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Ji et al.

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(54) **PERIPHERAL COMPONENT INTERCONNECT EXPRESS DEVICE RESET FOR AUTONOMOUS DRIVING SYSTEMS**

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(52) **U.S. Cl.**
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(58) **Field of Classification Search**
CPC G06F 13/4221; G06F 9/44505; G06F 2213/0026
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2012/0079312 A1*	3/2012	Muthrasanallur ...	G06F 11/0793 714/E11.023
2014/0344632 A1*	11/2014	Ge	G06F 11/3041 714/49

(Continued)

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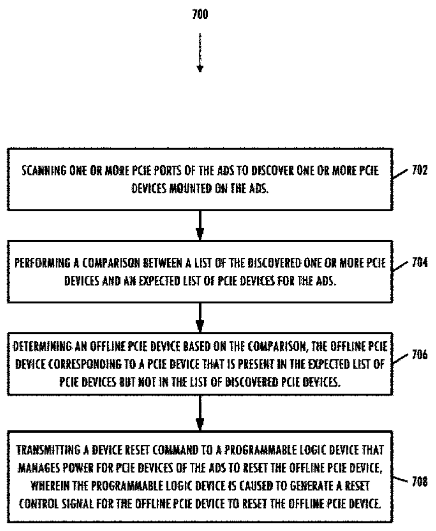
(57) **ABSTRACT**

In one embodiment, a method for controlling PCIe devices on an autonomous driving system (ADS) of an autonomous driving vehicle (ADV) is disclosed. The method includes scanning PCIe ports of the ADS to discover PCIe device(s) mounted on the ADS. Next, a comparison is performed between a list of the discovered PCIe device(s) and an expected list of PCIe devices for the ADS. Next, an offline PCIe device is determined based on the comparison, the offline PCIe device corresponding to a PCIe device that is present in the expected list of PCIe devices but not in the list of the discovered PCIe devices. Then a device reset command is transmitted to a programmable logic device that manages power for PCIe devices of the ADS to reset the offline PCIe device, wherein the programmable logic device generates a reset control signal for the offline PCIe device to reset the PCIe device.

20 Claims, 10 Drawing Sheets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SCANNING ONE OR MORE PCIE PORTS OF THE ADS TO DISCOVER ONE OR MORE PCIE DEVICES MOUNTED ON THE ADS.
702
PERFORMING A COMPARISON BETWEEN A LIST OF THE DISCOVERED ONE OR MORE PCIE DEVICES AND AN EXPECTED LIST OF PCIE DEVICES FOR THE ADS.
704
DETERMINING AN OFFLINE PCIE DEVICE BASED ON THE COMPARISON, THE OFFLINE PCIE DEVICE CORRESPONDING TO A PCIE DEVICE THAT IS PRESENT IN THE EXPECTED LIST OF PCIE DEVICES BUT NOT IN THE LIST OF DISCOVERED PCIE DEVICES.
706
TRANSMITTING A DEVICE RESET COMMAND TO A PROGRAMMABLE LOGIC DEVICE THAT MANAGES POWER FOR PCIE DEVICES OF THE ADS TO RESET THE OFFLINE PCIE DEVICE, WHEREIN THE PROGRAMMABLE LOGIC DEVICE IS CAUSED TO GENERATE A RESET CONTROL SIGNAL FOR THE OFFLINE PCIE DEVICE TO RESET THE OFFLINE PCIE DEVICE.
708

(56) **References Cited**

U.S. PATENT DOCUMENTS

2016/0210254	A1*	7/2016	Achlaug	G06F 13/4291
2017/0337069	A1*	11/2017	Huang	G06F 13/4282
2018/0074981	A1*	3/2018	Remis	G06F 13/4022
2018/0246840	A1*	8/2018	Bhutta	G06F 13/4282
2018/0373669	A1*	12/2018	Nash	G06F 13/4022
2020/0310933	A1*	10/2020	Zhu	G06F 11/0784

