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### Flexible backplane for system operations

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#### Abstract

A backplane that includes a first processor slot, a second processor slot, a plurality of input/output (I/O) slots, a first I/O bus, a second I/O bus electrically isolated from the first I/O bus, and a plurality of I/O connection ports. The first processor slot includes a first processor connection port having a plurality of pins electrically connected to a first processor bus. The second processor slot includes a second processor connection port having a plurality of pins connected to a second processor bus, that is electrically isolated from the first processor bus. The plurality of I/O connection ports each include a first set of pins electrically connected to the first I/O bus, and a second set of pins electrically connected to the second I/O bus. Each of the first processor slot, the second processor slot, and the plurality of I/O slots include at least one of the I/O connection ports.

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Background/Summary

BACKGROUND

(1) Industrial systems are specialized electronic computer systems used for the control of and protection of industrial machines or processes, for example, in a factory environment. Various hardware modules that perform control and safety operations for industrial systems are generally coupled together through an electronic backplane. A backplane includes the communication and power buses that tie all the modules together. The backplane allows different types of hardware

modules to be combined to suit a specific industrial application. For instance, hardware modules include central processing unit (CPU) modules, input/output (I/O) modules, power supplies, memory modules, etc.

(2) Typically, industrial applications that require a control system and safety supervision, segregate the control and safety systems using two individually dedicated backplanes physically separated from one another. Segregation between the control and safety systems is desired to ensure the integrity of the safety system. Other methods include backplanes which designate specific module connection slots to control modules and others to safety modules to maintain separation between safety systems and operational control systems. However, such designs limit the modularity and flexibility of permitted control and safety system design.

#### SUMMARY

(3) This specification describes an industrial system, e.g., an industrial control and/or safety system, that has a backplane having multiple slots. Each slot has one or more connectors for removably receiving one or more modules. Each of at least some of the connectors has two sets of pins, one coupled to a first communication bus and the other coupled to a second communication bus.

(4) In general, innovative aspects of the subject matter described in this specification can be embodied in an electronic backplane. The backplane includes a first processor slot, a second processor slot, a plurality of input/output (I/O) slots, a first I/O bus, a second I/O bus electrically isolated from the first I/O bus, and a plurality of I/O connection ports. The first processor slot includes a first processor connection port having a plurality of pins electrically connected to a first processor bus. The second processor slot includes a second processor connection port having a plurality of pins connected to a second processor bus, that is electrically isolated from the first processor bus. The plurality of I/O connection ports each include a first set of pins electrically connected to the first I/O bus, and a second set of pins electrically connected to the second I/O bus. Each of the first processor slot, the second processor slot, and the plurality of I/O slots include at least one of the I/O connection ports. This and other implementations can each optionally include one or more of the following features.

(5) Some implementations include a third processor slot including a third processor connection port having a plurality of pins electrically connected to the first processor bus enabling communication with a processor module connected to the first processor connection port of the first processor slot, and a fourth processor slot including a fourth processor connection port having a plurality of pins electrically connected to the second processor bus enabling communication with a processor module connected to the second processor connection port of the second processor slot.

(6) Some implementations include a power supply slot including a power connection port having at least two pins electrically connected to a power bus, and at least one of the I/O connection ports. In some implementations, the power supply slot comprises at least two of the I/O connection ports.

(7) In some implementations the plurality of I/O connection ports are aligned in a row along a bottom of the electronic backplane, and the first processor connection port and the second processor connection port are aligned in a row above a respective I/O connection port in the first processor slot and in the second processor slot.

(8) Some implementations include a first I/O module installed in a first one of the I/O slots and electrically connected to the I/O connection port of the first one of the I/O slots, where the first I/O module is configured to send and receive data communications only through the first set of pins; and a second I/O module installed in a second one of the I/O slots and electrically connected to the I/O connection port of the second one of the I/O slots, where the second I/O module is configured to send and receive data communications only through the second set of pins. In some implementations, the first I/O module is a control I/O module and the second I/O module is a safety I/O module. In some implementations, the first I/O module includes a first I/O port connection interface that has a first set of interface pins that align with and couple to the first set of pins of the

I/O connection port of the first one of the I/O slots, and the second I/O module includes a second I/O port connection interface that has a second set of interface pins that align with and couple to the second set of pins of the I/O connection port of the second one of the I/O slots. In some implementations, the first I/O module includes a first I/O port connection interface that has a first set of interface pins that align with and couple to the first set of pins of the I/O connection port of the first one of the I/O slots, and a second set of interface pins that align with and couple to the second set of pins of the I/O connection port of the first one of the I/O slots, and the first I/O module is configured to disable data communications through the second set of interface pins. In some implementations, the first I/O module includes non-transitory computer readable memory comprising computer instructions that, when executed, disable data communications through the second set of interface pins.

(9) In some implementations, the first processor connection port includes a third set of pins and a fourth set of pins, where the third set of pins include the plurality of pins that are electrically connected to the first processor bus, and the fourth set of pins are electrically connected to the second processor bus.

(10) Another general aspect can be embodied in an industrial system that includes a machine and a control/safety system coupled to the machine and configured to operate the machine. The control/safety system includes a backplane. The backplane includes a first input/output (I/O) bus, a second I/O bus electrically isolated from the first I/O bus, a plurality of I/O connection ports, and a plurality of module slots. The a plurality of I/O connection ports each include a first set of pins electrically connected to the first I/O bus, and a second set of pins electrically connected to the second I/O bus. The plurality of module slots is each configured to receive a hardware module and each module slot comprising an I/O connection port. The backplane includes a control processor module installed in a first one of the module slots, a safety processor module installed in a second one of the module slots, a control I/O module installed in a third one of the module slots, and a safety I/O module installed in a fourth one of the module slots. The control processor module is configured to communicate control data with the control I/O module through the first I/O bus, and the safety processor module is configured to communicate safety data with the safety I/O module through the second I/O bus. This and other implementations can each optionally include one or more of the following features.

