

AIRCRAFT COCKPIT TRAINING SIMULATOR AND ASSOCIATED METHOD

Priority Application

[0001] This PCT application is based upon U.S. patent application Serial No. 17/448,212 filed September 21, 2021, the disclosure which is hereby incorporated by reference in its entirety.

Field of the Invention

[0002] The present invention relates to the field of training systems, and, more particularly, to an aircraft cockpit training simulator and related method.

Background of the Invention

[0003] In many aircraft cockpit training simulators, the input/output (I/O) subsystem provides a functional Human Machine Interface (HMI), for example, an aircraft cockpit simulation panel having a display, instrument, or other machine interface. The panel bridges the software simulation with a student's physical capabilities such as touch or sight.

[0004] The accuracy of these simulators to real-life aircraft training varies greatly across training programs, from the use of real Avionics equipment to high fidelity simulated instruments and reconfigurable spatially, but inaccurate panels. A common goal with aircraft simulators is the requirement to interpret a student's physical input, or stimulate a student's senses.

[0005] Conventional aircraft cockpit training simulators are typically centralized and include a complex backbone of I/O equipment, power conversion and lighting control electronics. The centralized I/O simulator design requires densely populated distribution interfaces, custom wire harnesses, and in many cases, a large footprint of space. Additionally, the interface software for conventional training simulators is often proprietary and non-standardized. Small form factor versions of centralized simulators

are gaining popularity, but those centralized simulators are not typically modular and do not support edge computing, e.g., processing data nearest the location that sources or uses the data at a panel. These centralized aircraft simulators also typically include proprietary or custom Application Programming Interfaces (APIs), which may not conform to a single standard.

[0006] Most conventional training simulators are host-driven, where the simulator's host processor runs a loop containing a large state machine that reads and writes individual bits to drive the various components in an aircraft cockpit simulator panels. That type of simulator has disadvantages. For example, the host computer may require specialized add-in interface cards, increasing complexity, and driver issues. Conventional simulators may also have a high interface wiring density, which increases material and assembly costs and requires a lengthy integration time. The cockpit panels are usually not testable until final assembly, when the interface equipment and connecting wires are in place. There is little modularity and standardization, and since the software code controlling the individual panels is tightly integrated with the host computer, it is vendor-specific and usually highly proprietary. This vendor specificity places constraints on update and replacement options, potentially driving up life-cycle costs significantly.

Summary of the Invention

[0007] In general, an aircraft cockpit training simulator may include a plurality of aircraft cockpit simulation panels and power over Ethernet (POE) cabling extending therebetween. Each aircraft cockpit simulation panel may comprise at least one simulator user interface device, at least one of an input circuit and an output circuit coupled to the at least one simulator user interface device, a POE interface circuit, and a distributed controller coupled to the at least one of an input circuit and an output circuit and POE interface device configured to asynchronously communicate with other controllers using a publish/subscribe protocol. A host controller may be coupled to the plurality of distributed controllers via the POE cabling and configured to operate the plurality of aircraft cockpit simulation panels in accordance with a host computer model.

The plurality of distributed controllers may also be capable of operating independent of the host computer model.

[0008] Each distributed controller may be configured to send a plurality of status messages asynchronously with respect to other distributed controllers. The at least one simulator user interface device may comprise at least one lighting device. The at least one simulator user interface device may comprise at least one power consuming device. The at least one simulator user interface device may comprise at least one of a switch, a lamp, a potentiometer, a joystick, and a display.

[0009] The at least one of an input circuit and an output circuit may comprise at least one analog input circuit, and in an example, may comprise at least one analog output circuit. The at least one of an input circuit and an output circuit may comprise at least one digital input circuit, and in yet another example, may comprise at least one digital output circuit.

[0010] Each panel may comprise at least one connector, and wherein the at least one of an input circuit and an output circuit, the POE interface circuit, and the distributed controller are in a form of a line replaceable unit (LRU) coupled to the at least one connector.

