

US Patent & Trademark Office

Patent Public Search | Text View

United States Patent	12386344
Kind Code	B2
Date of Patent	August 12, 2025
Inventor(s)	Mazur; David C. et al.

Data driven digital twins for industrial automation device operation enhancement

Abstract

An industrial automation system may include a first computing device that may receive operational technology (OT) data from industrial automation devices of an industrial automation system, determine identities of the industrial automation devices based on the OT data, determine that the OT data includes data attributes having variations as compared to additional OT data, transmit the identifiers and the data attributes to a second computing device in response to determining that the data attributions have the variations, receive containers including updated digital representations of the industrial automation devices from the second computing device, execute the containers to output additional data attributes, and send commands to the industrial automation devices to modify processes based the additional data attributes.

Inventors: Mazur; David C. (Mequon, WI), Entzminger; Rob A. (Shawnee, KS), McCleave, Jr.; Bruce T. (Mission Viejo, CA), Teal; James M. (New Brunswick, NJ)

Applicant: Rockwell Automation Technologies, Inc. (Mayfield Heights, OH)

Family ID: 1000008752146

Assignee: Rockwell Automation Technologies, Inc. (Mayfield Heights, OH)

Appl. No.: 18/543908

Filed: December 18, 2023

Prior Publication Data

Document Identifier	Publication Date
US 20240118684 A1	Apr. 11, 2024

Related U.S. Application Data

continuation parent-doc US 17950586 20220922 US 11846918 child-doc US 18543908

Publication Classification

Int. Cl.: G05B19/418 (20060101)

U.S. Cl.:

CPC G05B19/41885 (20130101); G05B19/4186 (20130101); G05B2219/25064 (20130101)

Field of Classification Search

USPC: 703/13

References Cited

U.S. PATENT DOCUMENTS

Patent No.	Issued Date	Patentee Name	U.S. Cl.	CPC
10715388	12/2019	Fildebrandt et al.	N/A	N/A
11182206	12/2020	Jung et al.	N/A	N/A
11474873	12/2021	Biernat et al.	N/A	N/A
11513877	12/2021	Biernat et al.	N/A	N/A
2007/0078956	12/2006	VanGompel	N/A	N/A
2017/0220011	12/2016	Hart et al.	N/A	N/A
2018/0024537	12/2017	Chauvet et al.	N/A	N/A
2018/0054469	12/2017	Simoncelli	N/A	N/A
2019/0377604	12/2018	Cybulski	N/A	N/A
2020/0136906	12/2019	Bernat et al.	N/A	N/A
2020/0249928	12/2019	Zeng et al.	N/A	N/A
2020/0278892	12/2019	Nainar et al.	N/A	N/A
2020/0311617	12/2019	Swan et al.	N/A	N/A
2021/0089354	12/2020	Nixon et al.	N/A	N/A
2021/0200814	12/2020	Tal et al.	N/A	N/A
2021/0218617	12/2020	Palavalli et al.	N/A	N/A
2021/0271516	12/2020	Hs et al.	N/A	N/A
2021/0325861	12/2020	Hou et al.	N/A	N/A
2021/0382727	12/2020	Vigil et al.	N/A	N/A
2022/0027721	12/2021	Thoemmes et al.	N/A	N/A
2022/0091572	12/2021	Biernat	N/A	G05B 19/4188
2022/0100171	12/2021	Miller	N/A	G06N 20/00
2022/0100182	12/2021	Mehrotra	N/A	G05B 19/41885
2022/0284096	12/2021	Gadhe	N/A	N/A

FOREIGN PATENT DOCUMENTS

Patent No.	Application Date	Country	CPC
3696636	12/2019	EP	N/A
3979114	12/2021	EP	N/A
20200027783	12/2019	KR	N/A
2020184362	12/2019	WO	N/A

OTHER PUBLICATIONS

CN_113268044_A (Year: 2021). cited by examiner
EP_3748447_A1 (Year: 2020). cited by examiner
EP_3070550_A1 (Year: 2016). cited by examiner
Liu, Y. et al., “A Data-Centric Internet of Things Framework Based on Azure Cloud,” IEEE Access, vol. 7, Mar. 27, 2019, 20 pages. cited by applicant
Extended European Search Report for European Patent Application No. 21179775.8, dated Nov. 25, 2021, 9 pages. cited by applicant
Partial European Search Report for European Patent Application No. 21180068.5, dated Dec. 8, 2021, 17 pages. cited by applicant
Marshall, “Industry 4.0: The PLC evolves from Controller to Cloud Interface,” Feb. 9, 2018, <https://www.rs-online.com/designspark/evolution-of-the-industrial-plcfrom-controller-to-cloud-interface>, retrieved on Nov. 29, 2021, pp. 1-6. cited by applicant
European Search Report for European Patent Application No. 21180068.5, dated Mar. 28, 2022, 19 Pages. cited by applicant
Anonymous, “Pull an Image from a Private Registry”, Kubernetes, retrieved on Mar. 18, 2022, 5 Pages, <https://web.archive.org/web/20171003051312/https://kubernetes.io/docs/tasks/configure-pod-container/pull-image-private-registry/>. cited by applicant
European Search Report for European Patent Application No. 21180279.8, dated Apr. 19, 2022, 12 Pages. cited by applicant
D. Elliott, C. Otero, M. Ridley and X. Merino, “A Cloud-Agnostic Container Orchestrator for Improving Interoperability,” 2018 IEEE 11th International Conference on Cloud Computing (CLOUD), 2018, pp. 958-961, doi: 10.1109/CLOUD.2018.00145. (Year: 2018). cited by applicant
A. Khan, “Key Characteristics of a Container Orchestration Platform to Enable a Modern Application,” in IEEE Cloud Computing, vol. 4, No. 5, pp. 42-48, Sep./Oct. 2017, doi: 10.1109/MCC.2017.4250933. (Year: 2017). cited by applicant
Hung et al. “A Novel Implementation Framework of Digital Twins for Intelligent Manufacturing Based on Container Technology and Cloud Manufacturing Services”, IEEE, Jul. 2022, p. 1614-1630. (Year: 2022). cited by applicant
“What are device templates in Azure IoT Central,” Microsoft Learn, <https://web.archive.org/web/2022100201216/https://learn.microsoft.com/en-us/azure/iot-central/core/concepts-device-templates>, Aug. 31, 2022, 12 pages. cited by applicant
Lin Ting Yu et al., “Efficient container virtualization-based digital twin simulation of smart industrial systems,” Journal of Cleaner Production, Elsevier, Oct. 2, 2020, 19 pages. cited by applicant
Extended European Search Report for Application No. 23198195.2 mailed Feb. 9, 2024, 15 pages. cited by applicant

Primary Examiner: Khuu; Hien D

Attorney, Agent or Firm: Fletcher Yoder, P.C.

Background/Summary

CROSS REFERENCE TO RELATED APPLICATIONS (1) This application is a continuation of U.S. patent application Ser. No. 17/950,586, entitled “Data Driven Digital Twins for Industrial Automation Device Operation Enhancement,” filed Sep. 22, 2022, that is incorporated herein by reference in the entirety.

BACKGROUND

(1) The present disclosure generally relates to industrial automation device control. More specifically, the present disclosure relates to systems and methods for industrial automation device control using containerized digital representations implemented on edge devices.

(2) This section is intended to introduce the reader to various aspects of art that may be related to various aspects of the present disclosure, which are described and/or claimed below. This discussion is believed to help provide the reader with background information to facilitate a better understanding of the various aspects of the present disclosure. Accordingly, it is understood that these statements are to be read in this light, and not as admissions of prior art.

(3) As the industrial automation systems have evolved to harness edge computing, analytics, and the vast amounts of data generated by industrial automation devices, there are continuing interests to find new ways to modify, utilize, and process data. For example, in the case of utilizing edge computing devices to process data generated by industrial automation devices of an industrial automation system, the edge computing devices may be able to reduce the amount of data communicated to a cloud computing system and enhance operations of the industrial automation devices by utilizing containers that are implemented on the edge computing devices.

