Apparatus And Method For Simulating An Expanded Manufacturing Line

Field

The present invention relates to an apparatus and a method for simulating an expanded manufacturing line. In particular, there is provided at least one real manufacturing machine and at least one virtual manufacturing machine. The at least one virtual manufacturing machine is a simulation of at least one machine to be added to the expanded manufacturing line.

Background

Expansion of a production or manufacturing line typically involves addition of new machinery to the line to achieve increased productivity goals. A feasibility study is usually done to show that the expansion can and should be done, and also to show how the expansion can be done. However, it may be practically difficult and costly to set up a mock-up expanded manufacturing line for the purpose of conducting such feasibility study. In some cases, a digital simulation of the expanded manufacturing line may be created for the feasibility study. However, at the moment, such digital simulation still has some limitations in addressing, for example, issues that may occur in actual operation, compatibility and integration issues with existing machinery etc.

Summary

According to an example of the present disclosure, there are provided an apparatus and a method for simulating an expanded manufacturing line, as claimed in the independent claims. Some optional features are defined in the dependent claims.

Brief Description of the Drawings

Examples in the present disclosure will be better understood and readily apparent to one skilled in the art from the following written description, by way of example only and in conjunction with the drawings, in which:

FIG. 1 illustrates a system architecture comprising an apparatus for simulating an expanded manufacturing line according to an example of the present disclosure.

FIG. 2 shows a graphical representation of a simulation of an expanded manufacturing line comprising one real machine and two virtual machines according to an example of the present disclosure.

FIG. 3 shows a physical setup of an expanded manufacturing line comprising a display for displaying virtual machines and one real machine according to an example of the present disclosure.

Detailed Description

Examples of the present disclosure comprises an apparatus, a method, and/or a system for simulating an expanded manufacturing line. A need to increase productivity may require an existing manufacturing line to be expanded. Such expansion typically involves addition of machinery (e.g. robots for pick and place actions, conveyor mechanism, etc.) and/or peripheral equipment (e.g. sensors). A feasibility study is a first step to determine whether machinery and/or peripheral equipment from a machine/equipment supplier can be added to an existing manufacturing line set up to meet new productivity requirements. This study enables a manufacturer to check whether the machinery and/or peripheral equipment from the supplier

to be added are, for instance, compatible with existing set up, able to handle specific manufacturing tasks efficiently and cost effectively, etc. Whether or not the manufacturer will purchase the machinery and/or peripheral equipment largely depends on the results of the feasibility study.

It can be costly and require a lot of space to build a physical mock-up of an expanded manufacturing line or a proof-of-concept laboratory capable of demonstrating the efficiency and productivity of an expanded manufacturing line. Furthermore, preferably people should be physically present to view the demonstrations for the expanded manufacturing line.

A completely digital simulation of an entire expanded manufacturing line may be created to visualize workflow and allocation of products (i.e. objects or parts to be handled by a machine) and processes to identify possible future challenges, and to plan the setup of the expanded manufacturing line. For example, Omron Corporation has a Sysmac Studio 3D Simulation tool, which is a simulation software that can digitally reproduce an entire manufacturing facility and can verify the operation of a digitally created virtual machine with similar accuracy as an actual machine. For instance, the Sysmac Studio 3D simulation tool can allow users to simulate an entire machine, including customized robots developed in-house and/or machine and equipment supplied by some suppliers. However, although this tool is useful, it may still have limitations in addressing, for example, issues that may occur in actual operation, compatibility and integration issues with existing machinery etc. For instance, there is a possibility that an existing machine is not part of the library of the tool and its digital clone cannot be accurately created for the simulation.

Examples of the present disclosure can provide another option to manufacturers for the feasibility study in addition to physical demonstrations and a completely digital simulation of the expanded manufacturing line. This option may be a complement to the physical demonstration and/or the completely digital simulation, or a replacement for either one or both of them. The example adopts a digital twin concept wherein, for example, a virtual representation of a physical robot system, with all its peripherals, to perform a certain process is created for demonstration together with the physical robot system. The physical robot system can be built for testing, or can be existing manufacturing machines and/or equipment that a manufacturer already has. Both virtual and real machines are present in the demonstration, and the real and virtual machines are configured to work together. Events occurring in the real world and virtual world can affect the behavior of the real machines and the virtual machines. The virtual world can be created to show items in 2-dimensional (2D) and/or 3-dimensional (3D) view. There may be provided an option to toggle between 2D and 3D views.

In the present disclosure, a machine can refer to a robot, a conveyor mechanism, etc.

The example provides an advantage in terms of scalability and customizability in a digital world, without breaking off connection with the physical Robot system. This opens up new possibilities to demonstrate how multiple robots, both existing real robots and new robots to be added, can work with one another to carry out common or different processes. Digital simulation is still involved but there is reduction in the amount of work required to produce the simulation because only the machines and/or peripheral equipment to be added for the expanded manufacturing line have to be created digitally. Demonstrations and testings of the expanded manufacturing line may be conducted at the comfort of a manufacturer’s premises housing existing machines after connecting the existing machines with the digital simulation of the machines and/or peripheral equipment to be added for the expanded manufacturing line.