[0011] Another aspect is directed to a method of making an aircraft cockpit training simulator that may comprise coupling power over Ethernet (POE) cabling among a plurality of aircraft cockpit simulation panels, each aircraft cockpit simulation panel comprising at least one simulator user interface device, at least one of an input circuit and an output circuit coupled to the at least one simulator user interface device, a POE interface circuit, and a distributed controller coupled to the at least one of an input circuit and an output circuit and POE interface device configured to asynchronously communicate with other controllers using a publish/subscribe protocol. The method may also include coupling a host controller to the plurality of distributed controllers via the POE cabling and configured to operate the plurality of aircraft cockpit simulation panels in accordance with a host computer model, and wherein the plurality of distributed controllers are also capable of operating independent of the host computer model.

Brief Description of the Drawings

[0012] Other objects, features and advantages of the present invention will become apparent from the detailed description of the invention which follows, when considered in light of the accompanying drawings in which:

[0013] FIG. 1 is a block diagram of the aircraft cockpit training simulator according to the invention.

[0014] FIG. 2A is a timing diagram for data published by a distributed controller of an aircraft cockpit simulation panel incorporated in the aircraft cockpit training simulator shown in FIG. 1.

[0015] FIG. 2B is a timing diagram similar to that shown in FIG. 2A, but for data subscribing by a distributed controller.

[0016] FIG. 3 is a high-level flowchart of a method for making the aircraft cockpit training simulator of FIG. 1.

Detailed Description

[0017] The present description is made with reference to the accompanying drawings, in which exemplary embodiments are shown. However, many different embodiments may be used, and thus, the description should not be construed as limited to the particular embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete. Like numbers refer to like elements throughout.

[0018] Referring initially to FIG. 1, an aircraft cockpit training simulator is illustrated generally at **20** and includes a plurality of aircraft cockpit simulation panels **24** illustrated as No. 1 and continuing to No. "n" and "n+1" to represent that there may be numerous aircraft cockpit simulation panels connected to power over Ethernet (POE) cabling **28** that may be a POE Ethernet switch with normal Ethernet cabling and extending between each of the aircraft cockpit training simulation panels. As represented by the aircraft cockpit training simulation panel No. (n+1) **24**, each aircraft cockpit simulation panel includes at least one simulator user interface device **32** and at least one connector **36** coupled thereto. A line replaceable unit (LRU) **38** is at the

aircraft cockpit simulation panel **24** and is coupled to the at least one connector **36** and includes at least one of an input circuit **40** and an output circuit **42** coupled to the at least one simulator user interface device **32**.

[0019] The line replaceable unit **38** includes a POE interface circuit **46** that connects to the POE cabling **28**. A distributed controller **50** is coupled to the at least one of an input circuit **40** and an output circuit **42** and the POE interface circuit **46** and configured to asynchronously communicate with other distributed controllers using a publish/subscribe protocol, such as a Data Distribution Service (DDS) protocol. A host controller **54** is coupled to the plurality of distributed controllers **50** via the POE cabling **28** and configured to operate the plurality of aircraft cockpit simulation panels **24** in accordance with a host computer model. However, each of the distributed controllers **50** is also capable of operating independent of the host computer model operated by the host controller **54**. Each distributed controller **50** is configured to send a plurality of status messages asynchronously with respect to other distributed controllers. Status messages may be used to identify individual panels **24** and provide generic information about the panel to use for troubleshooting.

[0020] The simulator user interface device **32** may include at least one lighting device, at least one power consuming device, and at least one of a switch, a lamp, a potentiometer, a joystick, and a display. The output circuit **42** may include an analog output circuit and/or a digital output circuit, and the input circuit **40** may include an analog input circuit and/or a digital input circuit.

[0021] Each aircraft cockpit simulation panel **24** has its input and output functions controlled via the distributed controller **50**. The LRU **38** may be formed as an input/output circuit card assembly operating in accordance with IEEE.802 standards with data transmissions at up to 1,000 megabits per second to other aircraft cockpit simulation panels **24** connected to the POE cabling **28**. Each line replaceable unit **38**, and thus, each aircraft cockpit simulation panel **24** to which the line replaceable unit is incorporated includes a dynamic network address. Each aircraft cockpit simulation panel **24** is therefore connected by a single Ethernet POE cable **28**, which obtains power from POE and generates the voltage levels required for the different components

at each aircraft cockpit simulation panel such as lighting, displays, and analog signal devices.