(11) In some implementations, the control I/O module includes a first I/O port connection interface that has a first set of interface pins that align with and couple to the first set of pins of the I/O connection port of the third one of the I/O slots, and the safety I/O module includes a second I/O port connection interface that has a second set of interface pins that align with and couple to the second set of pins of the I/O connection port of the fourth one of the I/O slots.

(12) In some implementations, the control I/O module includes an I/O port connection interface that has a first set of interface pins that align with and couple to the first set of pins of the I/O connection port of the third one of the I/O slots, and a second set of interface pins that align with and couple to the second set of pins of the I/O connection port of the third one of the I/O slots, where the control I/O module is configured to disable data communications through the second set of interface pins. In some implementations, the control I/O module includes non-transitory computer readable memory comprising computer instructions that, when executed, disable data communications through the second set of interface pins.

(13) In some implementations, the safety I/O module includes an I/O port connection interface that has a first set of interface pins that align with and couple to the first set of pins of the I/O connection port of the fourth one of the I/O slots, and a second set of interface pins that align with and couple to the second set of pins of the I/O connection port of the fourth one of the I/O slots, where the safety I/O module is configured to disable data communications through the first set of interface pins. In some implementations, the safety I/O module includes non-transitory computer readable memory comprising computer instructions that, when executed, disable data

communications through the first set of interface pins.

(14) Another general aspect can be embodied in an electronic backplane that includes a first input/output (I/O) bus, a second I/O bus electrically isolated from the first I/O bus, a plurality of I/O connection ports, a first processor slot, a second processor slot, a third processor slot, a fourth processor slot, a power supply slot, and a plurality of I/O slots. The first processor slot is configured to receive a first processor module and includes a first one of the I/O connection ports and a first processor connection port having a plurality of pins electrically connected to a first processor bus. The second processor slot is configured to receive a second processor module and includes a second one of the I/O connection ports and a second processor connection port having a plurality of pins connected to a second processor bus, that is electrically isolated from the first processor bus. The third processor slot is configured to receive a third processor module and includes a third one of the I/O connection ports and a third processor connection port having a plurality of pins electrically connected to the first processor bus enabling data communication through the first processor connection port of the first processor slot. The fourth processor slot is configured to receive a fourth processor module and includes a fourth one of the I/O connection ports and a fourth processor connection port having a plurality of pins electrically connected to the second processor bus enabling data communication through the second processor connection port of the second processor slot. The power supply slot is configured to receive a power supply and includes a power connection port having at least two pins electrically connected to a power bus and a fifth one of the I/O connection ports. The plurality of I/O slots are each configured to receive a hardware module and each I/O slot comprising at least one of the I/O connection ports. This and other implementations can each optionally include one or more of the following features.

(15) In some implementations, the power supply slot includes at least one of the I/O connection ports.

(16) In some implementations, the plurality of I/O connection ports are aligned in a row along a bottom of the electronic backplane, and the first processor connection port and the second processor connection port are aligned in a row above a respective I/O connection port in the first processor slot and in the second processor slot.

(17) Some implementations include a first I/O module installed in a first one of the I/O slots and electrically connected to the I/O connection port of the first one of the I/O slots, where the first I/O module is configured to send and receive data communications only through the first set of pins; and a second I/O module installed in a second one of the I/O slots and electrically connected to the I/O connection port of the second one of the I/O slots, where the second I/O module is configured to send and receive data communications only through the second set of pins.

(18) Particular embodiments of the subject matter described in this specification can be implemented so as to realize one or more of the following advantages. The industrial system described in this specification provides the configurability and customizability that fit any of a wide range of industrial control applications. The described industrial system allows for efficient creation of new industrial functions which were previously unavailable or nonexistent by having a backplane having flexible slots that can each receive modules with different functionalities. By utilizing both separate pins and separate communication buses, data communication between various modules is less likely to interfere with each other, thus the described industrial system achieves robust and reliable performance even with the flexible configuration.

(19) The details of one or more embodiments of the subject matter of this specification are set forth in the accompanying drawings and the description below. Other features, aspects, and advantages of the subject matter will become apparent from the description, the drawings, and the claims.

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## Description

## BRIEF DESCRIPTION OF THE DRAWINGS

- (1) FIG. 1 is an illustration of example components of an industrial system.
- (2) FIG. 2 is an illustration of an example backplane of an industrial system.
- (3) FIG. 3 is a simplified schematic diagram of a region of the backplane of the industrial system of FIG. 2.
- (4) FIG. 4A is a block diagram of the back side of an example central processing unit (CPU) module compatible with the example backplane of FIG. 2.
- (5) FIG. 4B is a block diagram of the back side of an example input/output (I/O) module compatible with the example backplane of FIG. 2.
- (6) FIG. 4C is a block diagram of the back side of another example input/output (I/O) module compatible with the example backplane of FIG. 2.
- (7) FIG. 5 is a simplified schematic diagram of a region of the backplane of the industrial system of FIG. 2 according to an alternate implementation.
- (8) Like reference numbers and designations in the various drawings indicate like elements.