Specifically, the example can be used to facilitate machine/equipment suppliers to demonstrate and/or test robot systems, combined with a configurable and scalable digital

extension of the real robot system i.e. virtual and real machines are demonstrated and/or tested together. This can eliminate the need to set up multiple real robots including the real robots to be added to expand a manufacturing line for physical demonstration and/or testing of the expanded manufacturing line, and thus reduce the cost for building or constructing such real robots and peripherals for the physical demonstration. Adding a digital extension (i.e. virtual representation) of a real machine is relatively easy. A user only needs to setup a visual media i.e. a display to show the virtual world, which comprises the machines and/or equipment to be added to the expanded manufacturing line. The visual media can be for example, a television, projector, personal computer monitor, mobile device display, augmented reality display in a headset or goggles, etc. A mobile device having the mobile device display can be, for example, a smartphone, a laptop computer, a tablet computer, etc. The screen size of the visual media can be configured to be sufficiently large to showcase a life-sized version of the virtual machines. In the case of an augmented reality display in a headset or goggles and/or on a mobile device display, the virtual world shown in the display can overlap the images of the real world that are captured via imaging sensors (e.g. camera). In this case, virtual items will be programmed to overlay or appear at specific locations in the captured images of the real world. This will help interested parties seeking to purchase additional machines and/or equipment to visualize the expanded manufacturing system better and hopefully make better financial decisions for their purchases.

The example will be described in more detail as follows.

One or more digital twins of a real robot can be added to a physically existing (real) robot system and the one or more digital twins can be demonstrated or tested simultaneously, side by side with the real robot system, with the use of visual media. The one or more digital twins will not mirror the real robot in runtime but rather, it will be additional one or more virtual robots in the downstream or upstream that will work together with the real robot. The system may be configured such that real time data captured by the real robot system can be sent over to its digital extension (i.e. the one or more digital twins) including statuses and errors in the processing of products i.e. objects or parts to be handled by the real and virtual robots during operation. The digital extension is scalable such that one or more virtual robots can be added to the digital world as desired to imitate a planned system design. The digital extension or virtual world can be created with the help of tools such as the ACE (Automation Control Environment) Software created by Omron Corporation, and the like.

One key feature of the example is that the real robot system and its digital extension can interact with each other. A controller, processor or processing unit (hereinafter “processor”) can be provided to control the behavior of the real robot system based on input received on the operations of both the real and virtual robots. The same processor or a second processor in data communication with the processor can be used to control the behavior of the one or more virtual robots based on input received on the operations of both the real and virtual robots. The bridging of the real robot system and the one or more virtual robots can be made via Ethernet/IP (e.g. if required, using data communication ports such as routers) to exchange the real time data. In this manner, either the real robot or virtual robot can be controlled by the connected processor to react based on the received input. An event or action occurring during the operation of both the real and virtual robots can influence their behaviors.

For example, in the case of one real robot (R1), and one virtual robot (R2) downstream of R1, if R1 fails to pick up an object conveyed by a conveyor mechanism and the failure is notified to the processor, the failure to pick up can be notified to R2 by the processor, and R2 will proceed to pick up the object. The digital simulation will show a digital extension of the conveyor mechanism (virtual conveyor mechanism) conveying a digital extension of the object (virtual object) that was failed to pick up by R1. The virtual conveyor mechanism will convey the virtual object towards R2, and R2 will pick up the virtual object.

Furthermore, for example, the inputs that can be received by the processor from a virtual robot can be Idle Time, Processing Time, Parts per Minute, Parts not Processed, Targets not Processed, Parts Processed, Targets Processed, errors, etc. The inputs that can be received by the processor from a real robot can be hardware data such as Amplifier Temperature, Duty Cycle, Encoder Temperature, Torque, Velocity, Position Error, etc. All these inputs may affect the behavior of the real and virtual robots, the parts or objects being handled, and/or other machines such as a conveyor mechanism, if used. Furthermore, an event (e.g. an error, an expected event to occur during manufacturing etc.) that occur to real parts or objects being handled or processed by the real robot can also affect the behavior of virtual machines and/or virtual objects in the digital extension.

FIG. 1 illustrates a system architecture of an example of the present disclosure. The example is a real robot system 100 comprising at least one real machine set up (also known as a real robot cell) 110. In this example, the real robot cell 110 comprises one real robot 102 for picking and placing a plurality of objects, and one conveyor mechanism 108 for conveying the plurality of objects 106 to the real robot 102 for handling. In the present example, the real robot 102 is a pick and place robot mounted to a frame 112 configured to position the real robot 102 above the conveyor mechanism 108. Although a pick and place robot is described for this example, it should be appreciated that in other examples, the robot or robots in the real robot system 100 can be other types of robots used in a manufacturing or assembly line.

The real robot system 100 further comprises an apparatus 140. The apparatus 140 may be a personal (desktop) computer, Programmable Logic Controller (PLC), an Industrial Personal Computer, a server hosting a web-based simulation program accessible via Internet, a personal (desktop) computer, a laptop computer, a mobile device like a smartphone, an Augmented Reality (AR) headset or goggles (or Virtual Reality headset or goggles that can display augmented reality) comprising a processor to run a simulation program, or the like. In this example, the apparatus 140 is a laptop computer installed with a simulation program configured to show a digital extension of the real robot system and comprises a processor to execute instructions of the simulation program in a memory of the laptop computer 140. The simulation program enables users to create virtual items to interact with the real world. The apparatus 140 comprises a display for showing a simulation of the digital extension of the real robot system.