* cited by examiner

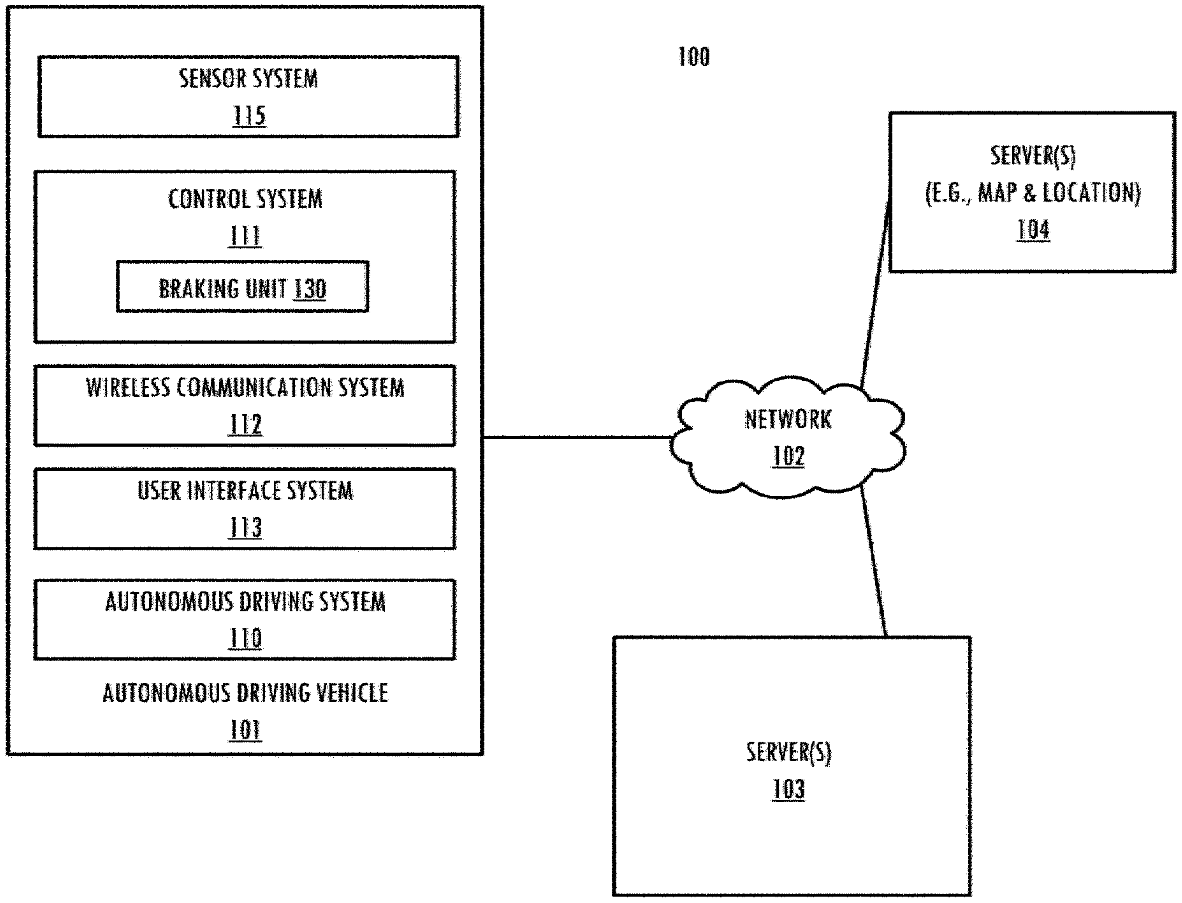

100
SENSOR SYSTEM 115
CONTROL SYSTEM 111
BRAKING UNIT 130
WIRELESS COMMUNICATION SYSTEM 112
USER INTERFACE SYSTEM 113
AUTONOMOUS DRIVING SYSTEM 110
AUTONOMOUS DRIVING VEHICLE 101
NETWORK 102
SERVER(S) (E.G., MAP & LOCATION) 104
SERVER(S) 103