BRIEF DESCRIPTION

(4) A summary of certain embodiments disclosed herein is set forth below. It should be understood that these aspects are presented merely to provide the reader with a brief summary of these certain embodiments and that these aspects are not intended to limit the scope of this disclosure. Indeed, this disclosure may encompass a variety of aspects that may not be set forth below.

(5) In one embodiment, a system may include a first computing device that may receive operational technology (OT) data from one or more industrial automation devices of an industrial automation system, determine one or more identities of the one or more industrial automation devices based on the OT data, determine that the OT data includes one or more data attributes having one or more variations as compared to additional OT data, transmit the one or more identifiers and the one or more data attributes to a second computing device in response to determining that the one or more data attributions have the one or more variations, receive one or more containers including one or more updated digital representations of the one or more industrial automation devices from the second computing device, execute the one or more containers to output one or more additional data attributes, and send one or more commands to the one or more industrial automation devices to modify one or more processes based the one or more additional data attributes.

(6) In another embodiment, a method may include receiving operational technology (OT) data from one or more industrial devices of an industrial system via a first computing device, determining one or more identities of the one or more industrial devices based on the OT data, determining that the OT data includes one or more data attributes having one or more variations as compared to additional OT data, transmitting the one or more identifiers and the one or more data attributes to a second computing device in response to determining that the one or more data attributions have the one or more variations, receiving one or more containers including one or more updated digital representations of the one or more industrial devices from the second computing device, executing the one or more containers to output one or more additional data attributes, and sending one or more commands to the one or more industrial devices to modify one or more processes based the one or more additional data attributes.

(7) In yet another embodiment, computer-readable medium storing instructions that, when executed by one or more processors, cause the one or more processors to perform operations including receiving operational technology (OT) data from one or more industrial devices of an industrial system, determining one or more identities of the one or more industrial devices based on the OT data, determining that the OT data includes one or more data attributes having one or more variations as compared to additional OT data, transmitting the one or more identifiers and the one

or more data attributes to a computing device in response to determining that the one or more data attributions have the one or more variations, receiving one or more containers including one or more updated digital representations of the one or more industrial devices from the computing device, executing the one or more containers to output one or more additional data attributes, and sending one or more commands to the one or more industrial devices to modify one or more processes based the one or more additional data attributes.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

- (1) These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:
- (2) FIG. 1 is a perspective view of an example industrial automation system, in accordance with an embodiment presented herein;
- (3) FIG. 2 is a block diagram of an industrial automation device management system that may be used to remotely access the industrial automation system of FIG. 1, in accordance with an embodiment presented herein;
- (4) FIG. 3 a block diagram of an example edge computing device with containers that may be used in the industrial automation device management system of FIG. 2, in accordance with an embodiment presented herein;
- (5) FIG. 4 is a flow diagram of a process for operating a digital representation of the industrial automation system of FIG. 1 using the edge computing device of FIG. 3, in accordance with an embodiment presented herein;
- (6) FIG. 5 is a flow diagram of a process for dynamically updating the digital representation of the industrial automation system of FIG. 1 based on a container executed within an edge device, in accordance with an embodiment presented herein; and
- (7) FIG. 6 is a flow diagram of a process for dynamically generating a container based on operational technology (OT) data via a cloud computing system, in accordance with an embodiment presented herein.

DETAILED DESCRIPTION

- (8) One or more specific embodiments will be described below. In an effort to provide a concise description of these embodiments, not all features of an actual implementation are described in the specification. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.
- (9) When introducing elements of various embodiments of the present invention, the articles “a,” “an,” “the,” and “said” are intended to mean that there are one or more of the elements. The terms “comprising,” “including,” and “having” are intended to be inclusive and mean that there may be additional elements other than the listed elements.
- (10) As digital twin technology becomes more and more prevalent, there are many potential uses for digital twins implemented on industrial automation devices. For example, three dimensional (3D) modeling may be used to create a device level digital twin (e.g., device twin) representing a physical industrial automation device. The device level digital twin may be used to monitor operations of the industrial automation device and simulate operations to identify potential

improvement opportunities or issues. However, in certain cases, industrial automation devices may not have computing resources (e.g., memory) to implement device twins and manage or replicate data in the device twins.

(11) In such cases, the device twins corresponding to the industrial automation devices may be executed in a cloud computing environment (e.g., using a cloud computing device or system) and the device twins may be integrated into a system level digital twin representing the industrial automation system. Such cloud-based digital twin implementation may utilize cloud computing resources to support operations of the digital twin. However, certain issues may inhibit the performance of the digital twin. For example, each industrial automation device may send data associated with multiple attributes (e.g., temperature, pressure, speed, orientation, and the like) to the digital twin and the industrial automation system may include a large number (e.g., hundreds, thousands, or more) of industrial automation devices. As a result, a large amount of data may be communicated to the cloud computing device or system. Furthermore, there may be only a small portion of the data including attributes having changes, but the entire digital twin will be updated based on the received data. Such update may cause increased latencies and amount of data communicated to the cloud computing device or system.

(12) With improvements of edge computing, an edge computing device may be used to implement the digital twin representing the industrial automation system described above. Implementing the digital twin on the edge that is closer to the industrial automation devices may reduce response time of the digital twin and communication time. The edge computing device may implement the digital twin by executing a container obtained from a cloud-based computing system containing a container database. The container database may include a collection of containers corresponding to a variety of industrial automation devices (e.g., including devices currently employed and available for future employment in the industrial automation system). Using the container allows the digital twin to be implemented regardless a host environment (e.g., operating system, library dependency) in which the digital twin is operating. The edge computing device may receive data from the industrial automation devices. Instead of sending the data directly to the cloud-based computing system, the edge device may identify those attributes having changes and only communicate the attribute changes to the cloud-based computing system. In this way, the edge computing device may reduce the amount of data communicated within (or out of) the industrial automation system and increase network bandwidth availability.

(13) Embodiments of the present disclosure are generally directed towards an industrial automation system that may utilize an edge computing device to implement a digital representation (e.g., digital twin) of the industrial automation system by executing a software container generated by a cloud-based container orchestration system. The edge computing device may use the digital representation to simulate processes of the industrial automation system. Based on the simulation, the edge device may cause one or more industrial automation devices to modify the processes to facilitate monitoring, operation, optimization, maintenance, and diagnosis of the industrial automation system. Moreover, the edge computing device may dynamically update the digital representation using updated data from the industrial automation devices. For example, the updated data may include an identifier associated with an industrial automation device and attribute values that may indicate potential optimizations or issues associated with the industrial automation devices. The edge device may determine attribute variations based on the updated data and only transmit the attribute variations and the identifier to the container orchestration system. The container orchestration system may query a database based on the identifier to determine a matched digital representation template. The container orchestration system may generate a new container based on the matched digital representation template and customize the new container based on the attribute variations. The new container may be pushed (e.g., from a container registry) to the edge device, which may execute the new container to update the digital representation.

(14) By way of introduction, FIG. 1 is a perspective view of an example industrial automation

system **10** controlled by one or more industrial control systems **12**. The industrial automation system **10** includes stations **14** having machine components and/or machines to conduct functions within an automated process, such as silicon wafer manufacturing, as is depicted. The automated process may begin at a station **14A** used for loading objects, such as substrates, into the industrial automation system **10** via a conveyor section **16**. The conveyor section **16** may transport the objects to a station **14B** to perform a first action, such as a printing solder paste to the substrate via stenciling. As objects exit from the station **14B**, the conveyor section **16** may transport the objects to a station **14C** for solder paste inspection (SPI) to inspect printer results, to a station **14D**, **14E**, and **14F** for surface mount technology (SMT) component placement, to a station **14G** for convection reflow oven to melt the solder to make electrical couplings, and finally to a station **14H** for automated optical inspection (AOI) to inspect the object manufactured (e.g., the manufactured printed circuit board). After the objects proceed through the various stations, the objects may be removed from the station **14H**, for example, for storage in a warehouse or for shipment. Clearly, for other applications, the particular system, machine components, machines, stations, and/or conveyors may be different or specially adapted to the application.