In the present example, the simulation program has a graphical user interface configured for a user to customize the features to be added to a planned expanded manufacturing line, and to run and display a simulation of the added features after the customization is completed. Two snapshots of the graphical user interface 122 and 122a captured at different time are shown in FIG. 1.

In the first snapshot 122, it is shown that the graphical user interface comprises a control panel 126 and a display panel 128 displaying a virtual robot 104 and a conveyor mechanism 118 added to the digital extension of the real robot system 100. The control panel 126 enables a user to track coordinates and/or orientation (e.g. angle, x, y, z, yaw, pitch, roll) of a selected location or a selected virtual item shown in the display panel 128, control speed and/or movement of the virtual robot 104 shown in the display panel 128, etc. For example, a specific location of the virtual robot 104, the entire virtual robot 104 or a part of the virtual robot 104, the conveyor mechanism 118 or a part of the conveyor mechanism 118 may be selected. Addition of virtual items and/or settings required to program the operation of the virtual robot 104 may be made using the control panel 126.

The second snapshot 122a is captured after the first snapshot 122. The second snapshot 122a also comprises a control panel 126a and a display panel 128a, which have the same functions as the control panel 126 and the display panel 128 respectively. The display panel

128a shows that two more virtual robots 104a and 104b are added to the digital extension of the real robot system 100.

FIG. 1 shows another snapshot 120, which is an actual simulation view displayable on the display of the apparatus 140. The graphical user interface may be configured to allow a user to see such simulation view after the required programming and settings of the digital extension of the real robot system 100 are completed. The snapshot 120 shows the virtual robot 104, another virtual robot 114, the conveyor mechanism 118 and a plurality of objects 116 to be conveyed by the conveyor mechanism 118 to the virtual robot 104 and/or the virtual robot 114 for handling. More details of snapshot 120 will be described with reference to FIG. 2 later.

One or more real sensors (not shown in FIG. 1) may be provided for detecting an event in the real world. The one or more real sensors and the real robot 102 are connected to the apparatus 140 via a data communication port 130 and cables 132 to enable data communication between the one or more real sensors, the real robot 102 and the apparatus 140. The data communication port 130 can be a router. In another example, the data communication port 130 can be configured for wireless data communication and the cable 132 would not be required. In the present example, the data being communicated are exchanged in real-time so that events occurring in real-time will influence the behavior of the real robot 102. In another example, the data being communicated need not be in real-time. Not real-time data communication may be required if pauses in the process are needed or expected, for example, during machine or equipment testing, network lag, etc.

The event to be detected by the one or more real sensors may be an event that is part of a manufacturing process and has to be monitored to trigger one or more other events. The event may also be an anomaly, exception or error, which is something that deviates from what is standard, normal, or expected in the manufacturing process. The one or more real sensors may be part of the real robot 102, or separately provided in the real robot system 100. The one or more real sensors may include, for example, an imaging sensor (e.g. camera) for capturing images (photograph or video), laser sensor (e.g. LiDAR scanner), infrared sensor, pressure sensor, temperature sensor, audio sensor (e.g. microphone), and/or ultrasonic sensor that may be used in a manufacturing line for detecting the event.

FIG. 2 further illustrates the example of FIG.1. FIG. 2 shows an enlarged view of the snapshot 120 in FIG. 1, which shows a simulation view of the two virtual robots 104 and 114 working on virtual objects 116 conveyed by the virtual conveyor mechanism 118. The example of FIG. 2 shows only a portion of the virtual world. In another example, the simulation may be configured such that a user can browse and move around (e.g. using touch control, arrow keys on a keyboard or keypad, etc.) in the virtual world to view the simulation of other virtual items created for the planned expanded manufacturing line that are not shown In FIG. 2. For illustration purposes, a picture of the real robot cell 110 comprising the real robot 102 mounted on the frame 112, the real conveyor mechanism 108, and real objects 106 conveyed by the real conveyor mechanism 108 is overlayed and located adjacent to the two virtual robots 104 and 114 to illustrate that the real robot system 100 and its digital extension are working together.

In the present example, the real robot 102 is a pick and place robot for picking up a real object 106 conveyed by a real incoming conveyor mechanism 108 and for placing the real object 106 into a real pouch unit (i.e. a container) 202. The pouch unit 202 is used to imitate a portion of an outgoing conveyor mechanism for conveying a plurality of placement targets. Each placement target is to be placed with an object by a real or virtual robot. In the present example, the outgoing conveyor mechanism is not provided in the real world but planned to be provided in the actual expanded manufacturing line that is being simulated.