[0022] In the aircraft cockpit training simulator **20** as described, there is no signal distribution wiring, card rack, back plane, power supply racks, or lighting control equipment, and instead, each line replaceable unit **38** as part of a respective aircraft cockpit simulation panel **24** may be formed as a circuit card assembly directly connected to a specific distributed aircraft cockpit simulation panel. Different simulator user interface devices **32** may include switches, lamps, potentiometers, joysticks, displays, analog drives, and similar devices that are used in the aircraft cockpit training simulator **20**. Each line replaceable unit **38** contains software that publishes and subscribes data in real-time over the POE cabling **28**.

[0023] It is possible to connect many different aircraft cockpit simulation panels **24** via the cabling **28** and line replaceable units **38** and communicate at up to about 1,000 megabits per second to the host controller **54**. Because each line replaceable unit **38** includes a unique Ethernet address, the host controller **54** may download specific configurations to each aircraft cockpit simulation panel **24** at power-up, allowing a single line replaceable unit to meet different functional simulator requirements and reduce the overall life cycle costs for the aircraft cockpit training simulator **20**.

[0024] Each distributed controller **50** may include different components to function, and although not illustrated in detail, may include a central processing unit (CPU) connected via a parallel address/data bus to a system RAM, an analog-to-digital (A/D) converter, a digital-to-analog (D/A) converter, an analog multiplexer, EEPROM, and a POE negotiation and conversion sub-system. A crystal oscillator may be coupled to the CPU. Each distributed controller **50** may also include a plurality of Darlington Arrays that drive lamp outputs. Pull-up resistors may be provided for each of the inputs. A CPU and its on-board peripherals may act in coordination to input and output data on a state change or at the request of another aircraft cockpit simulation panel **24** or host controller **54**. A digital input/output function as part of the digital output circuit **42** and digital input circuit **40** may have a function generated by the CPU, which provides extensibility and flexible boundary inputs and outputs. The distributed controllers **50**

may publish respective inputs upon a change of state. The distributed controllers **50** may also subscribe to published data from other aircraft cockpit simulation panels **24**.

[0025] Referring now to FIGS. 2A and 2B, timing diagrams illustrate the timing of data publication and data distribution for an aircraft cockpit training simulation panel **24**. These timing diagrams in both FIGS. 2A and 2B may occur during the same frame on the same controller **50**. At the top of a frame (FIG. 2A), the distributed controller **50** detects a state change by continuous sampling and filtering. The distributed controller **50** converts the data into a usable format and publishes the data for use by any subscribing distributed controller connected at other aircraft cockpit simulation panels **24** and to the host controller **54**. The other aircraft cockpit simulation panels **24** that receive this data may also process the data as shown in the graph of FIG. 2B, and make a corresponding input/output state change. This technique of sampling significantly reduces latencies as data is published upon a change of state. The sampling technique may provide latencies of less than 4 milliseconds.

[0026] Input and output events may be published when the input and output changes state or when subscribing events change the input and output state. These events may occur asynchronously, which allows for the inputs and outputs to be handled in a non-blocking manner, and thus, reduce latency. When input and output events change state, the data is published, and when subscribed events are received, the input and output changes state. Thus, the transmission time or the time it takes to write or read the input and output data is dependent on the type of input and output data being written or read. This makes the latency in the writing and reading of inputs and outputs dependent only on the transmission time and the publishing and subscribing of event data through the published/subscribe protocol, such as DDS.

[0027] During normal system operations, the aircraft cockpit training simulator **20** may publish and subscribe data from various DDS “topics,” which correspond to the state of a simulated aircraft and may include power and lighting bus information as non-limiting examples. The bus state may be controlled through specific switches in the panels **24** of the aircraft cockpit training simulator **20** and the host controller **54** may read the switches and registers and determine whether the bus should be on or off. Depending on an operating mode, the different aircraft cockpit simulation panels **24**

publish this data out to all other aircraft cockpit simulation panels as to state changes, periodically, or when queried. This information may be parsed.