FIG. 1

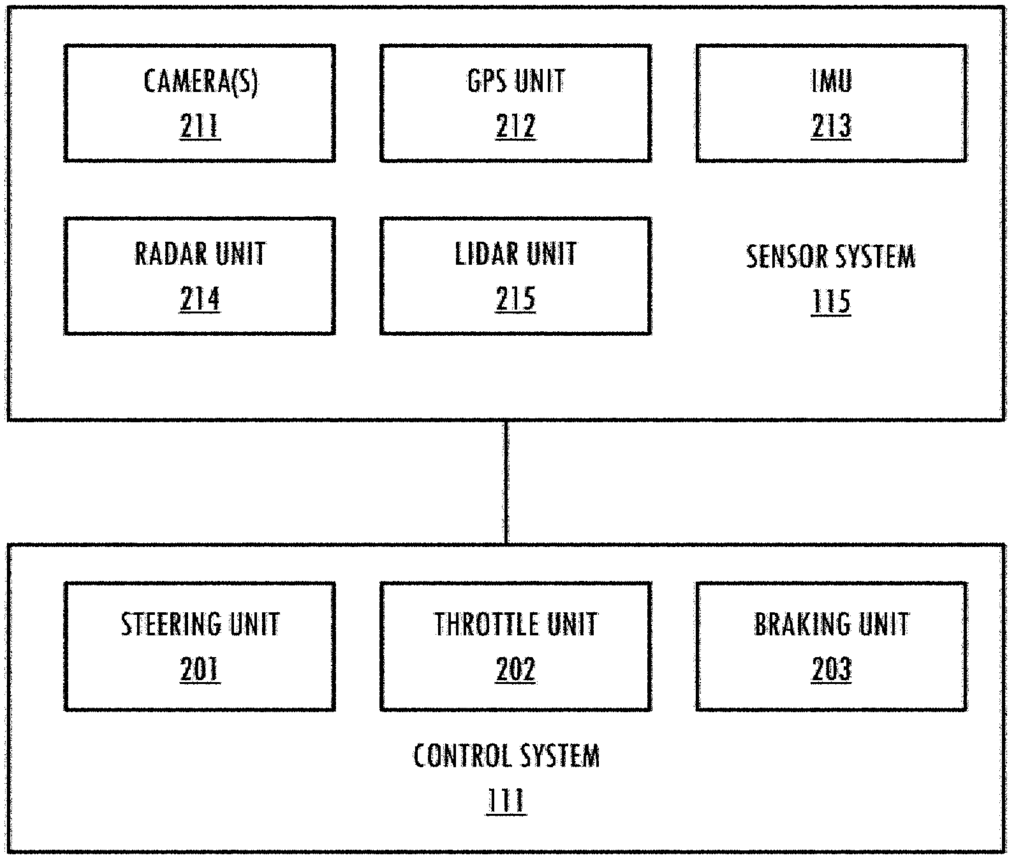

CAMERA(S)
211
GPS UNIT
212
IMU
213
RADAR UNIT
214
LIDAR UNIT
215
SENSOR SYSTEM
115
STEERING UNIT
201
THROTTLE UNIT
202
BRAKING UNIT
203
CONTROL SYSTEM
111