## DETAILED DESCRIPTION

(9) FIG. 1 is an illustration of example components of an industrial system **110**. The industrial system **110** allows for control and/or monitoring of a machine/process **160**. The machine/process **160** may take many forms and include devices for accomplishing many different and varied purposes. For example, the machine/process **160** can include an industrial turbine, a manufacturing line or station, a material handling system, an assembly process, a compressor station, an oil refinery, a batch operation for making food items, or any mechanized and automated system. Accordingly, the machine/process **160** may include a variety of operational components, such as electric motors, motor drives and controllers, sensors and instrumentation, actuators, feedback devices, automation controllers, computers, and so on. The machine/process **160** will typically include control and safety monitoring equipment for regulating process variables through automation and/or monitoring. The control and safety monitoring systems are segregated from one another to ensure the dependability and integrity of the safety systems. For instance, in many applications control and safety monitoring systems each use separate CPUs, I/O modules and sensors, controllers, actuators, and memory to avoid cross-talk between systems. Each system has a distinct, and often, competing purpose. Control systems are generally designed to maintain a machine running, whereas a safety monitoring system is designed to shut the machine down in the event of a fault or an emergency. Furthermore, safety systems are often certified to international safety standards, whereas control systems often are configured, programed, and tailored to the user needs without agency approvals.

(10) For example, the machine/process **160** has actuators and sensors. The actuators include one or more devices, e.g., motors and associated drives, adapted to perform a mechanical action in response to a signal from the industrial system **110**. The sensors include one or more devices that provide information regarding the operation and/or conditions of the machine/process **160** to the motors and associated drives, such as for monitoring, open and closed-loop control, and so on. The actuators and sensors serve to allow automation of the machine/process **160** in accordance with programming, protocols, or other control or safety profiles implemented by the industrial system **110**.

(11) The sensors and actuators may be utilized within any number of predetermined process loops that are monitored and controlled by the industrial system **110** or any other control and/or safety monitoring equipment located locally with the industrial system **110** or remotely (e.g., enterprise systems, remote monitoring systems, etc.). Such process loops may be activated based on process inputs (e.g., input from one of the sensors) or direct operator input (e.g., input received via a human-machine interface associated with the industrial system **110**). An industrial environment may include more than one industrial system **110**, and these may operate independently or inter-

independently in accordance with the nature and operation of the machine/process **160**.

(12) To control and/or monitor the machine/process **160**, the industrial system **110** includes multiple hardware modules **130a-n** including, for example, control processor modules, safety processor modules, input/output modules, memory modules, controller modules, and power supply modules. The industrial system **110** provides a backplane **120** on which the multiple modules **130a-n** can be installed. The backplane **120** also provides communication between the multiple modules **130a-n**. Each module **130a-n** may have a single housing or, optionally, a combination of modules including a single housing. Each module **130a-n** module can include one or more computer processors, memory, communication interfaces, other electronic circuits, and computer software configured to perform various control or safety/monitoring operations; including interfacing with and performing data communication through the backplane **120**.

(13) In particular, the industrial system **110** has a flexible configuration, e.g., with additional modules added or existing modules removed and the industrial system **110** reconfigured to accommodate a new configuration. The industrial system **110** can include any number of control processors, safety processors, or input/output processors, up to a maximum possible number of modules **130a-n** that can be installed, that can be combined in any combination that fits the needs of the machine/process **160**.

(14) The control processor is configured to execute a control program to control normal operation of the machine/process **160**. For example, the control processor receives feedback signals through an I/O module from sensors on the controlled machine/process **160** corresponding to the present operating state and generates output signals with the control program to actuators and to the associated drives as a function of the feedback signals to achieve a desired operation of the controlled machine/process **160**.

(15) The safety processor can disable the operation of the controlled machine/process **160** upon detecting a fault or emergency situation. For example, the safety processor selectively controls safety trips for the motors and associated drives to allow normal operation or to place the motors and associated drives into a safe condition, thereby preventing operation of the machine/process **160**.

(16) Generally, the control processor or the safety processor may be implemented using general purpose or specialized independently functioning computing devices, e.g., microprocessors, which may have internal or external static or dynamic memory for storing variables and/or program instructions (e.g., software or firmware) that describe a desired control or safety profile of the machine/process **160**.

(17) The input/output processor provides an interface to the actuators and sensors. The input processor receives signals from sensors, switches, and other devices providing the operating status of the controlled machine/process **160**. The control processor executes a control program which receives the input signals from the input processor and generates control output signals in response to the operating status of the controlled machine/process **160**. The control output signals of the control processor are delivered from the output processor to actuators, indicators, and/or other devices to achieve a desired operation of the controlled machine/process **160**. In the meantime, the safety processor executes a safety profile which recognizes an input signal from the input processor as being indicative of a safety hazard and generates safety output signals. The safety output signals of the safety processor are delivered from the output processor to the actuators, indicators, and/or other devices to stop or interrupt the machine/process **160**, or put the machine/process **160** into a safe state.

(18) The industrial system **100** can include a programming terminal **150**. The programming terminal **150** typically includes a human machine interface (HMI), which provides an operator interface that allows the configuring, modifying, debugging and maintaining of the industrial system **110**. The programming terminal **150** may be a standard desktop or laptop computer and include a keyboard, display screen, and the like to permit the entry and display of data and the

operation of a control program by a human operator.