[0028] At the physical level, when an aircraft cockpit simulation panel **24** receives a new DDS command to exercise its outputs, a state check on the panel is executed and outputs may be changed according to a command value. For example, if the output is cockpit lighting, a pulse-width modulation (PWM) signal may have its duty cycle increased or decreased to brighten or dim the cockpit lighting. In the case of a power bus, a relay may be turned on or an indicator lamp may be lit as the output. To determine lighting intensity, a potentiometer may be used and a reference voltage may be applied to fixed-resistance terminals of a potentiometer, while a third terminal of the potentiometer, the wiper, may be used as an input to the aircraft cockpit simulation panel **24**. The distributed controller **50** at the panel **24** may interpret this value through an A/D converter and the value may be published and the other aircraft cockpit simulation panels **24** connected via the POE cabling may have the updated state. This publish/subscribe approach may eliminate the requirement for the host controller **54** to be a broker.

[0029] In an example, two aircraft cockpit simulation panels **24** may be formed as an electrical control panel and an oxygen control panel and may interface to the host controller **54** via the POE cabling **28**. This may occur with or without the host controller **54**. An LRU **38** may communicate directly with another LRU. The electrical control panel may have a switch to control power, such as a 28 volt DC signal, and the oxygen control panel may have an indicator powered from the 28 volt DC. A signal from the host controller **54** may indicate how much oxygen is left. When the aircraft cockpit training simulator **20** is powered on, the host controller **54** may initiate a known-good state for the cockpit, including an oxygen level for the oxygen indicator. However, until the pilot flips the 28 volt DC bus switch to the “on” position, the oxygen indicator may not reflect any of the received oxygen level commands from the host controller **54** because it is performing the state check on the required bus. As soon as the pilot flips the 28 volt DC bus switch to the “on” position, the DDS message is sent and the oxygen indicator will reflect the oxygen level the host controller **54** has provided.

[0030] The host controller **54** may also induce failures into the cockpit training simulator **20**. Because the DDS as the publish/subscribe protocol allows for multiple publishers and subscribers, the host controller **54** may simulate a failure by sending a DDS message that shows the 28 volt DC bus is “off,” regardless of the switch position. By being able to mimic other aircraft cockpit simulation panels **24**, the host controller has the ability to introduce a large number of virtualized failures for different training experiences.

[0031] As noted before, each aircraft cockpit simulation panel **24** includes a line replaceable unit (LRU) **38** that may operate independent of the host computer model run by the host controller **54**. A real world example may be a radio that includes a black box LRU **38** where the radio enables a simulation model to reflect radio behavior experienced in an aircraft. This may include button responses, display pages, frequency updates, and related radio signal computation. Data required for integration into the larger aircraft cockpit training simulator **20**, such as frequency and encryption, may be published using DDS. It is possible that the radio as part of an aircraft cockpit simulation panel **24** may be operated independent of other panels. This allows development and testing of the radio panel **24** without reference to the aircraft cockpit training simulator **20**. This function may occur on a single aircraft cockpit simulation panel **24** or it may occur on any number of panels together, but still independent of the aircraft cockpit training simulator **20**.

[0032] Each line replaceable unit **38**, such as part of a lighting device, may generate 5 and 28 volts for use with different electromechanical and lighting devices. Lamp outputs may be driven by pulse width modulation (PWM) through low resistance Darlington Arrays configured as sinks. A continuous current of 1 amp and 3 amps peak may be provided with 100% loopback using variable voltage level sensing. The repair time of different aircraft cockpit simulation panels **24** may be reduced because of the use of the line replaceable units **38** that are at the panel level. A benefit is being able to remove an entire aircraft cockpit simulation panel **24** from the simulator **20** and swap it out without bringing the system down. This is not just limited to the LRU **38**. In addition, faulty line replaceable units **38** may be evaluated and repaired outside the aircraft cockpit training simulator **20**, which reduces downtime.