The two virtual robots 104 and 114 are also pick and place robots with configurations similar to the real robot 102. The virtual robots 104 and 114 are configured for picking up a virtual object 116 conveyed by the virtual conveyor mechanism 118 and for placing the picked virtual object 116 onto virtual placement targets 206 such as 206a, 206b, 206c and 206d shown in FIG. 2. The virtual placement targets 206 are placed on a virtual outgoing conveyor mechanism 208 for conveying the virtual placement targets 206 with placed virtual objects 116 to a desired location for further processing. The virtual outgoing conveyor mechanism 208 simulates a real outgoing conveyor mechanism that the pouch unit 202 is imitating and which will be provided in the actual expanded manufacturing line. The two virtual robots 104 and 114 may be configured to be in a downstream of the real robot 102. These three robots (both real and virtual) may be configured to pick and place objects (i.e. 106 and/or 116) in a predetermined order. For example, a first robot may only pick and place one object and then leave the picking and placing of two other objects to the other two robots downstream.

FIG. 2 shows belt windows 204a and 204b (i.e. rectangular dark patches on the virtual conveyor mechanism 118) of the virtual robots 104 and 114 respectively. Such belt windows 204a and 204b are virtual items not present in the real world. They are displayed in the virtual world to indicate where each virtual robot 104 or 114 would pick up virtual objects 116 from the virtual conveyor mechanism 118. They are provided to let users understand the picking up process better and/or to facilitate programming of the picking up process. The belt windows 204a and 204b are examples of useful virtual items that cannot be provided or practically difficult to provide in the real world.

In the real world, the real objects 106 picked by the robot 102 will be placed into the pouch unit 202 to imitate placing the real object 106 onto a placement target that is located on the outgoing conveyor mechanism. In the virtual world, the virtual outgoing conveyor mechanism 208 is provided and it is configured to convey the virtual placement targets 206 to a desired location after they are placed with virtual objects 116 by the virtual robots 104 and 114. Some of the virtual placement targets 206 will simulate being placed with objects by the real robot 102 and they will be configured to contain placed virtual objects that represents the objects placed by the real robot 102.

In FIG. 2, a virtual placement target with a dark color top portion such as the virtual placement target 206a refers to a virtual placement target that has not been allocated to any virtual or real robots 104, 114 or 102 to process i.e. not allocated to any robot to place an object thereon. If the virtual placement target 206a is not processed by the virtual robots 104 and 114 or allocated for the real robot 102 to process, it can be allocated to another virtual robot located downstream of the virtual robots 104 and 114. A virtual placement target with a gray color top portion such as the virtual placement target 206b refers to a virtual placement target that is already processed i.e. already placed with an object by either one of the virtual and real robots 102, 104, and 114 thereon and should be conveyed to a desired location by the virtual conveyor mechanism 208. A virtual placement target with a bright color (i.e. white) top portion such as virtual placement 206d refers to a virtual placement target that has been allocated to either one of the virtual and real robots 102, 104, and 114 for placing an object thereon but has yet to be processed i.e. not yet placed with an object thereon by either one of the virtual and real robots 102, 104, and 114. If an event happens that the virtual placement target 206d remains unprocessed, the system controlling the simulated expanded manufacturing line may allocate another virtual robot downstream of the virtual and real robots 102, 104, and 114 to process the virtual placement target 206d and the virtual outgoing conveyor mechanism 208 will move the virtual placement target 206d to a location of the allocated virtual robot. For example, the simulation may be configured to allow a user to move about in the virtual world to view this allocated virtual robot, which is downstream of the virtual and real robots 102, 104, and 114. The virtual placement target 206c shown in FIG. 2 has a gray color top portion, which means that it is already processed, and the virtual placement target 206c illustrates that the virtual object 116a is placed onto it.

Furthermore, in the present example, if an unexpected event detected by one or more real sensors such as a camera happens, and the unexpected event is that a (virtual or real) robot missed the picking and placing of one (virtual or real) object, another (virtual or real) robot downstream may be instructed to pick and place the object that is missed. That is, if a real robot makes a mistake or if an event happens to the real objects 106 (e.g. the orientation of a real object is misaligned for picking), such mistake or event can cause one or more events to occur in the virtual world. Likewise, if a virtual robot is deliberately configured to make a mistake for testing purposes, the behavior of the real robot and/or the real conveyor mechanism can also be affected by the mistake. Therefore, the present example can be used to test out the planned expanded manufacturing line to look for areas to improve in addition to serving as a demonstration of the planned expanded manufacturing line.

Specifically, FIG. 2 illustrates that the virtual robot 104 is waiting to pick up a virtual object 116 to place onto one of the virtual placement targets. The virtual robot 114 has picked up another virtual object 116 but has yet to place the virtual object 116 onto a virtual placement target. The processes and operations of the two virtual robots 104 and 114 and the real robot 102 have to be coordinated in order to provide a realistic demonstration of the capabilities of the planned expanded manufacturing line.

Images of real objects 106 conveyed by the real conveyor mechanism 108 may be captured via an imaging sensor and when the real objects 106 are moved by the real conveyor mechanism 108 to a location of where a virtual robot is programmed to be located, the digital extensions of the real objects 106 i.e. the virtual objects 116 representing the real objects 106 should also reach the location of the virtual robot for the virtual robot to handle. In other examples, it could be that no real object 106 is actually provided but virtual objects 116 are provided in the simulation of the digital extension, or that the number of real objects 106 is lower than the virtual objects 116 being displayed.