(15) For example, the industrial automation system **10** may include machinery to perform various operations in a compressor station, an oil refinery, a batch operation for making food items, chemical processing operations, brewery operations, mining operations, a mechanized assembly line, and so forth. Accordingly, the industrial automation system **10** may include a variety of operational components, such as electric motors, valves, actuators, temperature elements, pressure sensors, or a myriad of machinery or devices used for manufacturing, processing, material handling, and other applications. The industrial automation system **10** may also include electrical equipment, hydraulic equipment, compressed air equipment, steam equipment, mechanical tools, protective equipment, refrigeration equipment, power lines, hydraulic lines, steam lines, and the like. Some example types of equipment may include mixers, machine conveyors, tanks, skids, specialized original equipment manufacturer machines, and the like. In addition to the equipment described above, the industrial automation system **10** may also include motors, protection devices, switchgear, compressors, and the like. Each of these described operational components may correspond to and/or generate a variety of operational technology (OT) data regarding operation, status, sensor data, operational modes, alarm conditions, or the like, that may be desirable to output for analysis with IT data from an IT network, for storage in an IT network, for analysis with expected operation set points (e.g., thresholds), or the like.

(16) In certain embodiments, one or more properties of the industrial automation system **10** equipment, such as the stations **14**, may be monitored and controlled by the industrial control systems **12** for regulating control variables. For example, sensing devices (e.g., sensors **18**) may monitor various properties of the industrial automation system **10** and may be used by the industrial control systems **12** at least in part in adjusting operations of the industrial automation system **10** (e.g., as part of a control loop). In some cases, the industrial automation system **10** may be associated with devices used by other equipment. For instance, scanners, gauges, valves, flow meters, and the like may be disposed on or within the industrial automation system **10**. Here, the industrial control systems **12** may receive data from the associated devices and use the data to perform their respective operations more efficiently. For example, a controller of the industrial automation system **10** associated with a motor drive may receive data regarding a temperature of a connected motor and may adjust operations of the motor drive based on the data.

(17) The industrial control systems **12** may be communicatively coupled to a display/operator interface **20** (e.g., a human-machine interface (HMI)) and to devices of the industrial automation system **10**. It should be understood that any suitable number of industrial control systems **12** may be used in a particular industrial automation system **10** embodiment. The industrial control systems **12** may facilitate representing components of the industrial automation system **10** through programming objects that may be instantiated and executed to provide digital representations (e.g.,

digital twins) having simulated functionality similar or identical to the actual components, as well as visualization of the components, or both, on the display/operator interface **20**. The programming objects may include code and/or instructions stored in the industrial control systems **12** and executed by processing circuitry of the industrial control systems **12**. The processing circuitry may communicate with memory circuitry to permit the storage of the component visualizations.

(18) As illustrated, a display/operator interface **20** depicts representations **22** (e.g. digital representation with visualizations) of the components of the industrial automation system **10**. The industrial control systems **12** may use data transmitted by sensors **18** to update visualizations of the components via changing one or more statuses, states, and/or indications of current operations of the components. These sensors **18** may be any suitable device adapted to provide information regarding process conditions. Indeed, the sensors **18** may be used in a process loop (e.g., control loop) that may be monitored and controlled by the industrial control systems **12**. As such, a process loop may be activated based on process inputs (e.g., an input from the sensor **18**) or direct input from a person via the display/operator interface **20**. The person operating and/or monitoring the industrial automation system **10** may reference the display/operator interface **20** to determine various statuses, states, and/or current operations of the industrial automation system **10** and/or for a particular component. Furthermore, the person operating and/or monitoring the industrial automation system **10** may adjust to various components to start, stop, power-down, power-on, or otherwise adjust an operation of one or more components of the industrial automation system **10** through interactions with control panels or various input devices.

(19) The industrial automation system **10** may be considered a data-rich environment with several processes and operations that each respectively generate a variety of data. For example, the industrial automation system **10** may be associated with material data (e.g., data corresponding to substrate or raw material properties or characteristics), parametric data (e.g., data corresponding to machine and/or station performance, such as during operation of the industrial automation system **10**), test results data (e.g., data corresponding to various quality control tests performed on a final or intermediate product of the industrial automation system **10**), or the like, that may be organized and sorted as OT data. In addition, sensors **18** may gather OT data indicative of one or more operations of the industrial automation system **10** or the industrial control systems **12**. In this way, the OT data may be analog data or digital data indicative of measurements, statuses, alarms, or the like associated with operation of the industrial automation system **10** or the industrial control systems **12**.

(20) The industrial control systems **12** described above may operate in an OT space in which OT data is used to monitor and control OT assets, such as the equipment illustrated in the stations **14** of the industrial automation system **10** or other industrial equipment. The OT space, environment, or network generally includes direct monitoring and control operations that are coordinated by the industrial control systems **12** and a corresponding OT asset. For example, a programmable logic controller (PLC) may operate in the OT network to control operations of an OT asset (e.g., drive, motor). The industrial control systems **12** may be specifically programmed or configured to communicate directly with the respective OT assets.

(21) A container orchestration system **24**, on the other hand, may operate in an information technology (IT) environment (e.g., a cloud computing environment). That is, the container orchestration system **24** may include multiple computing devices (e.g., cloud computing devices) that coordinates an automatic process of managing or scheduling work of individual containers for applications within the multiple computing devices. In other words, the container orchestration system **24** may be used to automate various tasks at scale across the multiple computing devices. By way of example, the container orchestration system **24** may automate tasks such as configuring and scheduling of containers, provisioning and deployments of containers, determining availability of containers, configuring applications in terms of the containers that they run in, scaling of containers to equally balance application workloads across an infrastructure, allocating resources

between containers, performing load balancing, traffic routing and service discovery of containers, performing health monitoring of containers, securing the interactions between containers, and the like. In any case, the container orchestration system **24** may use configuration files to determine a network protocol to facilitate communication between containers, a storage location to save logs, and the like. The container orchestration system **24** may also schedule deployment of containers into hosts (e.g., industrial automation devices) that may execute the containers to implement digital representations (e.g., digital twins) of the industrial automation devices. The digital twins may simulate operations of the industrial automation devices and facilitate monitoring, operation, optimization, maintenance, and diagnosis of the industrial automation devices. Furthermore, the container orchestration system **24** may manage the lifecycle of the containers based on predetermined specifications.

(22) It should be noted that containers refer to technology for packaging an application along with its runtime dependencies. That is, containers include applications that are decoupled from an underlying host infrastructure (e.g., operating system). By including the run time dependencies with the container, the container may perform in the same manner regardless of the host in which it is operating. The containers may be easy to deploy in different hosts and may not need to be rewritten for different implementations. Furthermore, utilizing containers to perform industrial automation processes may reduce the amount of data communicated within (or out of) the industrial automation system **10**, thereby potentially decreasing network latency, freeing up bandwidth, or both.

(23) In some embodiments, containers may be stored in a container registry **26** (e.g., a cloud-based container registry) as container images **28**. The container registry **26** may be any suitable data storage or database that may be accessible to the container orchestration system **24**. The container orchestration system **24** may use the container registry **26** as a container repository to store, distribute, and track the containers. The container image **28** may correspond to an executable software package that includes the tools and data employed to execute a respective application. That is, the container image **28** may include related code for operating the application, application libraries, system libraries, runtime tools, default values for various settings, and the like. For example, the related code may include digital twin code corresponding to an industrial automation device (e.g., motor, protection device, switchgear, or compressor) of the industrial automation system **10**. The industrial automation device may receive (e.g., download) a container including the digital twin code. When executing the container, the industrial device may implement the digital twin to simulate processes performed by the industrial automation device. Additionally, the container image **28** may be updated based on certain operational changes (e.g., status, parameters, attributes) associated with the industrial automation device. The industrial automation device may receive an updated container (e.g., including updated code associated with new or improved functions) and update the digital twin by executing the updated container. As such, the digital twin may represent the industrial automation device more accurately throughout the lifecycle of the industrial automation device to improve operations of the industrial automation device.