(19) Components of the industrial system **110** such as the programming terminal **150**, and the machine/process **160**, including its actuators and sensors, may be coupled to and/or in communication with a data network **170**. The data network **170** may be used to send and receive data. For example, data from the sensors is relayed to the industrial system **110**, and output signals (or other commands that change operational parameters of the actuators of the machine/process **160**) from the industrial system **110** are sent to the actuators via the data network **170**. In some implementations, the data network **170** is an industrial control network, such as one using Common Industrial Protocols (CIP), e.g., an EtherCAT, CAN bus, or Modbus network.

(20) FIG. 2 is an illustration of an example backplane **220** of an industrial system. The backplane **220** may serve as a base for each module. In this example, the backplane **220** has fifteen slots **230a-n** that are spaced apart along a horizontal direction, some slots (e.g., slots **230b**, **230c**, **230l**, **230m**, and **230n**) also extending along a vertical direction. The backplane **220** uses the slots **230a-n** for removably receiving one or more modules, e.g., modules **130a-n** of FIG. 1.

(21) Different modules may be installed on the backplane **220** in the same or different ways. In the example of FIG. 2, one or more power supply modules may be removably mounted or may be a fixed component and integrally mounted to the backplane **220**, while one or more control processors, one or more safety processors, or one or more input/output processors may be removably inserted into the backplane **220**.

(22) The backplane **220** includes three general types of connectors: processor connection ports (e.g., connectors **231**, **233**, **237**, **238**), I/O connection ports (e.g., connectors **232**, **234**, **235**, **236** along the bottom row of the backplane **220**), and power supply connection ports **250a**, **250b**.

(23) Processor connection ports provide a communication channel between processor modules connected to the backplane **220** through processors busses **243**, **244**. Each processor bus **243**, **244** is electrically isolated from each other and provides a dedicated communication path between specific subsets of processor modules. For example, the communications between safety processors are isolated from communications between control processors. As another example, two pairs of control processors for different machines can be connected to the same backplane **220** and communications can be isolated between the different pairs.

(24) I/O connection ports provide two alternate communication paths (I/O busses **241**, **242**). Each path can be used independently to communicate with a particular group of processor modules. Power supply connection ports connect to power supply modules and are used to distribute power to the backplane **220** and each hardware module connected to the backplane **220**.

(25) Each slot, e.g., slot **230b**, has one or more connectors, e.g., connectors **231** and **232**, that each occupy a respective space of the slot. Each slot can interface with a module via a corresponding connector on the module. In the example of FIG. 2, four out of the fourteen slots of the backplane **220** each have two connectors, these can be referred to as “processor slots” (e.g., processor slots **230b**, **230c**, **230l**, and **230m**). Processor slots include a processor connection port and an I/O connection port. Because at least one power supply needs to be connected to the backplane **220** to supply power, one power supply slot **230a** only includes a power supply connection port **250a**. However, additional I/O connection ports are added to secondary power supply connection slots, e.g., slot **230n**, to allow for expansion of additional I/O modules when additional power supplies are not needed. Each I/O slot, e.g., slot **230d**, includes an I/O connection port, e.g., connector **235**.

(26) Each connector has multiple pins arranged within the space of the slot occupied by the connector. These pins may be of a complementary configuration and/or mating type than the pins used on the physical base of the modules, such that the connectors can engage (electrically connect with) and establish communication with the modules. For example, each connector has a number of female pins, while the physical base of a module has male pins in the same number. In this example, the male pins used on the physical base of the modules may be shrouded pins.

(27) When the male pins used on the physical base of a module are in contact with, e.g., releasably



inserted into, the female pins of a connector supported on the backplane **220**, the module is electrically connected and communicatively coupled to the backplane **220** via the connector. It will be appreciated that the connector may be an electrical connector, optical connector, or any suitable connector to establish communication between the backplane **220** and the modules.

(28) In particular, some of the connectors, e.g., all of the I/O connectors (e.g., connectors **232**, **234**, **235**, **236**, and the remaining bottom row connectors), include two sets of pins. The two sets of pins are separate (electrically isolated) from each other. In other words, the two sets of pins have no pins in common, where a first set of pins supports a first communication channel between a hardware module and the backplane **220**, and a second set of pins supports a second communication channel between a hardware module and the backplane **220**.

(29) Multiple dedicated communication buses **241**, **242**, **243**, and **244** are provided in the backplane **220** between the connectors. Data is transmitted via these communication buses between the modules that are electrically connected and communicatively coupled to the backplane **220** via the connectors. The backplane **220** is configured to accommodate high-speed and reliable data communications between the modules. In some implementations, because each bus is a dedicated bus configured to communicate between known modules, communication can occur in a predefined format, such as a proprietary communication protocol or utilizing a predefined communication schedule that requires little or no data overhead, such as headers, footers, checksums, and the like. However, each module must utilize the same protocol and be configured to communicate according to the predefined format on the backplane **220**.

(30) In particular, the backplane **220** includes two separate communication buses respectively coupled to the two sets of pins included in each of some of the connectors. In other words, for each of the I/O connectors, the backplane **220** includes one communication bus **241**, coupled to the first set of pins of the connector, and another communication bus **242**, coupled to the second set of pins of the connector, where the two communication buses are physically separated and electrically isolated from each other.