Furthermore, for example, a sensor such as a camera can be used in the example of FIG. 2 to track the location of a real object 106 in the real conveyor mechanism 108 and the location of its digital equivalent virtual object 116 in the virtual conveyor mechanism 118. The real conveyor mechanism 108 can comprise one or more conveyor belt encoder latches. Such latches can be used with the camera to track the location of a real object 106. For instance, one or more cameras may be used to detect the presence of a real object 106 at one or more predetermined locations on the real conveyor mechanism 108, and the detection of presence of the real object 106 at one predetermined location can cause an input signal to be generated to switch a latch to change state and capture a conveyor belt encoder position value that is associated with a specific belt location on the belt of the real conveyor mechanism 108. Thereafter, it will be known that this specific belt location has a real object 106 placed there. Based on such knowledge, the simulation program can generate data (including data for graphical demonstration) of the digital equivalent virtual object 116 of the real object 106 and placed it at the correct belt location of the virtual conveyor mechanism 118.

The latch signals for changing state and their corresponding captured belt encoder position values can be managed and stored in a memory or database for every object conveyed on the real conveyor mechanism 108. With such data stored in the memory or database, the real robot system 100 and its digital extension can determine where every object is placed on the belt of the real conveyor mechanism 108 and on the virtual conveyor mechanism 118 by referring to the current belt encoder position value.

If applicable, the camera may be configured to capture an orientation of the real object and data generated based on the orientation can be stored in the memory or database. Such orientation of the real object may affect how its digital equivalent virtual object would be handled by a virtual robot.

An example of a procedure to coordinate the real robot system 100 of FIG. 1 and its digital extension to demonstrate a planned expanded manufacturing line is described as follows. The digital extension comprises one or more virtual robots and can include other virtual machines like a conveyor mechanism as well.

Step 1: A user first programs the real robot system based on predetermined requirements to enable it to be used together with its digital extension. That is, the real robot system should be programmed to operate according to the plans for the expanded manufacturing line.

Step 2: A server (which can be a personal computer, laptop computer etc.) can be configured to collect all data or information from the real robot system via ethernet communication during the operation of the real robot system. This data or information can influence the behavior of the one or more virtual robots, and/or other virtual machines in the digital extension. This server is configured to run a simulation program configured with a scalable and configurable digital extension of the real robot system. The one or more virtual robots (and if required, other virtual machines) are configured to work together with the one or more real robots in the real robot system. The same simulation program or another program can be running in the background of the server to track data received in real-time from the real robot system and/or the one or more virtual robots. The one or more real robots in the real robot system and the one or more virtual robots (and if present the other virtual machines) are controlled by the program to react and/or to be adjusted according to the real-time data received. In this manner, the real robot system and its digital extension are bridged and combined to work on a plurality of real and/or virtual objects provided for handling by the real robot system and/or its digital extension.

Step 3: Optionally, the simulation of the digital extension can be displayed on a visual media (i.e. display) connected to the server. The visual media can be configured to be located adjacent to the real robot system to allow a user to better visualize how the expanded manufacturing line will look.

FIG. 3 shows examples of hardware (physical set up) that can be provided to demonstrate the real robot system 100 and its digital extension that are described above with reference to FIG. 1 and 2. Reference numerals of the elements in FIG. 1 and FIG. 2 are used for the same elements shown in FIG. 3. The real robot system 100 may include the following hardware.

1. A real robot cell 110 that is pre-programmed to work together with two virtual robots 104 and 114, and to process one or more real objects 106. The real robot cell 110 comprises:
   a) the real robot 102 mounted to the frame 112;
   b) an Industrial Personal Controller (IPC) (not visible in FIG. 3) for controlling the operation of the real robot 102;
   c) a real belt conveyor or real conveyor mechanism 108; and
   d) parts to be processed i.e. a plurality of real objects 106 conveyed by the conveyor mechanism 108 for the real robot 102 to handle.

The real conveyor mechanism 108 has a length sufficient to accommodate two real versions of the two virtual robots 104 and 114 that are downstream of the real robot 102.

An IPC is an industrial computer with programming functions similar to a Programmable Logic Controller (PLC). However, an IPC generally has a better processor or processors, and more memory than PLCs. An IPC can differ from a regular desktop Personal Computer in that it is constructed to handle a variety of environmental factors such as heat, dust, vibration and moisture. The IPC may also serve as a Human Machine Interface.

2. Hardware for the digital extension that may comprise:

e) a television monitor 304 mounted on a television stand 306;
f) a laptop or Personal Computer (not shown in FIG. 3) that will be used for simulating the Digital extension; and
g) Ethernet Cable, and if required, a data communication port (to connect the IPC to the laptop or Personal Computer and enable data communication between them).

In the present example, the television monitor 304 shows a 2D view of the two virtual robots 104 and 114 and the virtual conveyor mechanism 118. A user may toggle between 2D and 3D view. To be as realistic as possible, the present example is configured to try to let the television monitor 304 display the two virtual robots 104 and 114 with sizes of real robots.