(24) In some cases, certain industrial automation devices (e.g., non-compute-enabled devices) may not have memory or other computing resources to implement digital twins at a device level (referred to as device twins) and properly manage and replicate data in the device twins. In some embodiments, multiple device twins corresponding to the industrial automation devices of the industrial automation system **10** may be integrated or combined into a digital twin at a system level representing the industrial automation system **10**. The digital twin may be implemented in an edge computing device that is communicatively coupled to the industrial automation devices. The edge computing device may execute a digital twin container that includes code associated with the digital twin. In some embodiments, the digital twin container may include multiple device twin containers that, when being executed, may simulate the operations of the multiple device twins corresponding to the industrial automation devices in the edge computing device. Such container

approach may allow external, non-operation impacting updates to device twin containers without direct updates to the industrial automation devices. Moreover, utilizing containerized edge computing device positioned closer to the industrial automation devices may reduce the timing and amount of data communicated to a cloud computing system (e.g., system managing maintenance for the industrial automation system **10**).

(25) With the foregoing in mind, FIG. **2** is a block diagram of an industrial automation device management system **50** that may be used to remotely access the industrial automation system **10** of FIG. **1**. The industrial automation device management system **50** includes industrial automation devices **52** of the industrial automation system **10**, such as motor, sensors, protection device, switchgear, compressor, controllers, and so on. The industrial automation devices **52** may communicatively couple to an edge computing device **54** (e.g., a drive) located at an edge **60** of a cloud **62** (e.g., an industrial network). The edge computing device **54** may include a container **56** (e.g. a software container). One or more digital twins **58** may be implemented within the container **56**. The digital twins **58** may be virtual instances (e.g., digital representations) of the industrial automation system **10**. The digital twins **58** may provide flexible ways in which the edge computing device **54** may be implemented to monitor and control the industrial automation system **10**. In some embodiment, each of the digital twins **58** may represent one aspect (e.g., thermal, kinetic, pressure, acoustic, or power aspect) of the industrial automation system **10**,

(26) The cloud **62** may be implemented by a variety of computing devices (e.g., cloud computing devices **64**), storage devices, and connecting devices (e.g., routers, switches, gateways). The industrial automation device management system **50** may use the cloud **62** to facilitate communication between the industrial automation devices **52**, the edge computing device **54**, the container orchestration system **24**, and other relevant systems or components. The cloud **62** may include one or more wired or wireless networks, including, but not limited to, local area networks (LANs), wide area networks (WANs), wireless WANs (WWANs), wireless LANs (WLANs), mobile communications networks (e.g., 3G, 4G, 5G, Edge, etc.), and so forth. For example, an asset management system may use a local area network (LAN) that includes a variety of computing and network devices including, but not limited to, switches, servers (e.g., processors), storage (e.g., memory), and routers. The above-mentioned systems/devices may communicate with each other using a variety of communication protocols, such as Open Database Connectivity (ODBC), TCP/IP Protocol, Distributed Relational Database Architecture (DRDA) protocol, Database Change Protocol (DCP), HTTP protocol, Bluetooth, Wi-Fi, Near Field Communication (NFC), other suitable current or future protocols, or combinations thereof.

(27) As illustrated, the cloud **62** includes the container orchestration system **24**, the container registry **26**, the cloud computing devices **64**, and a container subscription component **66**. The container orchestration system **24** may include a digital twin template database **68** that stores various digital twin templates (e.g., Digital Twin Definition Language (DTDL) templates) associated with the industrial automation system **10** and the components (e.g., the industrial automation devices **52**) of the industrial automation system **10**. The DTDL may be used to create a container, when executed by a computing device (e.g., edge computing device **54**), implement a digital representation (e.g., digital twin **58**) of real-world things, places, and industrial or business processes, and the like. As such, the DTDL may include data structures, functions, expected inputs, expected outputs, and other elements for generating the digital representation. The digital representation may output insights that may lead to better products, optimize operations and costs, create breakthrough user experiences, and so on. In some embodiments, digital twin templates may correspond to certain aspects of the industrial automation system **10** at the system level, and other digital twin templates may correspond to the industrial automation devices **52** at the device level. The container orchestration system **24** may use the container subscription component **66** to provide a container subscription/publication service for the edge computing device **54**. The container subscription/publication service may include periodical monitoring the container registry **26** to

identify a new or updated container and sending a notification to prompt the edge computing device **54** to receive the new or updated container. Each of the container orchestration system **24**, the container registry **26**, the cloud computing devices **64**, and the container subscription component **66** may include one of more processors of the computing devices that may execute computer-readable instructions stored on memory/storage devices of the computing devices.

(28) In some embodiments, the container orchestration system **24** may collect information associated with the industrial automation system **10** during an initialization stage (e.g., a testing stage of the industrial automation system **10**). For instance, the container orchestration system **24** may collect the operational technology (OT) data (e.g., regarding operation, status, configuration, specification, operational modes) from the industrial automation devices **52** via the edge computing device **54**. The OT data may include OT datasets each generated from a specific device of the industrial automation devices **52**. Each OT dataset may include a unique dataset identifier associated with a corresponding device of the industrial automation devices **52**.

(29) Based on received OT datasets (e.g., using dataset identifiers), the container orchestration system **24** may query the digital twin template database **68** to retrieve digital twin templates corresponding to the dataset identifiers. The digital twin templates may include information related to the types of devices and equipment that are specified by the OT datasets. That is, the OT datasets may indicate a number of industrial automation devices **52** that may be present, the types of the industrial automation devices **52**, the operational parameter data (e.g., control settings) for each of the industrial automation devices **52**, the function of each of and the entire fleet of the industrial automation devices **52**, and the like. The container orchestration system **24** may then generate individual device twin containers based on the digital twin templates and other relevant information (e.g., configuration, specification, or mode) in the OT dataset. For example, the container orchestration system **24** may generate initial code for a device twin container associated with a specific device based on a digital twin template corresponding to a type of device that include the specific device. Next, the container orchestration system **24** may customize the initial code using the relevant information that may include specific (e.g., unique) details regarding the specific device. Each device twin container may include a unique container identifier correlated with the unique dataset identifier associated with the corresponding device. The container orchestration system **24** may utilize mappings (e.g., in a mapping file) to identify the correlations between dataset identifiers and container identifiers associated with different industrial automation devices **52**.

(30) In some embodiments, the container orchestration system **24** may integrate the individual device twin containers into a system-level digital twin container representing the industrial automation system **10** at the system level. The container orchestration system **24** may utilize one or more system files (e.g., configuration files) that include information related to a scope (e.g., aspect) represented by the system-level digital twin container, information detailing relations between the scope and other scopes (e.g., aspects) of the industrial automation system **10**, information detailing relations between the system-level digital twin container and the device twin containers, and information detailing relations between the individual device twin containers, and the like. The container orchestration system **24** may store the device twin containers, the system-level digital twin container, and the configuration files into the container registry **26**.

(31) In some embodiments, the container orchestration system **24** may cause the container registry **26** to push a copy of the digital twin container (e.g., container **56**) to the edge computing device **54**. After receiving the container **56**, the edge computing device may execute the container **56** to implement a digital twin representing the industrial automation system **10** (e.g., with respect to thermal aspect of the industrial automation system **10**). The processes described above may continue as the operations of the industrial automation system **10** continue, thereby implementing more digital twins (e.g., representing other aspects, such as) that become part of the digital twins **58**.

(32) Although FIG. 2 is depicted with respect to the industrial automation device management system **50**, it should be understood that the components described with respect to FIG. 2 are exemplary figures and the industrial automation device management system **50** may include additional or fewer components as detailed above. For instance, each of the container orchestration system **24**, the container registry **26**, the edge computing device **54**, the cloud computing devices **64**, and the container subscription component **66** may include one or more databases.

