Industrial Intelligence: AI's Implications on Security, Seamlessness and Services for the IIoT

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INTRODUCTION

The Internet of Things is a confluence of technologies that have matured earlier than anticipated. This precociousness is not a bad thing – it makes for clever devices that simplify our lives by turning lights on and off using timers or mobile applications. Other clever systems can check the traffic each morning and set my alarm to wake me optimally based on a utility function balancing my love of sleeping and in-car public radio with my distaste of sitting in gridlock. These applications make the world a little more fun, a little happier, a little more efficient. But…

As researchers watching IoT evolve from technological seedling into a powerful and scalable innovation platform, we can't help but feel a little like parents watching a child grow up. IoT is exciting, clever and lovable – but it's destined for greatness if it can cultivate its talents. Having watched other technologies grow, we know that being precocious and clever is not sufficient – we need IoT to be *intelligent*.

An intelligent IoT would read my emotion from wearable devices and change the color and brightness of my lights as I walk through the house to evoke a pleasant response. An intelligent alarm clock would consult my medical records, work e-mails and calendar events to ensure that I woke up at the right time able to perform my best, while still having enough time to complete all of my assigned tasks.

Shifting from cleverness to intelligence requires a degree of technical magic. Fortunately, the building blocks are in place and IoT and AI practitioners are jumping at the chance to build a Digital David Blaine.

ARTIFICIAL INTELLIGENCE: A GRAND, OLD VISION, COMING OF AGE

Artificial Intelligence is a suite of technologies capable of affording machines perception and cognition. Perception allows digital systems to observe themselves and the surrounding world through sensors and other data streams. Cognition allows machines to learn rules and to solve problems based on examples and models. These elements combine such that machines may develop an almost human-like intuition, with an awareness of their own place, purpose, and processes.

We are in the midst of an AI revolution – in the sense that we've seen evolutions before. AI has been used successfully in research since the 1950's. [1] However, Artificial Intelligence struggled with adoption due to the cost and complexity of its implementation. Limited input data and slow processing additionally challenged the technology's growth.

Today, things are a bit different from AI's nascent days. Computers are less expensive and more power efficient, while popular,

[1] Frank Rosenblatt is credited with creating the first perceptron in 1957 at the Cornell Aeronautical Laboratory. This is considered by many to be the forerunner to modern artificial intelligence.

open-source software libraries reduce complex applications into a few lines of quick-to-write code. Data are abundant, with billions of diverse, distributed connected devices uploading information to centralized repositories. Platforms for data sharing allow information to be moved, fused, and aggregated with ease.

As a result of this new technological frontier, AI has the power to turbocharge connected devices' data exhaust to make products and platforms smarter and more powerful than ever. We are entering the first AI revolution where technology can keep up with our dreams.

BUILDING TOWARDS AN INTELLIGENT INTERNET OF THINGS

It is our view that the Internet of Things describes products and services supporting connectivity, sensing, inference, and action.

Connectivity is well understood, with technologies and protocols ranging from 5G and LoRa to 6LoPan and MQTT. Sensing has been commoditized with the advent of low-cost, low-power MEMS sensors. Actuation is implemented through text messages, OLED displays, servos and stepper motors. We are quite good at making devices and services meeting these three objectives. Inference has been the challenge, until recently.

Older connected systems use rule-based logic to perform. System functionality can be reduced to a series of cascading conditional "if" statements. These statements may be complicated, as in the case of decision trees, or simple – turn on a light if the process temperature exceeds a set limit. Often, such "intelligence" uses few enough input parameters to be counted on fingers, at slow data rates allowing for human oversight.

These systems have their place where predictability is key, input data are controlled and the process limits can ensure safety. However, these systems are not extensible – binary logic cannot make use of new forms of data, and may fail when presented with a scenario outside the design specifications.

AI addresses the problem by imbuing physical objects and their digital duplicates with a degree of self-awareness. In this way, AI cultivates another IoT: the Intelligence of Things.