[0033] Each aircraft cockpit simulation panel **24** may have input and output functionality, and every light, switch, indicator, and other components may have a variable name, specific scaling, and hardware to software correlation. This data may be obtained from hardware design and interface data, which is usually manually hard coded or manually populated into files during code compilation. This process may be automated by standardizing hardware schematics and using a software application to write the required software definition directly from the hardware schematic into an aircraft cockpit simulation panel **24**, and thus, reduce the time to generate software interface code.

[0034] It is possible to boot a panel **24** using the Trivial File Transfer Protocol (TFTP) and a DHCP service. Different DDS messages may include a status message that may be published by every aircraft cockpit simulation panel **24**, such as at one second intervals, where each message will identify the aircraft cockpit simulation panel and provide generic information used for troubleshooting. A configuration message may be used to set specific panel **24** characteristics, such as how often to publish DDS data. Maintenance command messages may be available so that a panel **24** may subscribe to maintenance commands that perform common tasks, for example, on/off capabilities. A calibration message may be used because analog signals change over time and a message for calibrating analog devices and other components may be provided. A data message may contain input and output data and model data.

[0035] Different modes may be supported for DDS, including an event mode such as indicating a change in input and output data, or model data, and a polling or query mode where a subscriber may ask for data to initialize and synchronize itself with a publisher. A periodic or stream mode may be supported where data is continuously published at a set rate. Sample rates may be considered for different types of input and output data with simulator **20** specific requirements have rates that may be calculated using the speed of input signals, along with the simulator host frequency requirements such as 120 Hz. Different power over Ethernet categories may be employed such as Type 1 corresponding to Class 3 with 13 watts, and Type 2 as Class 4 with 25.5 watts. Type 3 as Class 6 may include 51 watts, and Type 4 as Class 8 may include 71 watts.

Where the Power over Ethernet does not supply sufficient power for an aircraft cockpit simulation panel **24**, an external DC voltage may be used.

[0036] Referring now to FIG. 3, there is illustrated a high-level flowchart of a method of making an aircraft cockpit training simulator **20** shown generally at **100**. The process starts (Block **102**) and power is coupled over POE cabling **28** among aircraft cockpit simulation panels **24** where each panel includes a simulator user interface device **32**, input and output circuits **40, 42**, POE interface circuit **46**, and distributed controller **50** (Block **104**). The host controller **54** is coupled to distributed controllers **50** via POE cabling **28** (Block **106**) and the aircraft cockpit simulation panels **24** are operated in accordance with the host computer model or independent of host computer model (Block **108**). The distributed controllers **50** asynchronously communicate using a publish/subscribe protocol (Block **110**). The process ends (Block **112**).

[0037] Many modifications and other embodiments of the invention will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is understood that the invention is not to be limited to the specific embodiments disclosed, and that modifications and embodiments are intended to be included within the scope of the appended claims.

CLAIMS

1. An aircraft cockpit training simulator comprising:
a plurality of aircraft cockpit simulation panels and power over Ethernet (POE) cabling extending therebetween;
each aircraft cockpit simulation panel comprising
at least one simulator user interface device,
at least one of an input circuit and an output circuit coupled to the at least one simulator user interface device,
a POE interface circuit, and
a distributed controller coupled to the at least one of an input circuit and an output circuit and POE interface device configured to asynchronously communicate with other controllers using a publish/subscribe protocol, and
a host controller coupled to the plurality of distributed controllers via the POE cabling and configured to operate the plurality of aircraft cockpit simulation panels in accordance with a host computer model;
the plurality of distributed controllers also capable of operating independent of the host computer model.
2. The aircraft cockpit training simulator of claim 1, wherein each distributed controller is configured to send a plurality of status messages asynchronously with respect to other distributed controllers.
3. The aircraft cockpit training simulator of claim 1, wherein the at least one simulator user interface device comprises at least one lighting device.
4. The aircraft cockpit training simulator of claim 1, wherein the at least one simulator user interface device comprises at least one power consuming device.

5. The aircraft cockpit training simulator of claim 1, wherein the at least one simulator user interface device comprises at least one of a switch, a lamp, a potentiometer, a joystick, and a display.