(33) FIG. 3 is a block diagram of an example edge computing device (e.g., edge computing device **54**) with containers that may be used in the industrial automation device management system **50** of FIG. 2. The edge computing device **54** may include a communication component **72**, a processor **74**, a memory **76**, a storage **78**, input/output (I/O) ports **80**, a display **82**, and the like. The communication component **72** may be a wireless or wired communication component that facilitates communication between the container orchestration system **24** and the edge computing device **54**, or any other suitable systems, components, or devices. The processor **84** may be any type of computer processor or microprocessor capable of executing computer-executable code. The processor **84** may also include multiple processors each including processing circuitry that may perform the operations described below.

(34) The memory **86** and the storage **88** may be any suitable article of manufacture that may serve as media to store processor-executable code, containers (e.g., container **56**) data (e.g. OT data), or the like. These articles of manufacture may represent computer-readable media (i.e., any suitable form of memory or storage) that may store the processor-executable code used by the processor **84** to perform the presently disclosed techniques. The memory **86** and the storage **88** may represent non-transitory computer-readable media (e.g., any suitable form of memory or storage) that may store the processor-executable code used by the processor **84** to perform various techniques described herein. It should be noted that non-transitory merely indicates that the media is tangible and not a signal.

(35) The I/O ports **80** may couple to one or more sensors **18**, one or more input devices, one or more displays, or the like to facilitate human or machine interaction with the industrial automation system **10**. For example, based on a notification provided to a user via the display **82**, the user may use an input device to instruct certain adjustments of one or more of the industrial automation devices **52** of the industrial automation system **10**.

(36) The display **82** may operate to depict visualizations associated with software (e.g., containers) or executable code being processed by the processor **84**. In one embodiment, the display **82** may be a touch display capable of receiving inputs from a user (e.g., operator) of the industrial automation system **10**. The display **82** may be any suitable type of display, such as a liquid crystal display (LCD), plasma display, or an organic light emitting diode (OLED) display, for example. Additionally, in one embodiment, the display **82** may be provided in conjunction with a touch-sensitive mechanism (e.g., a touch screen) that may function as part of a control interface for the industrial automation system **10**.

(37) Although FIG. 3 is depicted with respect to the edge computing device **54**, it should be noted that other computing systems (e.g., the container orchestration system **24**) or devices may also include the same or similar components to perform, or facilitate performing, the various techniques described herein. Moreover, it should be understood that the components described with respect to FIG. 3 are exemplary figures and the edge computing device **54** and other suitable computing systems or devices may include additional or fewer components as detailed above.

(38) With the foregoing in mind, FIG. 4 is a flow diagram of a process **100** for operating a digital representation of the industrial automation system **10** of FIG. 1 using the edge computing device **54** of FIG. 3. The process **120** may be performed by the edge computing device **54** using processing circuitry (e.g. the processor **74** included in the edge computing device **54**) executing computer-readable instructions stored on memory or storage (e.g., the memory **76** or storage **78**) of the edge computing device **54**.

- (39) Although the process **100** described in FIG. **4** is described in a particular order, it should be noted that the process **100** may be performed in any suitable order and is not limited to the order presented herein. It should also be noted that although each processing block is described below in the process **100** as being performed by the edge computing device **54**, other suitable devices may perform the methods described herein.
- (40) Referring now to FIG. **3**, at block **102**, the edge computing device **54** may implement a digital representation (e.g., digital twin **58**) of the industrial automation system **10**. For example, the edge computing device **54** may receive (e.g., download) a container (e.g., container **56**) from a cloud-based container registry (e.g., container registry **26**). In some embodiments, the computing device **54** may receive the container using a cloud-based container subscription service (e.g. provided by the container subscription component **66**). For instance, the container subscription component **66** may continuously or periodically (e.g., every day, every 3 days, every week, or every month) monitor the container registry **26** to identify whether a new container or an updated version of an existing container is available. The container subscription component **66** may send a notification indicative of the new or updated container to the edge computing device **54** to prompt the edge computing device **54** to receive the new or updated container.
- (41) The received container may include a set of device twin code corresponding to individual industrial automation devices (e.g., industrial automation devices **52**) at a device level to represent the operations of the respective industrial automation devices. When executing the set of device twin code, the edge computing device **54** may implement a set of device twins, each device twin representing a corresponding industrial automation device of the industrial automation system **10**. The edge computing device **54** may utilize each individual device twin to simulate various operations (e.g., parameter setting, operation mode, fault identification, maintenance, troubleshooting) of each corresponding industrial automation device at the device level.
- (42) The received container may also include a digital twin code corresponding to the industrial automation system **10** at a system level. When executing the digital twin code, the edge computing device **54** may integrate the set of device twins into the digital twin **58** representing the industrial automation system **10**. The digital twin **58** may include hierarchical levels of the industrial automation system **10**, such as information related to an aspect (e.g., thermal aspect) represented by the digital twin **58**, relations between the aspect and other aspects (e.g., kinetic, pressure, acoustic, and power aspects) of the industrial automation system **10**, relations between the digital twin **58** and the device twins, and relationships between the device twins, and the like.
- (43) The digital twin **58** may also include data structures (e.g., predetermined data structures) regulating procedures and formats used to process OT data (e.g., data received from the industrial automation devices **52**). For example, the digital twin **58** may have functions to manage data reception and transmission (e.g., filtering the OT data and only transmitting certain portions of the OT data to the container orchestration system **24**), format or convert the received OT data into a standard data format based on the predetermined data structures that may be shared by each device twin, setup input/output ports for each device twin based on the hierarchical levels of the industrial automation system **10** to facilitate data communication between the device twins within the digital twin **58**, and so on.
- (44) Furthermore, the digital twin **58** may include a variety of computational algorithms to facilitate data analysis and processing using the OT data received from the industrial automation device **52**. For example, the computational algorithms may include machine learning algorithms and/or artificial intelligence algorithms. The digital twin **58** may utilize the OT data and apply the machine learning algorithms to identify correlations, trends, patterns, potential issues, and other properties associated with individual industrial automation devices **52** and/or the industrial automation system **10**. In some embodiments, the digital twin **58** may include one or more models (e.g., mathematic models) that may be used to simulate various operations (e.g., parameter setting, operation mode, fault identification, maintenance, troubleshooting, and so on) of the industrial

automation system **10**. For example, the digital twin **58** may perform a machine learning process and generate a mathematical model based on a sample of the clean data, known as “training data,” in order to make predictions or decisions without being explicitly programmed to perform the task.

(45) After the digital twin **58** is implemented (e.g., downloaded and executed) in the container (e.g., container **56**), at block **104**, the edge computing device **54** may receive one or more datasets associated with one or more industrial automation devices (e.g., industrial automation device **52**) of the industrial automation system (e.g., industrial automation system **10**). For example, each of the one or more datasets may be generated from a specific industrial automation device **52** and may include a unique dataset identifier associated with that specific industrial automation device **52**. The one or more datasets may include the OT data, such as operational parameters, operational status, controller reading, sensor data, operational modes, alarm conditions, and so on. In some embodiments, the edge computing device **54** may format or convert the one or more datasets into the standard data format that may be shared by each device twin and setup input/output ports for each device twin to facilitate a distribution of the one or more datasets between the device twins.

(46) At block **106**, the industrial automation device **52** may simulate, using the digital representation (e.g., digital twin **58**) of the industrial automation system **10**, one or more processes performed by the one or more industrial automation devices **52**. For example, the edge computing device **54** may use the digital twin **58** to run simulations related to the one or more processes, such as operation performance analysis, diagnostics for existing issues, prediction for potential problems, and the like. The digital twin **58** may run the simulations based on the one or more datasets received from the one or more industrial automation devices **52** and other relevant data (e.g., historical data) associated with the one or more industrial automation devices **52**. In some embodiments, the digital twin **58** may identify relevant devices of the industrial automation devices **52** (e.g., based on the one or more datasets that may include certain identifiers associated with relevant devices), and cause relevant device twins corresponding to the relevant devices to run simulations at the device level. Furthermore, the digital twin **58** may receive device twin simulation result and run simulations at the system level based on the device twin simulation result. The edge computing device **54** may also use the digital twin **58** to analyze the simulation result (e.g., using the machine learning algorithms and/or artificial intelligence algorithms). For instance, the one or more processes may include process for optimize conveyor speeds of machine conveyors of a mechanized assembly line. The digital twin **58** may receive speed simulations (e.g., increasing speeds by 10% from current speeds) result from device twins corresponding to the machine conveyors and use the result as input to run a simulation to determine whether the increased speeds of the machine conveyors may overload the mechanized assembly line.