The software used for creating the digital extension of the real robot system 100 and for controlling the processes for the simulation can include ACE (Automation Control Environment) Software created by Omron Corporation. The ACE Software comprises an ACE workspace, which is essentially a library comprising details (such as controls, parameters, etc.) of a hierarchy of objects (i.e. manufacturing machinery and peripherals). This library may be used to control real manufacturing machines (like robots and end-effectors) and non-physical items associated with the real machines (like programs and variables), and/or to simulate them.

The ACE Software may be provided as a Personal Computer (PC) based software package to be installed in the laptop or Personal Computer. It can be used to enable a user to manage an entire portfolio of, both real and virtual, robotic, control, vision, and/or feeding systems. For instance, a user can program and deploy applications ranging from simple pick and place to multi-robot belt-tracking lines. The ACE Software can be programmed with the digital extension of an existing robot system, and may be used to control the behavior of a real robot by sending data associated with the operation of a virtual robot and/or data associated with a virtual event. Such virtual event may be a deliberate system error programmed to test how the system handles exceptions.

The ACE Software is configured for fast emulation or simulation, and 3D visualization for quick proof of concept. It comprises a Wizard-based user-friendly interface (e.g. the graphical user interface shown in FIG. 1) to calibrate, control, program, and teach robots, and a Recipe Manager to simplify management of manufacturing process and handle a range of product (e.g. parts or objects to be handled by robots) variations.

The ACE Software also comprises a Robot Vision Manager to enable vision guided conveyor-tracking and any feeder integration via wizards and to provide vision inspection tools to improve quality assurance and traceability. Robot Vision Manager provides algorithms and tools for easy integration of vision systems into robotic applications. Camera calibration, part identification, and image processing tools are supported as part of this manager. Hence, if a real imaging sensor is to be used to detect events in the real world that may influence the behavior of virtual machines or result in a virtual event to take place, such Robot Vision Manager can be used.

The ACE Software also provides a layer of simplification for application development, by means of Application Manager modules. These modules enable advanced programming capabilities for Packaging (“PackManager”) and Vision (“Robot Vision Manager”) applications. PackManager can manage scalable packaging lines from integration to deployment and step-by-step guidance without scripting. The software facilitates a user through a configuration of packaging applications to create process-specific virtual items, such as controllers, robots, and conveyor belts.

The ACE Software further comprises a Process Manager that can be used to optimize resources, decrease idle time and maximize the amount of parts to be processed by each real

or virtual robot. The Process Manager can be used to optimize the design of the expanded manufacturing line.

An example of the processor, IPC, the apparatus (e.g. apparatus 140) or the server described in examples of the present disclosure may have the following components in electronic communication via a bus:

1. a display device;
2. non-volatile memory and/or non-transitory computer readable medium;
3. random access memory ("RAM");
4. *N* number of processing components (i.e. “one or more controllers”, “one or more processors” or “one or more central processing units”);
5. a transceiver component that includes *N* number of transceivers for Internet/Intranet use, and/or Wireless Network communications;
6. user controls i.e. user input devices;
7. optionally, image capturing components such as a camera;
8. optionally, audio signal capturing components (e.g. microphone);
9. optionally, audio speakers; and
10. Input/Output interfaces for connecting to the user input devices (such as mouse, joystick, keyboard, sensors for detecting user gestures, and the like), the audio speakers, display, the image capturing components and/or the audio signal capturing components.

The apparatus may be a personal computer, a PLC, an IPC, a laptop computer, a server, an augmented reality (AR) or virtual reality (VR) headset that may or may not be wire or wirelessly connected to an external console, and the like.

The display device generally operates to provide a presentation of graphical content including graphical simulation content to a user, and may be realized by any of a variety of displays (e.g., CRT, LCD, HDMI, micro-projector and OLED displays). The display may be a touchscreen and in this case, the touchscreen is part of the user controls i.e. user input devices. The display device can be a display screen in an augmented reality (AR) or VR (VR) headset or goggles for a user to view virtual items being simulated.

In general, the non-volatile memory functions to store (e.g., persistently store) data and executable code including code that is associated with functional components of the example. In some cases, for example, the non-volatile memory includes bootloader code, modem software, operating system code, file system code, as well as other codes well known to those of ordinary skill in the art that are not depicted for simplicity.

In many implementations, the non-volatile memory is realized by flash memory (e.g., NAND or NOR memory), but it is certainly contemplated that other memory types may be utilized as well. Although it may be possible to execute the code from the non-volatile memory, the executable code in the non-volatile memory is typically loaded into RAM and executed by one or more of the *N* processing components.

One or more computer programs may be stored on any machine or computer readable medium that may be non-transitory in nature. The computer readable medium may include storage devices such as magnetic or optical disks, memory chips, or other suitable storage devices. The machine or computer readable medium may also include a hard-wired medium such as exemplified in the Internet system, or wireless medium such as exemplified in the Wireless LAN (WLAN) system.

The *N* processing components (or “one or more processors”) in connection with RAM generally operate to execute the instructions stored in non-volatile memory to effectuate the functional components. As one skilled in the art (including ordinarily skilled) will appreciate,

the *N* processing components may include a video processor, modem processor, DSP, graphics processing unit (GPU), and other processing components.