FIG. 2

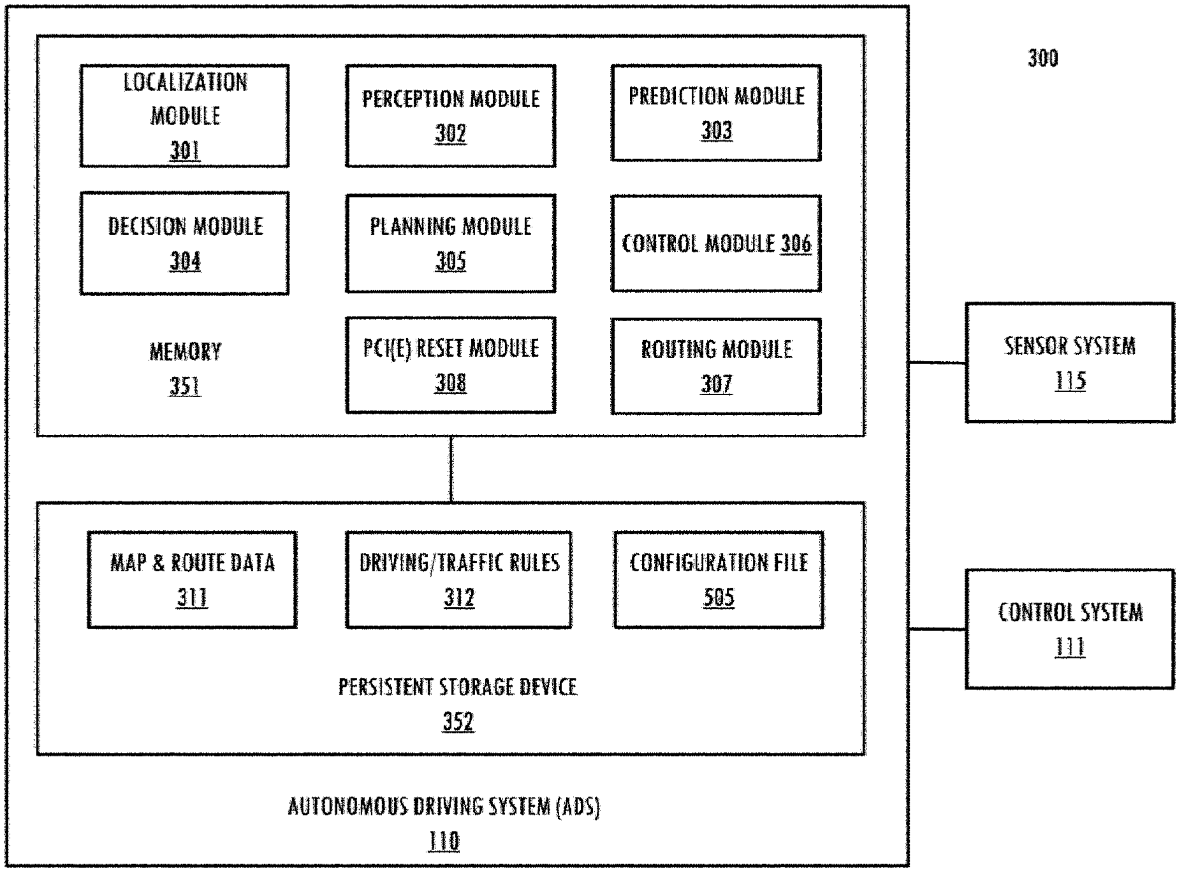

300
LOCALIZATION MODULE 301
PERCEPTION MODULE 302
PREDICTION MODULE 303
DECISION MODULE 304
PLANNING MODULE 305
CONTROL MODULE 306
MEMORY 351
PCI(E) RESET MODULE 308
ROUTING MODULE 307
SENSOR SYSTEM 115
MAP & ROUTE DATA 311
DRIVING/TRAFFIC RULES 312
CONFIGURATION FILE 505
CONTROL SYSTEM 111
PERSISTENT STORAGE DEVICE 352
AUTONOMOUS DRIVING SYSTEM (ADS) 110

