13 www.roboticsbusinessreview.com/health-medical/swarm-robotics-boosts-diagnosis/.

14 www.news18.com/news/india/gujarat-doctor-makes-history-performs-worlds-1st-robotic-heart-surgery-30-km-away-from-patient-1961729.html.

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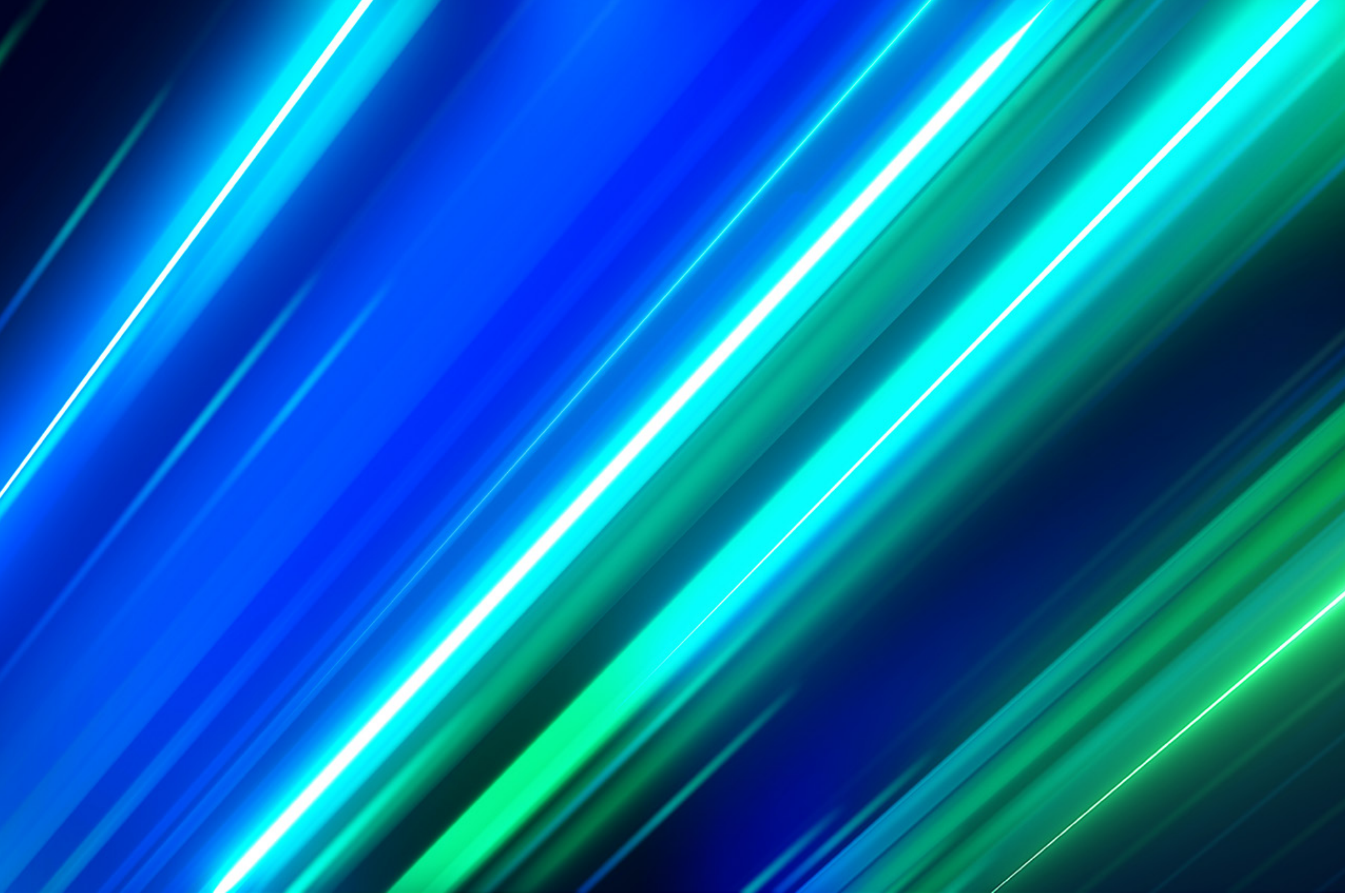

About the Global Technology Office

Cognizant's Global Technology Office (GTO) is a research and development incubator that explores how emerging technologies can be applied to solve our clients' business challenges — today and tomorrow. We partner with leading academic and research institutions worldwide, as well as our business units and practices, to research and experiment with a cornucopia of technologies – from advanced forms of artificial intelligence and swarm robotics, through quantum technologies and mixed reality — via pilots and proofs of concept that determine their real-world application and potential business benefit. To learn more, contact us at inquiry@cognizant.com.

About Cognizant

Cognizant (Nasdaq-100: CTSH) is one of the world's leading professional services companies, transforming clients' business, operating and technology models for the digital era. Our unique industry-based, consultative approach helps clients envision, build and run more innovative and efficient businesses. Headquartered in the U.S., Cognizant is ranked 195 on the Fortune 500 and is consistently listed among the most admired companies in the world. Learn how Cognizant helps clients lead with digital at www.cognizant.com or follow us @Cognizant.

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