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A collaboratively developed platform to introduce fundamentals of IoT and IIoT

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Abstract

Industrial Internet of Things (IIoT) is a core technology of Industry 4.0 capable of providing transformative data and insights. Successful implementation of IIoT requires knowledge bridging the Information Technology (IT) and Operational Technology (OT) domains. This work presents a collaborative effort between multiple industry partners and academia to provide a comprehensive, cost-effective orientation to IIoT scoped for an undergraduate engineering audience. The outcome is a scalable solution that allows for the presentation and development of core skills focused on IoT concepts, cloud, edge, on-premises, hybrid IIoT solutions, data fundamentals, monitoring, control, analysis, and data applications utilizing IIoT systems and devices. Presentations also focus on demonstrating the best methods for securely deploying IIoT technologies in hybrid architectures. In addition to serving as a pathway to safely prepare and upskill students before they engage with industrial-scale systems in the learning factory, the platform also serves as a foundation for a new undergraduate curriculum for preparing graduates for Industry 4.0 and the digital transformation of the manufacturing industry.

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1. Overview

A global shortage of technically capable workers currently limits the adoption of Industry 4.0 technology in the manufacturing sector. Forecasts predict [1] the largest shortfalls will occur in positions staffed by engineers, researchers, and scientists. This critical need has prompted a collaboration across Industry, Higher Education, and

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Technology partners to help address this shortage by developing an accessible technology platform and related curriculum focused on introducing the transformative technologies of Industry 4.0 to a broader audience. This pathway allows for greater flexibility in introducing technologies in early coursework to better prepare students to engage with the systems found in a learning factory efficiently. Additionally, the low barrier to entry of the technology platform allows for a larger audience to engage in upskilling activities critical to developing a technical workforce to support the adoption of Industry 4.0 technologies. The technology platform allows for an initial focus on introducing general concepts of the Internet of Things (IoT) devices, IT networking, cloud connectivity, and general data science processes. Later activities focus on manufacturing-specific implementations IoT, Industrial Internet of Things (IIoT) that conform to industry standards. Additionally, the platform walks through an introductory integration of OT devices with cloud systems while providing exposure to mixed reality deployments that support manufacturing operations and training.

2. Internet of Things

The collaboratively developed IoT platform allows for learning and exposure to introductory industrial scenarios independent of a physical lab or learning factory. This platform aims to support the learning of foundational IoT concepts and extend industry-relevant scenarios [2], driving experimentation and innovation. The Microsoft led design effort included multiple teams, including those specializing in hardware, software, education resources, and industry solutions.

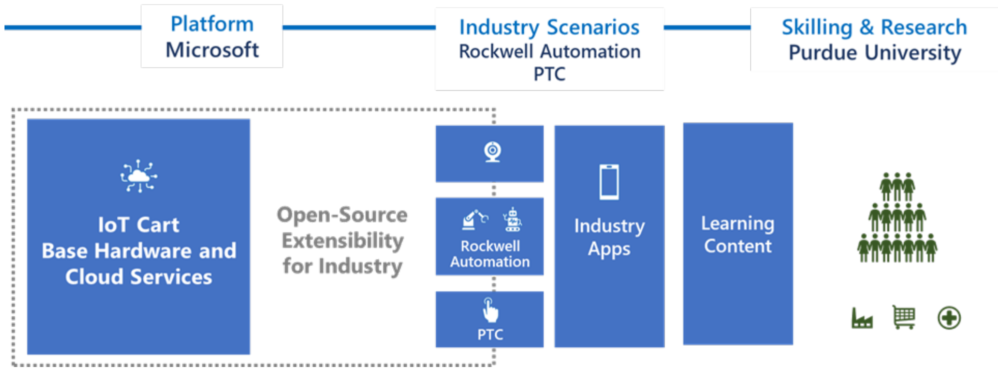

Fig. 1. IoT and IIoT Collaborations.