(47) Executing digital twins (e.g., digital twin **58**) on edge devices (e.g., edge computing device **54**) may provide various advantages for operating industrial systems (e.g., industrial automation system **10**) using vast amount of OT data, advanced edge computing resources (e.g., fast data processing, prompt device control), and abundant cloud computing and storage resources. In some cases where one or more industrial systems may be integrated to form a sophisticated system (e.g., an automated manufacturing system), the system may include a great number of industrial automation devices and sensors that may produce vast amount of OT data. With certain limitations (e.g., limited connectivity), sending such large amount of data to digital twins executed on cloud computing systems/device may cause data communication latency and delayed response time. In contrast, using digital twins on the edge devices may enable data processing locally (e.g., close to the data sources) for more efficient processing and analysis to trigger real-time responses, thereby increasing network bandwidth to cloud computing devices and other network devices.

(48) The edge-based digital twins may also deliver fast analytics (e.g., identifying potential issues based on simulations), quick solution (e.g., to identified issues), and prompt commands to related devices (e.g., to adjust operations to solve the identified issues). Moreover, the edge-based digital twins may regulate data communications such that a limited amount of OT data is transmitted to

the cloud computing systems/devices. In this way, the cloud computing systems/devices may focus on larger scaled data collection (e.g., collecting data from other relevant industrial systems), data mining, advanced simulations based on transmitted OT data from the automated manufacturing system and other relevant data (e.g., historical data and/or synthetic data from other industrial systems related (e.g., similar, upstream, downstream) to the automated manufacturing system), and the like. Furthermore, using containerized digital twins implemented on edge devices may allow fast and convenient deployment (e.g., with reduced coding, less dependency on running environment) of digital twins in new places where there is limited computing resources (e.g., limited memory and/or data processing capabilities associated with certain industrial devices) and/or network connectivity, or where there are industrial devices having different running environment (e.g., operating systems or libraries from different vendors).

(49) Additionally, using containerized digital twin implemented on edge devices may improve network security. For instance, certain sensitive OT data associated with the industrial automation system **10** may be stored locally on the edge computing device **54**. In some cases, the OT data may be encrypted (e.g., adding meta-data) by the edge computing device **54** using the digital twin **58** such that only the encrypted OT data is transmitted to the cloud computing systems/devices.

(50) At block **108**, the edge computing device **54** may cause the one or more industrial automation devices **52** to modify the one or more processes based on simulation data. In the example process of optimizing conveyor speeds as described above, the digital twin **58** may determine that increasing speeds by 10% from current speeds of the machine conveyors will not overload the mechanized assembly line based on speed simulation result. As such, the edge computing device **54** may cause (e.g., by sending commands to conveyor controllers) motors of the machine conveyors to increase speeds (e.g., by 10% from current speeds).

(51) After a digital representation (e.g., digital twin **58**) of an industrial system (e.g., industrial automation system **10**) is implemented on a computing device (e.g., the edge computing device **54**), the digital representation may be updated when the industrial system has certain changes and/or updates. For example, the computing device may receive data indicating new aspect(s) of the industrial system, new device(s) or component(s) of the industrial system, new or updated firmware(s) of the industrial system, and so on. In response to the changes and/or updates, the computing device may receive new container(s) corresponding to such changes and implement an updated digital representation by executing the new container(s). The updated digital representation may represent the changed or updated industrial system.

(52) With the proceeding in mind, FIG. **5** is a flow diagram of a process **150** for dynamically updating the digital representation (e.g., digital twin **58**) of the industrial automation system **10** of FIG. **1** based on a container (e.g., container **56**) executed within an edge device (e.g., edge computing device **54**). The process **150** may be performed by the edge computing device **54** using processing circuitry (e.g. the processor **74** included in the edge computing device **54**) executing computer-readable instructions stored on memory or storage (e.g., the memory **76** or storage **78**) of the edge computing device **54**.

(53) Although the process **150** described in FIG. **5** is described in a particular order, it should be noted that the process **150** may be performed in any suitable order and is not limited to the order presented herein. It should also be noted that although each processing block is described below in the process **150** as being performed by the edge computing device **54**, other suitable devices may perform the methods described herein.

(54) Referring now to FIG. **5**, at block **152**, the edge computing device **54** may receive OT data from an industrial automation device (e.g., industrial automation device **52**) of an industrial automation system (e.g., industrial automation system **10**). The OT data may include operational parameters, operational status, operational modes, and so on. The OT data may be generated directly from the industrial automation device **52**, a control device (e.g., device controller) communicatively coupled to the industrial automation device **52**, one or more sensors (e.g., sensing

temperature, pressure, speed, distance, vibration, and the like) communicatively coupled to the industrial automation device **52**, or any combination thereof. Based on received OT data, at block **154**, the edge computing device **54** may identify an information identifier associated with the industrial automation device. For instance, the OT data generating device (e.g., the industrial automation device **52**, device controller, or sensors) may add the information identifier into the OT data. The information identifier may include information related to a device identifier (e.g., model number, serial number, Media Access Control (MAC) address, or the like) of the industrial automation device **52**, and other relevant information (e.g., timing/location information indicating when/where the OT data is generated). The edge computing device **54** may perform a namespace reading and identify the information identifier embedded in the OT data. A namespace may be referred to as a set of elements (e.g., signs) used to identify objects of various types. Using the namespace allows all of a given set of objects have unique identifiers so that they can be easily identified. Namespaces may be structured based on hierarchy information (e.g., hierarchical levels of the industrial automation system **10** stored in the digital twin **58**) to allow reuse of identifiers in different contexts. The edge computing device **54** may determine one or more identifiers by retrieving one or more namespace elements associated with one or more industrial devices via the OT data. The one or more namespace elements may correspond to one or more model numbers, one or more serial numbers, one or more Media Access Control (MAC) addresses, or any combination thereof associated with the one or more industrial devices.

(55) At block **156**, the edge computing device **54** may determine attributes having variations based on the received OT data and expected OT data determined based on a container executing a digital twin of the industrial automation device. For example, the OT data may include data related to a certain amount (e.g., **200**) of attributes (e.g., temperature, pressure, speed, distance, vibration, and the like) associated with the industrial automation device **52**. However, the edge computing device **54** may determine (e.g., using the digital twin **58**) that only a portion of the attributes (e.g., **50** attributes) have variations (e.g., changed values or modes), for example, when comparing to expected data outputs provided by the digital twin **58** that is related to the industrial automation device **52**. Furthermore, the edge computing device **54** may determine each variation (e.g., temperature change) associated with the portion of the attributes.

(56) At block **158**, the edge computing device **54** may transmit the information identifier and the attribute variations to a container orchestration system (e.g., container orchestration system **24**). For example, the edge computing device **54** may create a dataset to include the information identifier and the attribute variations (e.g., temperature change ΔT , instead of the temperature values related to ΔT , such as T.sub.Present and T.sub.History) based on the predetermined hierarchical levels and data structures of the industrial automation system **10**. In some embodiments, the edge computing device **54** may convert or transform the dataset into metadata in a predetermined data format that may include additional data (e.g., contextual data (e.g., data history) related to the industrial automation device **52**). In this way, the timing and amount of data communicated to a cloud computing system (e.g., container orchestration system **24**) may be reduced.

(57) At block **160**, the edge computing device **54** may receive a container from the container orchestration system **24**. For example, the container may include new code corresponding to a new device twin representing the industrial automation device **52** that is identified (e.g., by the container orchestration system **24**) as a new device, or updated code corresponding to an existing device twin representing the industrial automation device **52** that has been identified in the past. The new code or the updated code may include new or updated functions that can be added to the digital twin **58** to enable or improve operational control, parameter setting, fault identification, maintenance, and troubleshooting associated with the industrial automation device **52**.