6. The aircraft cockpit training simulator of claim 1, wherein the at least one of an input circuit and an output circuit comprises at least one analog input circuit.

7. The aircraft cockpit training simulator of claim 1, wherein the at least one of an input circuit and an output circuit comprises at least one analog output circuit.

8. The aircraft cockpit training simulator of claim 1, wherein the at least one of an input circuit and an output circuit comprises at least one digital input circuit.

9. The aircraft cockpit training simulator of claim 1, wherein the at least one of an input circuit and an output circuit comprises at least one digital output circuit.

10. The aircraft cockpit training simulator of claim 1, wherein each panel comprises at least one connector; and wherein the at least one of an input circuit and an output circuit, the POE interface circuit, and the distributed controller are in a form of a line replaceable unit (LRU) coupled to the at least one connector.

11. An aircraft cockpit training simulator comprising:
a plurality of aircraft cockpit simulation panels and power over Ethernet (POE) cabling extending therebetween;
each aircraft cockpit simulation panel comprising
at least one simulator user interface device and at least one connector coupled thereto, and

a line replaceable unit (LRU) coupled to the at least one connector comprising

- at least one of an input circuit and an output circuit coupled to the at least one simulator user interface device,
- a POE interface circuit, and
- a distributed controller coupled to the at least one of an input circuit and an output circuit and POE interface circuit configured to asynchronously communicate with other distributed controllers using a publish/subscribe Data Distribution Service (DDS) protocol; and
- a host controller coupled to the plurality of distributed controllers via the POE cabling and configured to operate the plurality of aircraft cockpit simulation panels in accordance with a host computer model;

the plurality of distributed controllers also capable of operating independent of the host computer model.

12. The aircraft cockpit training simulator of claim 11, wherein each distributed controller is configured to send a plurality of status messages asynchronously with respect to other distributed controllers.

13. The aircraft cockpit training simulator of claim 11, wherein the at least one simulator user interface device comprises at least one lighting device.

14. The aircraft cockpit training simulator of claim 11, wherein the at least one simulator user interface device comprises at least one power consuming device.

15. The aircraft cockpit training simulator of claim 11, wherein the at least one simulator user interface device comprises at least one of a switch, a lamp, a potentiometer, a joystick, and a display.

16. The aircraft cockpit training simulator of claim 11, wherein the at least one of an input circuit and an output circuit comprises at least one analog input circuit.

17. The aircraft cockpit training simulator of claim 11, wherein the at least one of an input circuit and an output circuit comprises at least one analog output circuit.

18. The aircraft cockpit training simulator of claim 11, wherein the at least one of an input circuit and an output circuit comprises at least one digital input circuit.

19. The aircraft cockpit training simulator of claim 11, wherein the at least one of an input circuit and an output circuit comprises at least one digital output circuit.

20. A method of making an aircraft cockpit training simulator comprising:

coupling power over Ethernet (POE) cabling among a plurality of aircraft cockpit simulation panels, each aircraft cockpit simulation panel comprising

- at least one simulator user interface device,
- at least one of an input circuit and an output circuit coupled to the at least one simulator user interface device,
- a POE interface circuit, and
- a distributed controller coupled to the at least one of an input circuit and an output circuit and POE interface device configured to asynchronously communicate with other controllers using a publish/subscribe protocol, and

coupling a host controller to the plurality of distributed controllers via the POE cabling and configured to operate the plurality of aircraft cockpit simulation panels in accordance with a host computer model;

the plurality of distributed controllers also capable of operating independent of the host computer model.

21. The method of claim 20, wherein each distributed controller is configured to send a plurality of status messages asynchronously with respect to other distributed controllers.

22. The method of claim 20, wherein the at least one simulator user interface device comprises at least one lighting device.

23. The method of claim 20, wherein the at least one simulator user interface device comprises at least one power consuming device.

24. The method of claim 20, wherein each panel comprises at least one connector; and wherein the at least one of an input circuit and an output circuit, the POE interface circuit, and the distributed controller are in a form of a line replaceable unit (LRU) coupled to the at least one connector.