2.1. *IoT Platform*

The IoT platform uses widely available components allowing for incremental construction and expansion based on needs. Platform specifications include a Microprocessor, Radio Network connectors, a collection of Input Sensors such as Pressure, Water, Temperature, Acceleration, Cameras, Microphones, and Outputs, including Motors, LEDs, and Displays. It leverages Azure cloud technologies at its center to access computing services like storage and analytics over the internet. The hardware was selected to support multiple learning scenarios, such as:

- Data Storage and Optimization
- Speech and Vision Cognitive Services
- Device Management Security
- Industrial Automation
- System Scalability
- Quality Control
- Machine Learning

- Predictive Maintenance

All hardware in the IoT platform has wide availability is low cost, and is simple to interface. The IoT platform utilizes Microsoft Azure, with many services offering free tiers allowing no-cost experimentation with the same technology used in industry deployments of IoT.

2.2. IoT Learning Content

Supplemental content is available as an online collection [3] of open-source learning materials, developed with input from educators and IoT experts globally. It was also designed with tools and techniques to support teaching IoT virtually, leveraging simulated processes, where access to physical hardware is not practical. The open, online library presents materials in a flexible format allowing educators and facilitators to match their course structures and pedagogies.

The content's primary audience is students in higher education; however, the intent is to cover all abilities, including those with no formal computer science background. Links to introductory programming content and activities include all required code. Additionally, the content can be readily modified and expanded to fit other scenarios. The library includes curated content on IoT from a wide range of online documentation, learning platforms, code samples, SDK references, and working examples. Topics include IoT, AIoT (AI on edge), TinyML, and IIoT.

Content is available for investigations using a range of low-cost microcontroller families, including Arduino, Raspberry Pi, and NVIDIA Jetson AI boards with Python and C++ programming languages. Cloud technologies include IoT gateways, IoT SaaS platforms, AI model training and deployment to IoT devices, data storage, data analytics. Hands-on experiences explore a range of hardware and IoT scenarios, from IoT devices with sensors to more complex AI on the edge and TinyML scenarios. Experiences illustrate the power of IoT, along with the power of the intelligent cloud and intelligent edge. In instances where access to the hardware is limited, some of the experiences can use virtualized hardware with simulated values for sensor data and console-based output from actuators.

The library also includes teaching guides and suggested course outlines for a range of IoT courses focusing on a wide range of learners from early to experienced. Included are learning pathways to upskill with and explore specific IoT technologies to expand and augment existing skillsets.

3. Industrial Internet of Things

The collaboratively developed Industrial Internet of Things (IIoT) platform builds on the IoT platform's capabilities and presents converged Information Technology and Operational Technology systems. The platform allows for secure integrations of on-premises devices and cloud systems in a manner that conforms to industry standards. It includes industry-grade components and provides technology pathways to explore IT/OT convergence, brownfield implementation of IoT, digital twin, machine learning, artificial intelligence [8], and mixed-reality in manufacturing scenarios. The platform's flexibility allows for offline development, modeling, and simulation of processes designed for the learning factory before implementation.

3.1. IIoT Platform

The IIoT platform utilizes a ControlLogix 5480 PLC to coordinate all OT devices and a Factory Talk Analytic Edge Gateway to connect to cloud resources securely in an architecture that conforms to recognized industry standards. Data ingested in the cloud system is available for storage or further processing using a range of analytics, Machine Learning, and Artificial Intelligence tools. The architecture allows for the scaling of cloud storage and computing resources based on demand.

Emulate3D provides the ability to create a digital twin of a production system, allowing hypothetical scenarios, emulation, and testing of a process before implementation in the learning factory. Vuforia Studio, in conjunction with