(31) In the example of FIG. 2, the backplane **220** includes two power supply slots **230a** and **230n**, two control processor slots **230b** and **230m**, two safety processor slots **230c** and **230l**, and eight I/O slots **230d-k**. Power supply slot **230a** has one power supply connection port **250a** for interfacing with a power supply module. Power supply slot **230n** has one power supply connection port **250b** for interfacing with a power supply module, and two I/O connection ports. Control processor slots **230b** and **230m** each have one processor connection port (e.g., connector **231** in slot **230b**) and one I/O connection port (e.g., connector **232** in slot **230b**). Safety processor slots **230c** and **230l** each have one processor connection port (e.g., connector **233** in slot **230c**) and one I/O connection port (e.g., connector **234** in slot **230c**). I/O slots **230d-k** each have one I/O connection port (e.g., connector **235** in slot **230d**) for interfacing with an I/O hardware module. It will be appreciated that in other examples, the backplane **220** can also be configured to support more or less slots, each having more or less connectors.

(32) FIG. 3 shows a simplified electrical schematic diagram of the backplane **220**. FIG. 3 shows the bus architecture of the backplane **220** in more detail. For simplicity, FIG. 3 only shows the left-hand side of the backplane **220** including hardware slots **230b-230e**. The description below is generally applicable to corresponding parts along the full backplane **220**. For example, the backplane **220** can have four data communication busses **241**, **242**, **243**, and **244**. Busses **241** and **242** are I/O busses, and busses **243** and **244** are processor busses. The bus architecture provides flexibility by permitting two separate systems to be mounted on the backplane **220** and electrical isolated from one another while not strictly limiting particular slots for use with any one system. For example, the backplane **220** can be used to simultaneously for a machinery control system and a machinery safety system for the same machine. Alternatively, the backplane **220** can be used for two separate control systems for two separate machines.

(33) In FIG. 3, each I/O bus **241**, **242** connects with a different set of pins on each of the I/O

connection ports (e.g., connectors **232**, **234**, **235**, and **236**). Each connector **232**, **234**, **235**, and **236** has a first set of pins **302a** and a second set of pins **302b** that are separate from each other and electrically isolated from each other. Within each connector **232**, **234**, **235**, and **236**, the first and second sets of pins **302a**, **302b** are located respectively at the upper and lower halves of the connector. In other implementations, the sets of pins can be located on either side of the connector, for example.

(34) The I/O bus **241** is coupled to the first sets of pins **302a** of the connectors **232**, **234**, **235**, and **236**. The I/O bus **242** is coupled to the second sets of pins **302b** of the connectors **232**, **234**, **235**, and **236**. I/O bus **241** is physically separated and electrically isolated from I/O bus **242**. For example, I/O bus **241** provides a data communication channel between I/O modules and processor modules connected to the first set of I/O communication port pins **302a** in each slot. Similarly, I/O bus **242** provides a data communication channel between I/O modules and processor modules connected to the second set of I/O communication port pins **302b** in each slot.

(35) For example, a control I/O module, which is coupled to the backplane **220** in slot **230d** and connected to the first set of pins **302a** can communicate with a control processor module in slot **230b** through I/O bus **241**. A safety I/O module, which is coupled to the backplane **220** in slot **230e** and connected to the second set of pins **302b** can communicate with a safety processor module in slot **230c** through I/O bus **242**.

(36) In the example implementation shown in FIGS. **2** and **3**, each processor bus **243**, **244** connects separate processor connection ports to allow data communication between multiple processor modules related to the same system or type of system (e.g., between two control processor modules and between two safety processor modules), but maintains data isolation between processor modules that are not related to the same system or type of system. Processor bus **243** provides a data communication channel between processor connection ports in slots **230b** (connector **231**) and in slot **230m** (connector **238**). Processor bus **244** provides a data communication channel between processor connection ports in slots **230c** (connector **233**) and in slot **230l** (connector **237**). For example, two safety processor modules may be connected to the same backplane **220** to provide redundancy and data sharing between the two may be required to carry out that function. But there should be no cross-talk between the safety processor modules and a control processor module connected to the same backplane **220**. The processor bus architecture of the backplane **220** allows for two or more sets of processor modules to be connected to the backplane **220** with communication enabled between processor modules in the same set but communications isolated between different sets.

(37) FIG. **4A** is a block diagram of the back side of an example central processing unit (CPU) module compatible with the example backplane of FIG. **2**. A processor module **400** includes two connection ports; an I/O connection port **402** and a processor connection port **404**. The I/O connection port **402** is configured to interface with the I/O connection ports on the backplane **220** (e.g., connectors **232**, **234**). The processor connection port **404** is configured to interface with any of the processor connection ports on the backplane **220** (e.g., connectors **231**, **233**, **237**, **238**). I/O connection port **402** is divided into two sets of pins: set **404a** and **404b**. In some implementations, during operation the processor module only communicates with other hardware modules using one set of pins on the I/O connection port **402**. Thus, the processor module can isolate its communications on only one of the I/O busses on the backplane. In some implementations, the processor module **400** is configured to permit a user to select which set of I/O pins to use for output. For example, the processor module **400** can include a hardware switch that selects between pin sets **404a** and **404b**. One set is effectively turned off or disabled while the other is turned on or enabled to prevent cross-talk with hardware modules used for a different system (e.g., a safety system) on the same backplane **220**. In other examples, the processor module can include software or firmware settings that allow a user to enable communications on one set of pins and disable communications on the other.