FIG. 3A

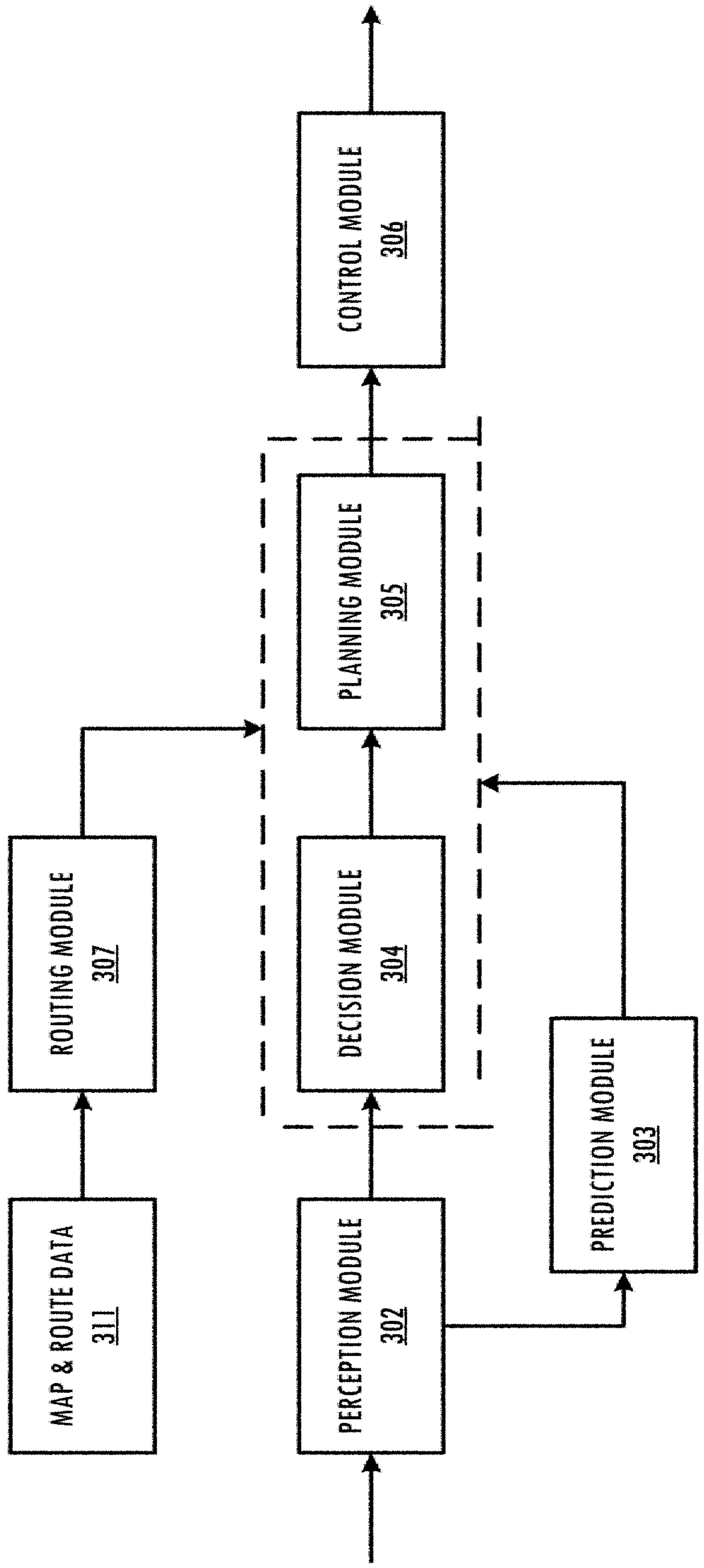

MAP & ROUTE DATA 311
ROUTING MODULE 307
PERCEPTION MODULE 302
DECISION MODULE 304
PLANNING MODULE 305
CONTROL MODULE 306
PREDICTION MODULE 303