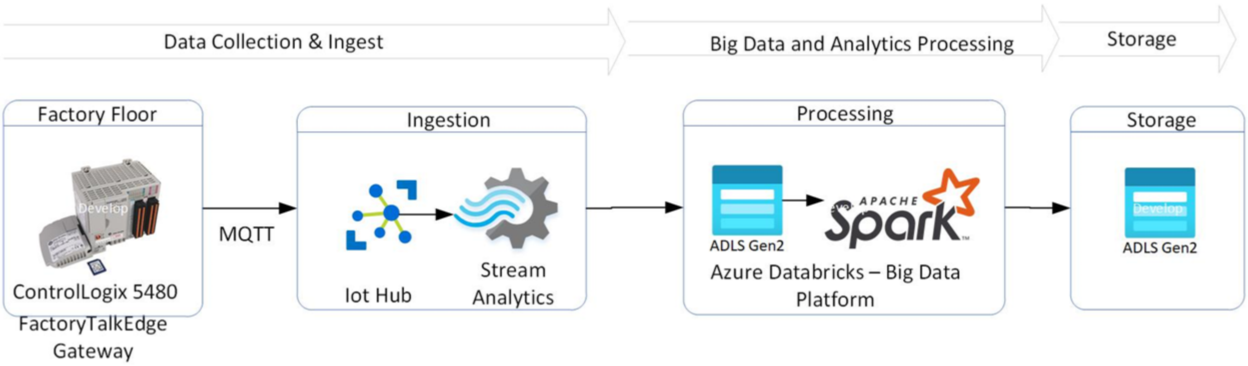

Fig. 2. IIoT Platform Data Architecture [4].

Thingworx, allows for the development of live dashboards, interfaces, and mixed reality interfaces utilizing real-time manufacturing data bringing visibility to the data driving processes.

3.2. IIoT Learning Content

A growing catalog of experiences is under development for the platform. An introductory activity uses a traffic signal scenario to showcase the integration of all technologies from on-premises control through cloud ingest. This activity also incorporates the development of a virtual dashboard and virtual control interface utilizing OPC-UA data.

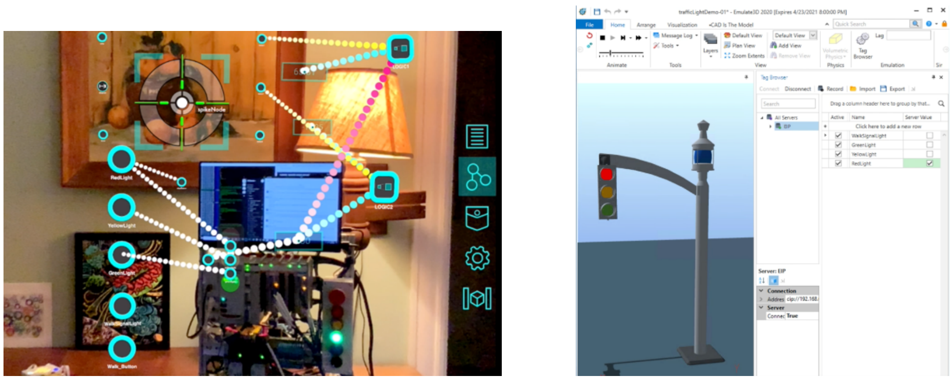

Fig. 3. IIoT Learning Content Examples.

4. Smart Manufacturing Curriculum and Learning Factory Ecosystem

This section illustrates how IoT and IIoT serve as the foundation of Purdue University's newly developed undergraduate program focused on Industry 4.0 [7]. In addition, this project illustrates an extensive collaboration between technology providers, industry partners, and academia that serves as a model undergraduate program that the US Department of Energy's Clean Energy Smart Manufacturing Innovation Institute (CESMII) intends to democratize to other universities across the US. Two key frameworks, the curriculum and the physical and digital infrastructure, guide the undergraduate program's development. The following sections describe how IoT and IIoT knowledge has been integrated and operationalized within these frameworks to develop this project.

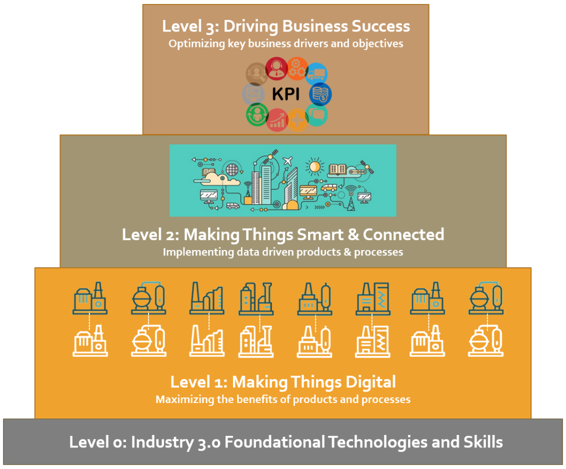

Fig. 4. Smart Manufacturing Curriculum Framework.