(38) FIG. 4B is a block diagram of the back side of an example input/output (I/O) module compatible with the example backplane of FIG. 2. An I/O module **420** includes an I/O connection port **422** that is configured to interface with the I/O connection ports on the backplane **220** (e.g., connectors **232**, **234**, **235**, **236**, etc.). An I/O module **420** can be installed and operate in any one of slots **230b-230n** of the backplane **220**. The I/O connection port **422** is divided into two sets of pins: set **424a** and **424b**. During operation the I/O module **420** only communicates with other hardware modules using one set of pins on the I/O connection port **422**. Thus, the I/O module **420** can isolate its communications on only one of the I/O busses on the backplane. In some implementations, the I/O module **420** is configured to permit a user to select which set of I/O pins to use for output. For example, the I/O module **420** can include a hardware switch that selects between pin sets **424a** and **424b**. One set is effectively turned off or disabled while the other is turned on or enabled to prevent cross-talk with hardware modules used for a different system (e.g., a safety system) on the same backplane **220**. In other examples, the I/O module **420** can include software or firmware settings that allow a user to enable communications on one set of pins and disable communications on the other. In some implementations, the I/O connection port can be configured with only one set of pins. For example, an I/O module can be dedicated to communication on only one of the backplane's I/O busses. FIG. 4C is a block diagram of the back side of another example input/output (I/O) module **440** with only one set of pins, e.g., set **444a** in an I/O connection port **442**. For example, in some cases all hardware modules designed for use with control systems can be configured with only one set of I/O port pins, e.g., set **444a**. In the same example, all hardware modules designed for use with safety systems can be configured with only the second set of pins **444b**. Thus, one of the backplanes I/O busses can be configured as a dedicated control bus and the other can be configured as a dedicated safety bus.

(39) For example, with reference to FIGS. 2-4, backplane **220** can include a power supply module installed in slot **230a**, control processors modules installed in slots **230b** and **230m**, safety system processors installed in slots **230c** and **230l**, control I/O modules installed in slots **230d** through **230i**, and safety system I/O modules installed in slots **230j**, **230k**, and **230n**. The control processors can communicate with each other, and independent from the safety system processors, through processor bus **243** connected through connectors **231** and **238**. Similarly, the safety system processors can communicate with each other, and independent from the control processors, through processor bus **244** connected through connectors **233** and **237**. Furthermore, the control processors can be configured to communicate on their respective first set of I/O pins (e.g., pin set **404a**). Therefore, the control processors can communicate with each respective control I/O module using the backplanes I/O bus **241** as a dedicated control I/O channel. Each respective control I/O module would also be configured to enable its respective first set of I/O pins (e.g., pin set **424a**). Similarly, the safety system processors can be configured to communicate on their respective second set of I/O pins (e.g., pin set **404b**). Therefore, the safety system processors can communicate with each respective safety I/O module using the backplanes I/O bus **242** as a dedicated safety I/O channel. Each respective safety system I/O module would also be configured to enable its respective second set of I/O pins (e.g., pin set **424b**). In another example, independent control systems for two different machines can be installed on the same backplane **220** in a manner similar to that described above, with the second control system taking the place of the safety system.

(40) As mentioned above, the industrial system has a flexible configuration, meaning that it has the flexibility for adding, removing and/or modifying the installed modules. Thus, in other implementations, it may be desirable to add a control processor, a safety processor, or an input/output processor, thereby increasing the capability or capacity of the industrial system. Similarly, it may be desirable to modify or remove an existing control processor, an existing safety processor, or an existing input/output processor due to changes in requirements in the industrial system, such as a controlled process or machine that has become obsolete. Moreover, the industrial system may be configured to use redundant modules to achieve a desired safety rating or a desired

operational reliability. For example, the industrial system may include two control processors, two safety processors, two input/output processors, and two pairs of communication busses between each of the modules.

(41) In these other implementations, various numbers of modules can be received by any of the unused connectors at any of the slots **230b-n** of FIG. 2. For example, the connectors located at the input/output slots **230d-230k** and the connectors located at the power supply slot **230n** can each receive any type of input/output processor that is suitable according to the requirements of the controlled machine/process. The input/output processors may be analog or digital input/output processors, and the input/output processors may include only inputs, only outputs, or a combination thereof. The input/output processors may be configured to receive or supply DC voltage or AC voltage. In fact, some of the connectors can receive different types of modules. For example, the top connectors at the control processor slots **230b** and **230m** can each receive either a control processor, or a safety processor.

(42) FIG. 5 shows a simplified electrical schematic diagram of the backplane **220** according to an alternate embodiment **500**. For simplicity, FIG. 5 only shows the left-hand side of the backplane **500** including hardware slots **230b-230e**. The description below is generally applicable to corresponding parts along the full backplane **500**. The bus architecture of the backplane **500** is similar to that of backplane **220** shown in FIG. 3, except that the processor connectors **531**, **533** (corresponding with connectors **231**, **233**) are each divided into two sets of pins, (**237**, **238** which are not shown would likewise be divided into two sets of pins). Connector **531** is divided into pin sets **531a** and **531b**, and connector **533** is divided into pin set **533a** and **533b**. Furthermore, the processors busses **543** and **544** are extended to connect two both connectors **531** and **533**. However, to maintain electrical isolation between processors each pin set is connected to a different processor bus. For instance, the upper pin sets **531a** and **533a** are connected to bus **543**, while the lower pin sets **531b** and **533b** are connected to bus **544**. The same configuration would be reflected on the right side of the backplane **500**, as connectors **237** and **238** would be similarly modified.

(43) As used herein, the terms “perpendicular,” “substantially perpendicular,” or “approximately perpendicular” refer to an orientation of two elements (e.g., lines, axes, planes, surfaces, walls, or components) with respect to one and other that forms a ninety degree (perpendicular) angle within acceptable engineering, machining, or measurement tolerances. For example, two surfaces can be considered orthogonal to each other if the angle between the surfaces is within an acceptable tolerance of ninety degrees (e.g.,  $\pm 1-5$  degrees).