(58) After receiving the container, at block **162**, the edge computing device **54** may execute the container to update the digital twin **58** of the industrial automation system **10**. For example, the update may include creating a new device twin, updating one or more existing device twins (e.g.,

representing the industrial automation device **52** and other devices related to the industrial automation device **52**), updating the digital twin **58** at the system level, and so forth. The updated digital twin **58** with new/updated functions may provide a more accurate representation of the industrial automation system **10** (e.g., in response to determined attribute variations that may indicate potential optimizations or issues). For example, the updated digital twin **58** may output one or more additional data attributes indicative of new features of the industrial automation system **10**. (59) Using the updated digital twin **58**, the edge computing device **54** may run new simulations based on the OT data and other relevant data (e.g., historical data, synthetic data). At block **164**, the edge computing device **54** may send commands to one or more industrial automation devices to adjust one or more processes based on new simulations of the updated digital twin **58**. Adjusting the one or more processes may facilitate operational control, parameter setting, fault identification, maintenance, and troubleshooting associated with the industrial automation device **52**.

(60) At block **166**, the edge computing device **54** may update a device level digital twin list. For example, the update may include adding a new device twin (e.g., with a device twin identifier) into the device level digital twin list created previously and stored in the digital twin **58**. In some embodiments, the device level digital twin list may be associated with a namespace that may be updated accordingly. The namespace may be used to identify the information identifier associated with the industrial automation device **52**, as described at block **154**.

(61) Additionally, at block **168**, the edge computing device **54** may regulate data usage on an edge (e.g., edge **60**). In one embodiment, the edge computing device **54** may receive an indication (e.g., from an operator) that certain aspects of the industrial automation system **10** or certain devices are no longer used. As such, the edge computing device **54** may query a database (e.g., stored in the memory **76** or storage **78**) and identify target datasets based on certain identifiers (e.g., information identifiers) associated with the aspects or devices. The edge computing device **54** may remove the target datasets from the database.

(62) The process **150** described above with respect to FIG. **5** is related to operations performed by the edge computing device **54**. Such operations may be correlated or coordinated with corresponding operations performed by a cloud-based management system (e.g., container orchestration system **24**). FIG. **6** is a flow diagram of a process **200** for dynamically generating a container based on operational technology (OT) data via a cloud computing system (e.g., container orchestration system **24**). The process **200** may be performed by the container orchestration system **24** using processing circuitry (e.g. one or more processors included in the cloud computing devices **64**) executing computer-readable instructions stored on memory or storage of the cloud computing devices **64**.

(63) Although the process **200** described in FIG. **6** is described in a particular order, it should be noted that the process **200** may be performed in any suitable order and is not limited to the order presented herein. It should also be noted that although each processing block is described below in the process **200** as being performed by the container orchestration system **24**, other suitable systems may perform the methods described herein.

(64) Referring now to FIG. **6**, at block **202**, the container orchestration system **24** may receive the information identifier and the attribute variations from the edge computing device **54**. Based on the information identifier, at block **204**, the container orchestration system **24** may determine whether the information identifier matches any known digital twin (DT) template. For example, the container orchestration system **24** may query a database (e.g., the digital twin template database **68**) storing digital twin templates corresponding to previously identified industrial automation devices **52** and any potentially available/implementable devices of the industrial automation system **10**. The digital twin templates may be created by a computing device (e.g. a server) using certain computing languages (e.g., Digital Twin Definition Language (DTDLD)) based on information associated with the corresponding devices, such as specifications, parameters, relevant data (e.g., historical data, synthetic data), mathematic models, and so on. Each digital twin template may

include a template identifier related to an identification (e.g., device identifier) associated with a corresponding industrial automation device **52** represented by a digital twin implemented based on the digital twin template. In one embodiment, the container orchestration system **24** may use a database server to search available template identifiers based on the device identifier to identify a digital twin template having a template identifier in match with (e.g., based on a mapping) the information identifier. For example, the database may store the mapping indicating relationships between the information identifiers and the device identifiers, as well as relationships between the device identifiers and the template identifiers.

(65) In response to determine that the information identifier matches a digital twin template stored in the database, at block **206**, the container orchestration system **24** may generate a container based on the matching digital twin template. For example, the container orchestration system **24** may convert the digital twin template to the container using certain computing languages (e.g., software containerization languages). The container may include code and code dependencies that allow digital twin implemented using the container to run in any environment (e.g., operating system) consistently and reliably. Using the container orchestration system **24** to manage digital twin template and container operations (e.g., collecting and storing templates, creating containers based on templates) on the cloud **62** may take advantage of the cloud computing. For example, container orchestration system **24** may have access to a number of different edge computing devices coupled to different industrial systems operated by different entities. The container orchestration system **24** may also have access to cloud-based computing systems/devices that may perform large scale data collection, data mining, advanced simulations based on collected data, and container creation/update based on advance simulations, and the like. As such, the container orchestration system **24** may provide an up-to-date digital twin template database that may be used to determine a particular template matching newly identified industrial automation device.

(66) In response to determining that the information identifier does not matches any digital twin template stored in the database, at block **208**, the container orchestration system **24** may send a request for a new digital twin template to another computing device (e.g., server associated with a digital twin template developer). The request may include information related to the requested template, such as device specifications, parameters, relevant data (e.g., historical data, synthetic data), mathematic models, and so on. The computing device may send the new digital twin template to the container orchestration system **24** after a template development process. At block **206**, the container orchestration system **24** may generate a container based on the new digital twin template.

(67) At block **210**, the container orchestration system **24** may customize the container generated at block **206** based on the attribute variations. For example, the container may include basic functions executable by the digital twin to be updated based on the container. The container orchestration system **24** may customize the container to include new functions associated with the attribute variations that may indicate potential optimizations or issues of the industrial automation system **10**. For instance, the container may include a speed control function allow a corresponding digital twin (e.g. when implemented using the container) to regulate motors of the industrial automation system **10** to maintain the speeds within a predetermined range. However, the attribute variations may include temperature variations at certain given speeds that may indicate (e.g., based on simulations using the cloud computing device **64**) that generated heat from the motors operating at or above a specific speed may exceed a cooling capacity of the industrial automation system **10**. As such, the container orchestration system **24** may add a new function that allow the digital twin to be updated to cause a cool system to adjust cooling capacity (e.g., by enabling backup cooling unit).

(68) In some embodiments, the container generated at block **206** may be created by a first party by modifying another container developed by a second party. In this way, an entity (e.g., a factory) may integrate different digital twins based on different containers developed by different parties, thereby reducing the time for developing new containers.

(69) At block 212, the container orchestration system 24 may push the container to the edge computing device 54. For example, the container orchestration system 24 may store the container in the container registry 26. The container registry 26 may update a container list to include the container generated at block 206. The container orchestration system 24 may use the container registry 26 to store, distribute, and track the container. In some embodiments, a container image (e.g., the container image 28) may be created to include code related to executing the container, such as libraries, tools, runtime variables, and the like. In some embodiments, the container subscription component 66 may be used to send a notification indicative of the container to the edge computing device 54 to prompt the edge computing device 54 to receive the container.

(70) After pushing the container to the edge computing device 54, at block 214, the container orchestration system 24 may update a system level digital twin template list. For instance, the digital twin template database 68 may include the system level digital twin template list. When determining that the information identifier does not match any digital twin template stored in the digital twin template database 68 (at block 204), the container orchestration system 24 may add information (e.g., digital twin template identifier) associated with the new digital twin template into the system level digital twin template list.

(71) Additionally, the container orchestration system 24 may manage data usage on a cloud (e.g., cloud 62). In one embodiment, the container orchestration system 24 may determine that certain digital twins are no longer used (e.g., based on data consumptions), thereby removing digital twin templates related to such digital twins from the digital twin template database 68. Moreover, the container orchestration system 24 may send a request to the edge computing device 54 to remove such digital twins from corresponding containers where the digital twins implemented, and data related to such digital twins from the database.