The transceiver component may include *N* transceiver chains, which may be used for communicating with external devices via wireless networks. Each of the *N* transceiver chains may represent a transceiver associated with a particular communication scheme. For example, each transceiver may correspond to protocols that are specific to local area networks, cellular networks (e.g. a WIFI network, a CDMA network, a GPRS network, a UMTS networks, a 5G network etc.), and other types of communication networks. In some implementations, the communication of the transceiver component with communication networks enables a location of connected devices to be determined.

Examples of the present disclosure may have the following features. Reference numerals of elements in the figures of the present disclosure that are examples of these features are stated.

An apparatus (e.g. 140) for simulating an expanded manufacturing line, wherein the apparatus comprises:

a processor configured to execute instructions in a memory to operate the apparatus to:

generate data associated with simulation of operation of at least one virtual machine (e.g. 104, 104a, 104b, 114, 118) configured to work together with at least one real machine (e.g. 102) in an expanded manufacturing line;

receive input associated with (real-time or not real-time) operation of the at least one real machine;

receive input associated with (real-time or not real-time) operation of the at least one virtual machine (such input can be received in real-time or not real-time);

control behavior of the at least one real machine and the at least one virtual machine according to the input received (in real-time or not real-time) from the at least one real machine and/or the input received from the at least one virtual machine.

The apparatus may be operable to:

generate data associated with simulation of handling of one or more virtual objects (e.g. 116) by the at least one virtual machine, wherein the one or more virtual objects are digital equivalents of one or more real objects (e.g. 106) and are configured as if they are transferred to virtual world from real world.

The apparatus may be operable to:

generate data associated with an event detected in the operation of the at least one real machine and/or the at least one virtual machine (e.g. the generated data may be data associated with the detected event which occurred in the real world, data associated with the detected event which occurred in the virtual world, data associated with an instruction to trigger simulation of one or more event resulting from the detected event, etc.); and

generate data associated with simulation of one or more expected events resulting from the event (e.g. issues with real and/or virtual machines that lead to errors in virtual and/or real world).

The apparatus may be operable to:

generate data associated with an event detected from one or more real objects (e.g. 106) handled by the at least one real machine and/or from one or more virtual objects (e.g. 116) handled by the at least one virtual machine (e.g. the generated data may be data associated with the detected event which occurred in the real world, data associated with the detected event which occurred in the virtual world, data associated

with an instruction to trigger simulation of one or more event resulting from the detected event etc.); and

generate data associated with simulation of one or more expected events resulting from the event (e.g. issues with real and/or virtual objects that lead to errors in virtual and/or real world).

The apparatus may comprise at least one real sensor, and the apparatus is operable to:

receive input from the at least one real sensor; and

control behavior of the at least one real machine and the at least one virtual machine according to

input from the at least one real sensor, or

a combination of inputs from one or more of the at least one real machine, the at least one virtual machine and the at least one real sensor.

The apparatus may comprise an imaging sensor configured to capture images of one or more real objects that the at least one real machine is configured to handle,

wherein the apparatus is operable to:

generate data associated with simulation of one or more virtual objects that the at least one virtual machine is configured to handle based on the captured images.

The at least one real machine may comprise:

a real robot (e.g. 102); and

a real conveyor mechanism (e.g. 108) for conveying one or more real objects (e.g. 106) that the real robot is configured to handle,

wherein the at least one virtual machine comprises:

one or more virtual robots (e.g. 104, 104a, 104b, 114) configured to handle one or more virtual objects (e.g. 116); and

a virtual conveyor mechanism (e.g. 118) for conveying the one or more virtual objects that the one or more virtual robots is configured to handle,

wherein the one or more virtual objects is a simulation of one or more of the one or more real objects that the real conveyor mechanism is configured to convey, and the virtual conveyor mechanism is a simulation of the real conveyor mechanism.

The apparatus may comprise:

one or more display devices (e.g. 304) configured to display a graphical simulation according to all data associated with simulation generated by the apparatus.

A method for simulating an expanded manufacturing line, wherein the method comprises:

generating data associated with simulation of operation of at least one virtual machine configured to work together with at least one real machine in an expanded manufacturing line;

receive input associated with (real-time or not real-time) operation of the at least one real machine;

receive input associated with (real-time or not real-time) operation of the at least one virtual machine; and

control behavior of the at least one real machine and the at least one virtual machine according to the input received (in real-time or not real-time) from the at least one real machine and/or the input received from the at least one virtual machine.

The method may comprise:

generating data associated with simulation of handling of one or more virtual objects by the at least one virtual machine, wherein the one or more virtual objects are digital equivalents of one or more real objects and are configured as if they are transferred to virtual world from real world.

The method may comprise:

generating data associated with an event detected in the operation of the at least one real machine and/or the at least one virtual machine (e.g. the generated data may be data associated with the detected event which occurred in the real world, data associated with the detected event which occurred in the virtual world, data associated with an instruction to trigger simulation of one or more event resulting from the detected event, etc.); and

generating data associated with simulation of one or more expected events resulting from the detected event.

The method may comprise:

generating data associated with an event detected from one or more real objects handled by the at least one real machine and/or from one or more virtual objects handled by the at least one virtual machine (e.g. the generated data may be data associated with the detected event which occurred in the real world, data associated with the detected event which occurred in the virtual world, data associated with an instruction to trigger simulation of one or more event resulting from the detected event etc.); and

generate data associated with simulation of one or more expected events resulting from the detected event.