(44) As used herein, the terms “aligned,” “substantially aligned,” “parallel,” or “substantially parallel” refer to a relation between two elements (e.g., lines, axes, planes, surfaces, or components) as being oriented generally along the same direction within acceptable engineering, machining, drawing measurement, or part size tolerances such that the elements do not intersect or intersect at a minimal angle. For example, two surfaces can be considered aligned with each other if surfaces extend along the same general direction of a device.

(45) It should be noted that the orientation of various elements may differ according to other exemplary embodiments, and that such variations are intended to be encompassed by the present disclosure.

(46) Some of the features or components described can be implemented in digital electronic circuitry, or in computer hardware, firmware, software, or in combinations of them (e.g., the hardware modules **130a-130n**). The apparatus can be implemented in a computer program product tangibly embodied in an information carrier, e.g., in a machine-readable storage device for execution by a programmable processor; and method steps can be performed by a programmable processor executing a program of instructions to perform functions of the described implementations by operating on input data and generating output. The described features can be implemented advantageously in one or more computer programs that are executable on a programmable system including at least one programmable processor coupled to receive data and

instructions from, and to transmit data and instructions to, a data storage system, at least one input device, and at least one output device. A computer program is a set of instructions that can be used, directly or indirectly, in a computer to perform a certain activity or bring about a certain result. A computer program can be written in any form of programming language, including compiled or interpreted languages, and it can be deployed in any form, including as a stand-alone program or as a module, component, subroutine, or other unit suitable for use in a computing environment.

(47) Suitable processors for the execution of a program of instructions include, by way of example, both general and special purpose microprocessors, and the sole processor or one of multiple processors of any kind of computer. Generally, a processor will receive instructions and data from a read-only memory or a random-access memory or both. The essential elements of a computer are a processor for executing instructions and one or more memories for storing instructions and data. Generally, a computer will also include, or be operatively coupled to communicate with, one or more mass storage devices for storing data files; such devices include magnetic disks, such as internal hard disks and removable disks; magneto-optical disks; and optical disks. Storage devices suitable for tangibly embodying computer program instructions and data include all forms of non-volatile memory, including by way of example semiconductor memory devices, such as EPROM, EEPROM, and flash memory devices; magnetic disks such as internal hard disks and removable disks; magneto-optical disks; and CD-ROM and DVD-ROM disks. The processor and the memory can be supplemented by, or incorporated in, ASICs (application-specific integrated circuits).

(48) While a number of examples have been described for illustration purposes, the foregoing description is not intended to limit the scope of the invention, which is defined by the scope of the appended claims. There are and will be other examples and modifications within the scope of the following claims. Although only a few embodiments of the present inventions have been described in detail in this disclosure, those skilled in the art who review this disclosure will readily appreciate that many modifications are possible (e.g., variations in sizes, dimensions, structures, shapes and proportions of the various elements, values of parameters, mounting arrangements, use of materials, colors, orientations, etc.) without materially departing from the description and advantages of the subject matter disclosed herein. For example, elements shown as integrally formed may be constructed of multiple parts or elements, the position of elements may be reversed or otherwise varied, and the nature or number of discrete elements or positions may be altered or varied. Accordingly, all such modifications are intended to be included within the scope of the present invention as defined in the appended claims. Other substitutions, modifications, changes and omissions may be made in the design, operating conditions and arrangement of the various exemplary embodiments without departing from the scope of the present inventions.

## Claims

1. An electronic backplane comprising: a first processor slot comprising a first processor connection port having a plurality of pins electrically connected to a first processor bus; a second processor slot comprising a second processor connection port having a plurality of pins connected to a second processor bus, that is electrically isolated from the first processor bus; a plurality of input/output (I/O) slots; a first I/O bus; a second I/O bus electrically isolated from the first I/O bus; and a plurality of I/O connection ports each comprising a first set of pins electrically connected to the first I/O bus, and a second set of pins electrically connected to the second I/O bus, and wherein; the plurality of I/O connection ports are aligned in a first row along the electronic backplane; the first processor connection port and the second processor connection port are aligned in a second row; and each of the first processor slot, the second processor slot, and the plurality of I/O slots comprise at least one of the I/O connection ports.

2. The electronic backplane of claim 1 comprising: a third processor slot comprising a third processor connection port having a plurality of pins electrically connected to the first processor bus

enabling communication with a processor module connected to the first processor connection port of the first processor slot; and a fourth processor slot comprising a fourth processor connection port having a plurality of pins electrically connected to the second processor bus enabling communication with a processor module connected to the second processor connection port of the second processor slot.

3. The electronic backplane of claim 1 comprising a power supply slot comprising a power connection port having at least two pins electrically connected to a power bus, and at least one of the I/O connection ports.

4. The electronic backplane of claim 3, wherein the power supply slot comprises at least two of the I/O connection ports.

5. The electronic backplane of claim 1 comprising: a first I/O module installed in a first one of the I/O slots and electrically connected to the I/O connection port of the first one of the I/O slots, the first I/O module configured to send and receive data communications only through the first set of pins; and a second I/O module installed in a second one of the I/O slots and electrically connected to the I/O connection port of the second one of the I/O slots, the second I/O module configured to send and receive data communications only through the second set of pins.

6. The electronic backplane of claim 5 wherein the first I/O module is a control I/O module and the second I/O module is a safety I/O module.

7. The electronic backplane of claim 5, wherein the first I/O module comprises a first I/O port connection interface that has a first set of interface pins that align with and couple to the first set of pins of the I/O connection port of the first one of the I/O slots, and wherein the second I/O module comprises a second I/O port connection interface that has a second set of interface pins that align with and couple to the second set of pins of the I/O connection port of the second one of the I/O slots.