(72) The specific embodiments described above have been shown by way of example, and it should be understood that these embodiments may be susceptible to various modifications and alternative forms. It should be further understood that the claims are not intended to be limited to the particular forms disclosed, but rather to cover all modifications, equivalents, and alternatives falling within the spirit and scope of this disclosure.

(73) The techniques presented and claimed herein are referenced and applied to material objects and concrete examples of a practical nature that demonstrably improve the present technical field and, as such, are not abstract, intangible or purely theoretical. Further, if any claims appended to the end of this specification contain one or more elements designated as “means for [perform]ing [a function] . . . ” or “step for [perform]ing [a function] . . . ,” it is intended that such elements are to be interpreted under 35 U.S.C. 112(f). However, for any claims containing elements designated in any other manner, it is intended that such elements are not to be interpreted under 35 U.S.C. 112(f).

Claims

1. A computing device comprising processing circuitry configured to: receive one or more containers configured to simulate a plurality of digital representations corresponding to a plurality of industrial automation devices of an industrial automation system; receive operational technology (OT) data from the plurality of industrial automation devices, wherein a portion of the OT data comprises: an identifier associated with a first industrial automation device of the plurality of industrial automation devices, wherein the identifier comprises an indication of a second industrial automation device of the plurality of industrial automation devices associated with the first industrial automation device; simulate, using the one or more containers, a first digital representation of the plurality of digital representations corresponding to one or more simulated operations of the second industrial automation device at a device level based on an additional portion of the OT data associated with the second industrial automation device; simulate, using the one or more containers, a second digital representation of the plurality of digital representations

corresponding to one or more processes performed by the plurality of industrial automation devices at a system level to generate one or more simulated processes, wherein the second digital representation is simulated based on the OT data and the one or more simulated operations; generate one or more commands to modify the one or more processes based on the second digital representation; and send the one or more commands to at least a portion of the plurality of industrial automation devices, wherein the one or more commands are configured to cause the at least a portion of the plurality of industrial automation devices to modify one or more operational settings to cause a change to the one or more processes.

2. The computing device of claim 1, wherein the computing device comprises an edge computing device of the industrial automation system.

3. The computing device of claim 1, wherein the computing device is part of a drive of the industrial automation system.

4. The computing device of claim 1, wherein the processing circuitry is configured to: transmit one or more identifiers of one or more industrial automation devices of the plurality of industrial automation devices and one or more data attributes of the OT data to a second computing device in response to determining that the one or more data attributes have one or more variations as compared to additional OT data; receive, from the second computing device, one or more additional containers comprising one or more updated digital representations of the one or more industrial automation devices; execute the one or more additional containers configured to output one or more additional data attributes; and send the one or more commands to the at least a portion of the plurality of industrial automation devices to cause the one or more processes to change based on the one or more additional data attributes.

5. The computing device of claim 4, wherein the processing circuitry is configured to: determine the one or more identifiers of the one or more industrial automation devices based on the OT data; and determine that the OT data comprises the one or more data attributes having the one or more variations.

6. The computing device of claim 5, wherein the processing circuitry is configured to determine the one or more identifiers by retrieving one or more namespace elements associated with the one or more industrial automation devices via the OT data.

7. The computing device of claim 6, wherein the one or more namespace elements correspond to one or more model numbers, one or more serial numbers, one or more Media Access Control (MAC) addresses, or any combination thereof associated with the one or more industrial automation devices.

8. A method, comprising: receiving, via a computing device, one or more containers configured to simulate a plurality of digital representations corresponding to a plurality of industrial automation devices of an industrial automation system; receiving, via the computing device, operational technology (OT) data from the plurality of industrial automation devices, wherein a portion of the OT data comprises: an identifier associated with a first industrial automation device of the plurality of industrial automation devices, wherein the identifier comprises an indication of a second industrial automation device of the plurality of industrial automation devices associated with the first industrial automation device; simulating, using the one or more containers, a first digital representation of the plurality of digital representations corresponding to one or more simulated operations of the second industrial automation device at a device level based on an additional portion of the OT data associated with the second industrial automation device; simulating, via the computing device and using the one or more containers, a second digital representation of the plurality of digital representations corresponding to one or more processes performed by the plurality of industrial automation devices at a system level to generate one or more simulated processes, wherein the second digital representation is simulated based on the OT data and the one or more simulated operations; generating, via the computing device, one or more commands to modify the one or more processes based on the second digital representation; and sending, via the

computing device, the one or more commands to at least a portion of the plurality of industrial automation devices, wherein the one or more commands are configured to cause the at least a portion of the plurality of industrial automation devices to modify one or more operational settings to cause a change to the one or more processes.

9. The method of claim 8, comprising, outputting, via the one or more containers, one or more data attributes of the OT data based on the one or more simulated operations.

10. The method of claim 8, wherein simulating the first digital representation and the second digital representation comprises using one or more mathematic models based on one or more machine learning or artificial intelligence algorithms.

11. The method of claim 8, comprising: transmitting, via the computing device, one or more identifiers of one or more industrial automation devices of the plurality of industrial automation devices and one or more data attributes of the OT data to a second computing device in response to determining that the one or more data attributes have one or more variations as compared to additional OT data; receiving, via the computing device, from the second computing device, one or more additional containers comprising one or more updated digital representations of the one or more industrial automation devices; executing, via the computing device, the one or more additional containers configured to output one or more additional data attributes; and sending, via the computing device, the one or more commands to the at least a portion of the plurality of industrial automation devices to modify cause the one or more processes to change based on the one or more additional data attributes.

12. The method of claim 11, comprising determining, via the computing device, the one or more identifiers of the one or more industrial automation devices based on the OT data.

13. The method of claim 11, comprising determining, via the computing device, the OT data comprises the one or more data attributes having the one or more variations.

14. The method of claim 8, wherein receiving the one or more containers comprises receiving the one or more containers from a container registry via a subscription service provided by a container subscription component.

15. A non-transitory, computer-readable medium storing instructions that, when executed by processing circuitry, cause the processing circuitry to: receive one or more containers configured to simulate a plurality of digital representations a plurality of industrial automation devices of an industrial automation system; receive operational technology (OT) data from the plurality of industrial automation devices, wherein a portion of the OT data comprises: an identifier associated with a first industrial automation device of the plurality of industrial automation devices, wherein the identifier comprises an indication of a second industrial automation device of the plurality of industrial automation devices associated with the first industrial automation device; simulate, using the one or more containers, a first digital representation of the plurality of digital representations corresponding to one or more simulated operations of the second industrial automation device at a device level based on an additional portion of the OT data associated with the second industrial automation device; simulate, using the one or more containers, a second digital representation of the plurality of digital representations corresponding to one or more processes performed by the plurality of industrial automation devices at a system level to generate one or more simulated processes, wherein the second digital representation is simulated based on the OT data and the one or more simulated operations; and generate one or more commands to modify the one or more processes based on the second digital representation; and send the one or more commands to at least a portion of the plurality of industrial automation devices, wherein the one or more commands are configured to cause the at least a portion of the plurality of industrial automation devices to modify one or more operational settings to cause a change to the one or more processes.

16. The non-transitory, computer-readable medium of claim 15, wherein the instructions, when executed, cause the processing circuitry to: transmit one or more identifiers of one or more industrial automation devices of the plurality of industrial automation devices and one or more data

attributes of the OT data to a second computing device in response to determining that the one or more data attributes have one or more variations as compared to additional OT data; receive, from the second computing device, one or more additional containers comprising one or more updated digital representations of the one or more industrial automation devices; and execute the one or more additional containers configured to output one or more additional data attributes.

17. The non-transitory, computer-readable medium of claim 16, wherein the instructions, when executed, cause the processing circuitry to send the one or more commands to the at least a portion of the plurality of industrial automation devices to modify cause the one or more processes to change based on the one or more additional data attributes.

18. The non-transitory, computer-readable medium of claim 16, wherein the one or more updated digital representations are configured to convert the OT data into formatted data based on hierarchical information of the industrial automation system and a predetermined data structure, wherein the formatted data enables sharing the formatted data within the one or more updated digital representations.