The method may comprise:

receiving input from at least one real sensor; and

control behavior of the at least one real machine and the at least one virtual machine according to

input from the at least one real sensor, or

a combination of inputs from one or more of the at least one real machine, the at least one virtual machine and the at least one real sensor.

The method may comprise:

capturing images of one or more real objects that the at least one real machine is configured to handle using an imaging sensor; and

generating data associated with simulation of one or more virtual objects that the at least one virtual machine is configured to handle based on the captured images.

The at least one real machine may comprise:

a real robot; and

a real conveyor mechanism for conveying one or more real objects that the real robot is configured to handle,

wherein the at least one virtual machine comprises:

one or more virtual robots configured to handle one or more virtual objects; and

a virtual conveyor mechanism for conveying the one or more virtual objects that the one or more virtual robots is configured to handle,

wherein the one or more virtual objects is a simulation of one or more of the one or more real objects that the real conveyor mechanism is configured to convey, and the virtual conveyor mechanism is a simulation of the real conveyor mechanism.

The method may comprise:

displaying on one or more display devices a graphical simulation according to all generated data associated with simulation.

A system for simulating an expanded manufacturing line, wherein the system comprises:

at least one real machine;

the apparatus; and

one or more displays configured to display a graphical simulation according to all data associated with simulation generated by the apparatus.

In the specification and claims, unless the context clearly indicates otherwise, the term "comprising" has the non-exclusive meaning of the word, in the sense of "including at least" rather than the exclusive meaning in the sense of "consisting only of". The same applies with corresponding grammatical changes to other forms of the word such as "comprise", "comprises" and so on.

While the invention has been described in the present disclosure in connection with a number of examples and implementations, the invention is not so limited but covers various obvious modifications and equivalent arrangements, which fall within the purview of the appended claims. Although features of the invention are expressed in certain combinations among the claims, it is contemplated that these features can be arranged in any combination and order.

Claims

1. An apparatus for simulating an expanded manufacturing line, wherein the apparatus comprises:
a processor configured to execute instructions in a memory to operate the apparatus to:
generate data associated with simulation of operation of at least one virtual machine configured to work together with at least one real machine in an expanded manufacturing line;
receive input associated with operation of the at least one real machine;
receive input associated with operation of the at least one virtual machine; and
control behavior of the at least one real machine and the at least one virtual machine according to the input received from the at least one real machine and/or the input received from the at least one virtual machine.

2. The apparatus as claimed in claim 1, wherein the apparatus is operable to:
generate data associated with simulation of handling of one or more virtual objects by the at least one virtual machine, wherein the one or more virtual objects are digital equivalents of one or more real objects and are configured as if they are transferred to virtual world from real world.

3. The apparatus as claimed in claim 1 or 2, wherein the apparatus is operable to:
generate data associated with an event detected in the operation of the at least one real machine and/or the at least one virtual machine; and
generate data associated with simulation of one or more expected events resulting from the detected event.

4. The apparatus as claimed in any one of the preceding claims, wherein the apparatus is operable to:
generate data associated with an event detected from one or more real objects handled by the at least one real machine and/or from one or more virtual objects handled by the at least one virtual machine; and
generate data associated with simulation of one or more expected events resulting from the detected event.

5. The apparatus as claimed in any one of the preceding claims, wherein the apparatus comprises at least one real sensor, and the apparatus is operable to:
receive input from the at least one real sensor; and
control behavior of the at least one real machine and the at least one virtual machine according to
input from the at least one real sensor, or
a combination of inputs from one or more of the at least one real machine, the at least one virtual machine and the at least one real sensor.

6. The apparatus as claimed in any one of the preceding claims, wherein the apparatus comprises an imaging sensor configured to capture images of one or more real objects that the at least one real machine is configured to handle,
wherein the apparatus is operable to:
generate data associated with simulation of one or more virtual objects that the at least one virtual machine is configured to handle based on the captured images.

7. The apparatus as claimed in any one of the preceding claims, wherein the at least one real machine comprises:
a real robot; and

a real conveyor mechanism for conveying one or more real objects that the real robot is configured to handle,

wherein the at least one virtual machine comprises:

one or more virtual robots configured to handle one or more virtual objects; and

a virtual conveyor mechanism for conveying the one or more virtual objects that the one or more virtual robots is configured to handle,

wherein the one or more virtual objects is a simulation of one or more of the one or more real objects that the real conveyor mechanism is configured to convey, and the virtual conveyor mechanism is a simulation of the real conveyor mechanism.

8. The apparatus as claimed in any one of the preceding claims, wherein the apparatus comprises:

one or more display devices configured to display a graphical simulation according to all data associated with simulation generated by the apparatus.

9. A method for simulating an expanded manufacturing line, wherein the method comprises:

generating data associated with simulation of operation of at least one virtual machine configured to work together with at least one real machine in an expanded manufacturing line;

receive input associated with operation of the at least one real machine;

receive input associated with operation of the at least one virtual machine;

control behavior of the at least one real machine and the at least one virtual machine according to the input received from the at least one real machine and/or the input received from the at least one virtual machine.