8. The electronic backplane of claim 5, wherein the first I/O module comprises a first I/O port connection interface that has a first set of interface pins that align with and couple to the first set of pins of the I/O connection port of the first one of the I/O slots, and a second set of interface pins that align with and couple to the second set of pins of the I/O connection port of the first one of the I/O slots, and wherein the first I/O module is configured to disable data communications through the second set of interface pins.

9. The electronic backplane of claim 8, wherein the first I/O module comprises non-transitory computer readable memory comprising computer instructions that, when executed, disable data communications through the second set of interface pins.

10. The electronic backplane of claim 1, wherein the first processor connection port comprises a third set of pins and a fourth set of pins, wherein the third set of pins comprises the plurality of pins that are electrically connected to the first processor bus, and wherein the fourth set of pins are electrically connected to the second processor bus.

11. The electronic backplane of claim 1, wherein, during operation of the electronic backplane, only one of the first set of pins or the second set of pins of an I/O connection port is enabled for data communications.

12. An industrial system comprising: a machine; and a control and safety system coupled to the machine and configured to operate the machine, the control and safety system comprising: an electronic backplane comprising: a first input/output (I/O) bus, a second I/O bus electrically isolated from the first I/O bus, a plurality of I/O connection ports each comprising a first set of pins electrically connected to the first I/O bus, and a second set of pins electrically connected to the second I/O bus, wherein, during operation of the industrial system, only one of the first set of pins or the second set of pins of an I/O connection port is enabled for data communications; a plurality of module slots each configured to receive a hardware module and each module slot comprising an I/O connection port, a control processor module installed in a first one of the module slots, a safety processor module installed in a second one of the module slots, a control I/O module installed in a

third one of the module slots, and a safety I/O module installed in a fourth one of the module slots, wherein the control processor module is configured to communicate control data with the control I/O module through the first I/O bus, and wherein the safety processor module is configured to communicate safety data with the safety I/O module through the second I/O bus.

13. The industrial system of claim 12, wherein the control I/O module comprises a first I/O port connection interface that has a first set of interface pins that align with and couple to the first set of pins of the I/O connection port of the third one of the I/O slots, and wherein the safety I/O module comprises a second I/O port connection interface that has a second set of interface pins that align with and couple to the second set of pins of the I/O connection port of the fourth one of the I/O slots.

14. The industrial system of claim 12, wherein the control I/O module comprises an I/O port connection interface that has a first set of interface pins that align with and couple to the first set of pins of the I/O connection port of the third one of the I/O slots, and a second set of interface pins that align with and couple to the second set of pins of the I/O connection port of the third one of the I/O slots, and wherein the control I/O module is configured to disable data communications through the second set of interface pins.

15. The industrial system of claim 14, wherein the control I/O module comprises non-transitory computer readable memory comprising computer instructions that, when executed, disable data communications through the second set of interface pins.

16. The industrial system of claim 12, wherein the safety I/O module comprises an I/O port connection interface that has a first set of interface pins that align with and couple to the first set of pins of the I/O connection port of the fourth one of the I/O slots, and a second set of interface pins that align with and couple to the second set of pins of the I/O connection port of the fourth one of the I/O slots, and wherein the safety I/O module is configured to disable data communications through the first set of interface pins.

17. The industrial system of claim 16, wherein the safety I/O module comprises non-transitory computer readable memory comprising computer instructions that, when executed, disable data communications through the first set of interface pins.

18. The industrial system of claim 12, wherein the plurality of I/O connection ports are aligned in a row along a bottom of the electronic backplane.

19. An electronic backplane comprising: a first input/output (I/O) bus; a second I/O bus electrically isolated from the first I/O bus; a plurality of I/O connection ports each comprising a first set of pins electrically connected to the first I/O bus, and a second set of pins electrically connected to the second I/O bus, wherein the plurality of I/O connection ports are aligned in a first row along the electronic backplane; a first processor slot configured to receive a first processor module and comprising a first one of the I/O connection ports and a first processor connection port having a plurality of pins electrically connected to a first processor bus; a second processor slot configured to receive a second processor module and comprising a second one of the I/O connection ports and a second processor connection port having a plurality of pins connected to a second processor bus, that is electrically isolated from the first processor bus, wherein the first processor connection port and the second processor connection port are aligned in a second row; a third processor slot configured to receive a third processor module and comprising a third one of the I/O connection ports and a third processor connection port having a plurality of pins electrically connected to the first processor bus enabling data communication through the first processor connection port of the first processor slot; a fourth processor slot configured to receive a fourth processor module and comprising a fourth one of the I/O connection ports and a fourth processor connection port having a plurality of pins electrically connected to the second processor bus enabling data communication through the second processor connection port of the second processor slot; a power supply slot configured to receive a power supply and comprising a power connection port having at least two pins electrically connected to a power bus and a fifth one of the I/O connection ports; and a

plurality of I/O slots each configured to receive a hardware module and each I/O slot comprising at least one of the I/O connection ports.

20. The electronic backplane of claim 19 comprising: a first I/O module installed in a first one of the I/O slots and electrically connected to the I/O connection port of the first one of the I/O slots, the first I/O module configured to send and receive data communications only through the first set of pins; and a second I/O module installed in a second one of the I/O slots and electrically connected to the I/O connection port of the second one of the I/O slots, the second I/O module configured to send and receive data communications only through the second set of pins.

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