4.1. Smart Manufacturing Curriculum

The curriculum framework in Figure 4 highlights the three core foundations of digital transformation. In Level 1 of this framework, IoT and IIoT serve as the foundation for digitalizing the machines, products, and processes. Level 2 utilizes data from the IoT and IIoT devices, networks, and the cloud/edge infrastructure to implement connected intelligent manufacturing systems. Level 3 of the framework is to derive value using IoT and IIoT data to create new levels of efficiency, productivity, precision, and performance. The curriculum includes twelve new courses to introduce students to the concepts of IoT, IIoT, and cyber-physical systems in manufacturing using this framework. Two of these new courses (Industrial IoT Networks and Systems I and II) introduce the IIoT learning platform with the learning content in this project. Topics covered in these courses include examining IT and OT networks, hardware, architecture, protocols, standards, and security practices in Edge, hybrid, and Cloud-based industrial applications.

4.2. Smart Manufacturing Facilities

Students apply knowledge from the two courses and practical knowledge gained on the IIoT platforms across various manufacturing systems in the learning facilities developed to support the program.

In the Smart Learning Factory, a scale model of a cyber-physical production system, the IIoT system provides data from machines and manufacturing operations to deliver real-time insights and control of operations across the value chain of a production system. Using the IoT architecture, students will create a connected production system and use the data retrieved from sensors, controllers, gateway devices, and communication networks to develop applications using premise servers, off-premise cloud, and hybrid environments.

The Smart Foundry is a state-of-the-art industry-grade green sand gravity casting testbed with capabilities for real-time monitoring, control, with full operational traceability of all processes from melt to finished casting. With a broad spectrum of integrated digital technologies, including scalable cloud-based AI, analytics, and advanced MES solutions, the Smart Foundry continuously monitors and improves the reliability of its processes to generate quality and consistency of the castings via predictive outcomes. Students will use IIoT in the Smart Foundry to acquire data from the molding machine, furnace, sand system, and pouring, robot and exchange and manage this information across the manufacturing ecosystem. This data will be analyzed and utilized to optimize quality management processes to meet the quality standards of casting operations.

The Intelligent Process laboratory features a state-of-the-art continuous process manufacturing system with instrumentation, mobile communication, internet, and cloud computing technologies for real-time access to process status, data, analytics, and system alarms. This process manufacturing system uses IIoT technology that enables connected operations and allows students to collect data from sensors and devices so they can perform analytics, create a knowledge database, and develop operational intelligence for the process. In addition, this IIoT based system will enable real-time monitoring with network-wide visibility of all process parameters, allowing remote visualization, control, and optimization of the process manufacturing system.

The Industrial Systems and IoT Laboratory introduce students to activities involving the embedding of processors, sensors, software, intelligence, and connectivity to exchange data from product/process across a network using mobile and internet technologies. This laboratory facilitates student learning in using IIoT technology to develop various manufacturing applications ranging from remote monitoring to intelligently controlling operation/s across a network. In addition, this laboratory will provide facilities for students to design, build, test, and deploy IIoT devices for use in manufacturing applications and embed them into smart products.

5. Conclusions

This work showcases industry/academia collaboration to develop a platform capable of presenting IoT and IIoT. The collaboration between industry, academia, and agency was not without challenges and required consideration of a range of perspectives. Industry focus is firmly grounded in the delivery of solutions while academic focus is on the experiences that generate skill sets. Initial conversations must develop an understanding around areas where participants may have competitive technologies. Participant focus can range from the pragmatic short term (brownfield) to the futuristic ideal (greenfield) and there must be consideration to allow for both. Data is the key component to realizing the potential of Industry 4.0 technologies. The ability to access and utilize data from real industrial systems is crucial to presenting the value of technologies and allowing student exploration. While true industrial data is desirable, the economic value of this internal data may preclude its availability for instructional use. This enhances the importance of a learning factory and supporting facilities to serve as a data engine for academic experiences. This collaborative learning platform will be used to introduce IoT and IIoT concepts that will be used in depth in the learning factory.

Using IoT and IIoT as the foundation, we also demonstrated how a university can successfully collaborate with technology companies and industry partners to develop an undergraduate engineering curriculum and an ecosystem of Learning Factory facilities scoped for student learning activities. The concepts and framework presented in this work could be used to upskill the workforce and prepare them for Industry 4.0 and the digital transformation of the manufacturing industry.

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