Self-learning models will allow devices to monitor themselves, their users, environments, processes and outputs. These models can identify impending failures, minimizing downtime, optimize process efficiency to limit work-in-progress, or even identify tampering. Because these models use rich input data and continually learn, they evolve to become better over time.

AI brings a human element to IoT by applying data and context-awareness to problem solving. This allows machines to adopt some of people's best traits: resilience in the face of unexpected situations, data-informed rationality, and the ability to make (and break) rules as new information is made available. And unlike humans, artificial intelligence is always learning and has a perfect memory.

By becoming more human, AI has made the IoT relatable and accessible to individuals. Artificial Intelligence is at the core of favored digital assistants, consumer photo sorting software, and movie recommendation engines. Unlike in AI's early days, these systems work seamlessly and have been

welcomed into everyday life. The result is a virtuous cycle where AI has gained consumer trust and business interest that has led to a snowballing growth.

Three Cases for Artificial Intelligence

Just as in the consumer space, industry has seen the benefit of AI as an effective force (revenue) multiplier. Corporations have visions of synthesizing AI and IoT to improve operational efficiency while reducing cost and to provide process analytics, though the biggest opportunities have yet to be explored.

We present a non-exhaustive list of three areas where AI can transform the IoT, and in turn industry:

1. Context-aware security
2. Building seamless "human" IoT interactions
3. Intelligent services

Security

IoT relies on the ability to collect data and control systems at scale. Collection and control demand a high level of practitioner and end-user trust.

Trusting users are more likely to share valuable data, while trusting companies are more likely to use IoT to control core operations where analytics may unlock the biggest efficiency improvements. Creating systems that can adequately secure equipment from intentional and accidental malicious use is challenging. When sensitive actuators such as power infrastructure or connected vehicles join the mix, the stakes are raised. AI may be used to develop context-aware security systems and alarms for IoT devices.

This AI leverages the fact that most IoT devices are mirrored in the Cloud or another central repository with scalable computing. Physical system behavior is observed, with sparse data being sent to a digital duplicate using a model to "interpolate" these data into a rich representation. This model starts out as generalized by object type, but over time adapts to the particular nuances of the mirrored object's own sensors, environment, and use cases. These models interact with one another in the Cloud so that they learn their place in a larger system.

"Cognitive Firewalls" and "Cognitive Supervisors" use each model to evaluate the impact of commands to ensure they are benign prior to execution, or to identify when a process behaves anomalously. [2] The Firewall uses the adaptively-learned model to "test" a command digitally to ensure it does not violate any known or learned limits prior to forwarding it to the related physical device. For example, the Cognitive Firewall could be used to protect a robot arm from malicious commands. When the arm is sent commands that cause the arm's mirror to intersect with a second robotic arm in the same Cloud Factory, the command is rejected. Similarly, an oven may learn that it is located within a food processing facility and that its purpose is to bake cookies, so a safe maximum temperature limit is 500F.

The Cognitive Supervisor may be used to identify process problems. For example, the Supervisor may learn that a particular smelting furnace at 80% duty cycle reaches a

[2] The Future Internet of Things: Secure, Efficient, and Model-Based http://ieeexplore.ieee.org/document/8055694/

particular steady-state temperature. If the Supervisor detects than an 80% duty cycle results in a lower temperature, an alert is sent to a user to check whether the heating element or sensor have failed, or if an insulating door was left open. If an extruder notices that the processing force increases suddenly, the system can identify that the die has yielded.

Using our IoT-as-a-child example from earlier, AI can teach devices and services right from wrong, not to believe everything they hear, not to take advice from strangers, and cause and effect. These examples show the potential for Artificial Intelligence to supervise and protect digitally mirrored systems.

Seamlessness

Artificial Intelligence allows IoT to become seamless in industrial environments. Intelligence helps devices find pervasive deployment, creates frictionless user interactions and intuitive integration into conventional workflows, and simplifies human hand-offs.

IoT works best when it is implemented at scale, though resource constraints challenge IoT's deployment. Using the same models described in the previous section, AI can be used as the basis of "Data Proxies" capable of turning sparse input signals into rich digital representation of physical objects. [3] Reducing the amount of data required to mirror a system using Artificial Intelligence lowers costs and allows the pervasive deployment of devices. With smart, connected things everywhere, they can become an integral and invisible part of our lives, blending into the background of industrial environments.

AI can also be used to reduce user friction, integrating smart objects transparently into conventional workflows or allowing them to operate on their own in the background. Voice assistants provide pervasive intelligence by utilizing AI to allow individuals to speak to a computer as they would a person, while other technologies leverage AI to proactively control environments based on learned trends and current conditions. In both cases, the ease of interaction allows these smart devices and systems to fade transparently into the background, while they simultaneously make worker's lives more comfortable and optimize processes.

These same machines may even learn about their environment in order to allow for automated process optimization at scale, reducing or eliminating the need for human involvement. IoT has changed how we see machines, but it also changes how machines see themselves – with richer data and Artificial Intelligence, machines are now able to learn their context and to understand their place, purpose, and processes. Machines that understand their role in an organization may optimize at scale and in aggregate as opposed to individually. These devices can then reduce a factory's operating costs, energy use, work-in-progress, and exposure to safety hazards with a minimum of human interaction. This invisibility paired with efficacy at scale is what makes AI such an integral, and non-invasive, part of our daily lives.

[3] The Future Internet of Things: Secure, Efficient, and Model-Based http://ieeexplore.ieee.org/document/8055694/

Services

In the context of smart things, Artificial Intelligence is what allows devices to evolve. Physical objects ship with one manifestation; malleable, adaptive software can allow these goods to remain relevant over the long haul. AI allows software to remain secure and useful, improving with age as opposed to becoming deprecated when the world continues to evolve.

In addition to allowing devices a modicum of self-awareness, Artificial Intelligence itself can become a valuable service. We observe from the automotive industry that autonomy stemming from advances in artificial intelligence can fundamentally change how people view vehicles – transitioning them from single-purchase, durable goods to shared mobility services. Outside the obvious uses for artificial intelligence and connectivity in enabling these vehicles' scheduling and operation, the same technology can be used to create smart, self-diagnosing vehicles that shift maintenance from responsive to proactive. Eventually, AI may be used to not only detect faults, but to create self-healing vehicles.

Already, artificial intelligence has been used to learn "fingerprints" for characteristic faults and maintenance needs in vehicles.[4] Other industrial processes can be similarly monitored, to identify the optimal time for tool replacement, or to correlate production issues with particular machine tools or operators. Connectivity at scale allows these analytics to monitor not just individual processes or plants, but to monitor stock levels, supply chains, and market forces. In agriculture, AI can identify optimal planting locations, watering schedules, and harvest timing.

Because AI is rational and data-informed, it can become an unbiased, trusted advisor, removing human subjectivity and improving practitioners' confidence in decisions. Those organizations adopting AI will have significant competitive advantages, more resilience to turbulent markets, improved operational efficiency and will work towards a vision of zero downtime, zero waste, zero accidents, and zero missed opportunities.

A Roadmap Towards Cognition in the IoT

As AI continues to improve and IoT scales up, the marriage between the two will become increasingly valuable to industry. Improved security, seamless and pervasive implementation, and outcome-based applications will become transformative across verticals. The resulting better-designed systems taking security, data privacy and ownership, interoperability, and resilience into account will ensure a bright future for all connected devices and services, so businesses can reap the benefits of accepting good technologies into their industries.

At the end of the day, AI's continued use will make IoT safer and more effective leading to a grand vision where the default question becomes "is there a reason this shouldn't be

[4] Let Your Car Tell You What It Needs: http://news.mit.edu/2017/software-let-your-car-tell-you-what-it-needs-1026

connected" rather than "why would we want to connect this?"

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