FIG. 3B

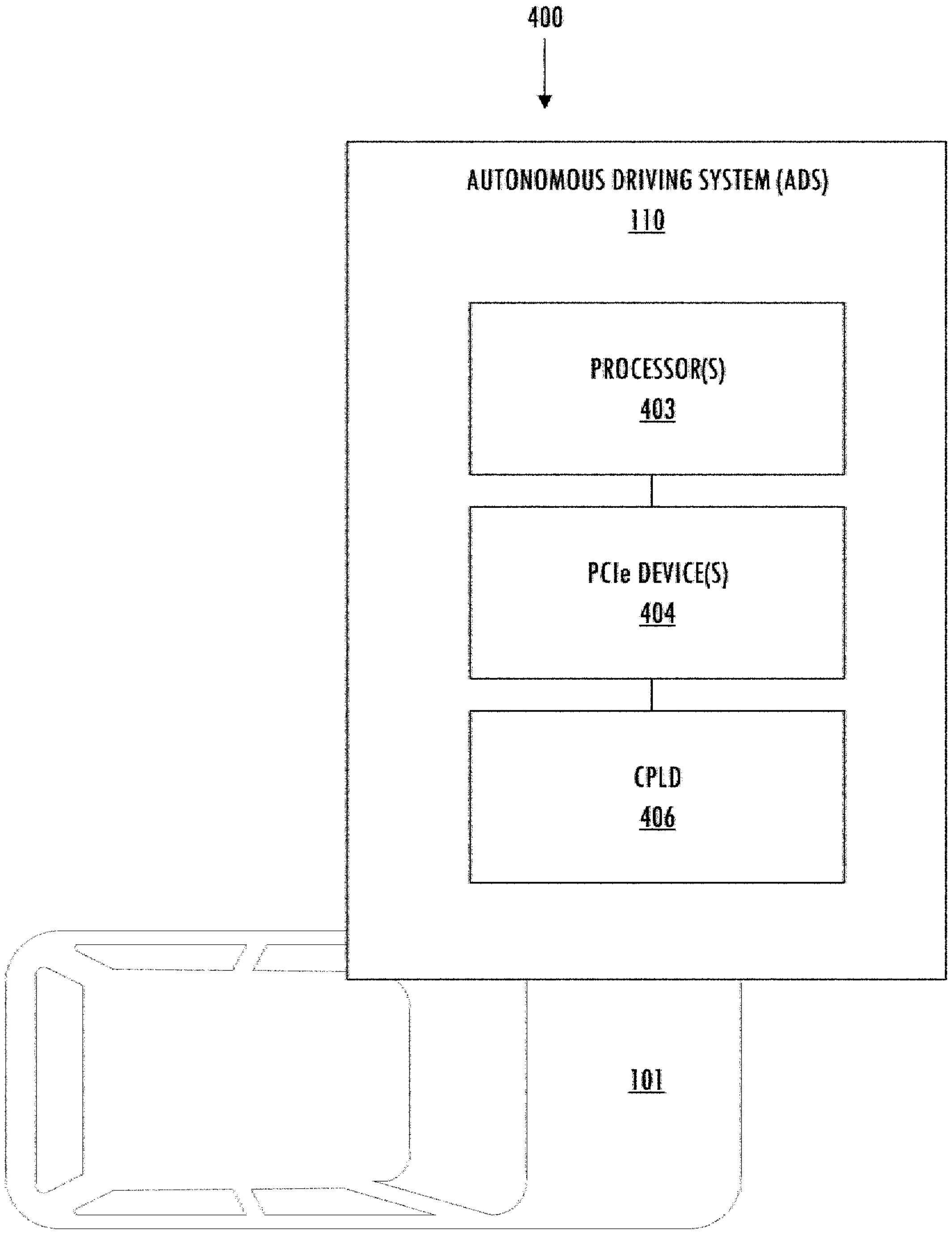

400
AUTONOMOUS DRIVING SYSTEM (ADS)
110
PROCESSOR(S)
403
PCIe DEVICE(S)
404
CPLD
406
101

FIG. 4

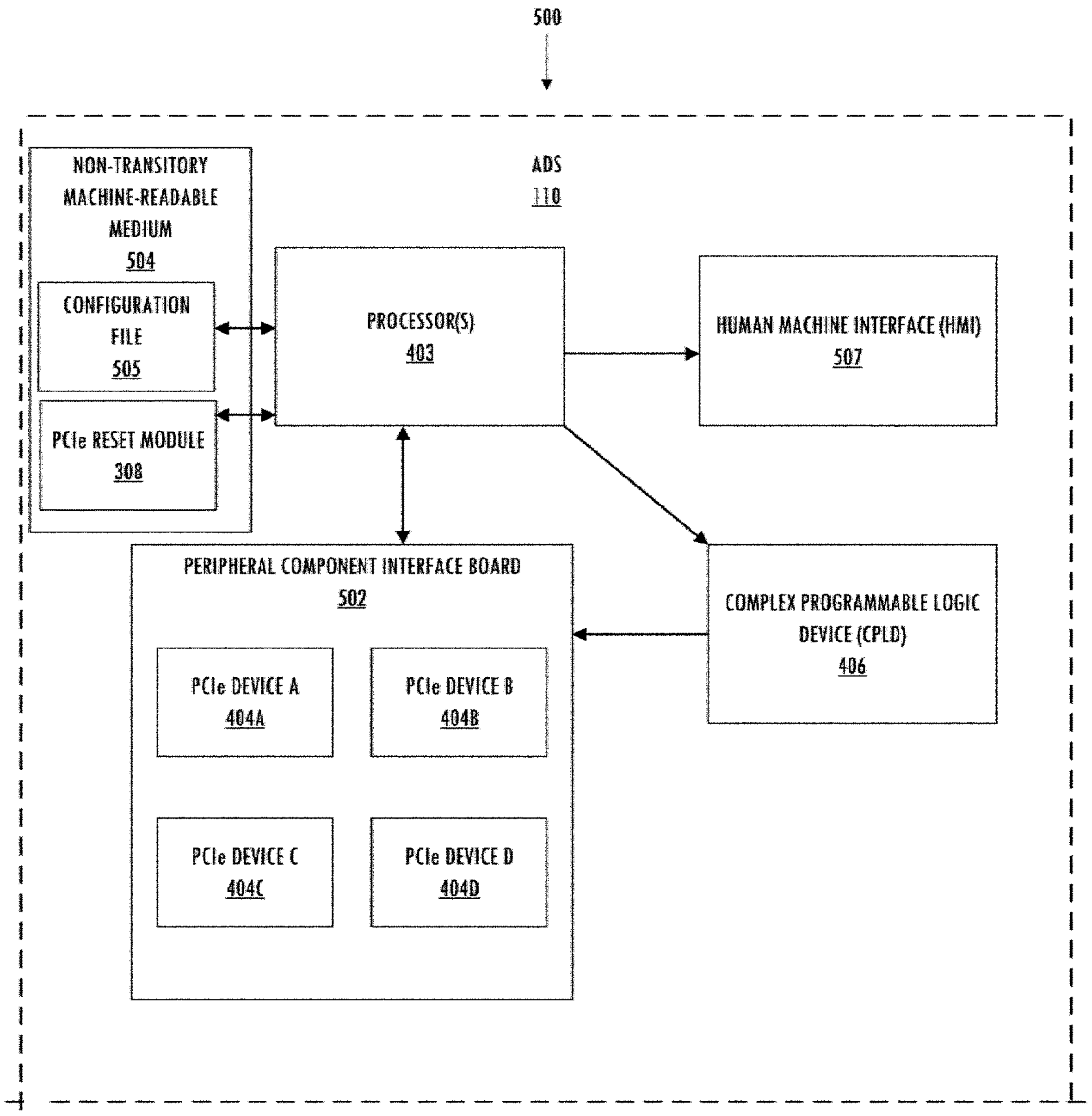

500
ADS
110
NON-TRANSITORY MACHINE-READABLE MEDIUM
504
CONFIGURATION FILE
505
PCIe RESET MODULE
308
PROCESSOR(S)
403
HUMAN MACHINE INTERFACE (HMI)
507
PERIPHERAL COMPONENT INTERFACE BOARD
502
COMPLEX PROGRAMMABLE LOGIC DEVICE (CPLD)
406
PCIe DEVICE A
404A
PCIe DEVICE B
404B
PCIe DEVICE C
404C
PCIe DEVICE D
404D

FIG. 5A

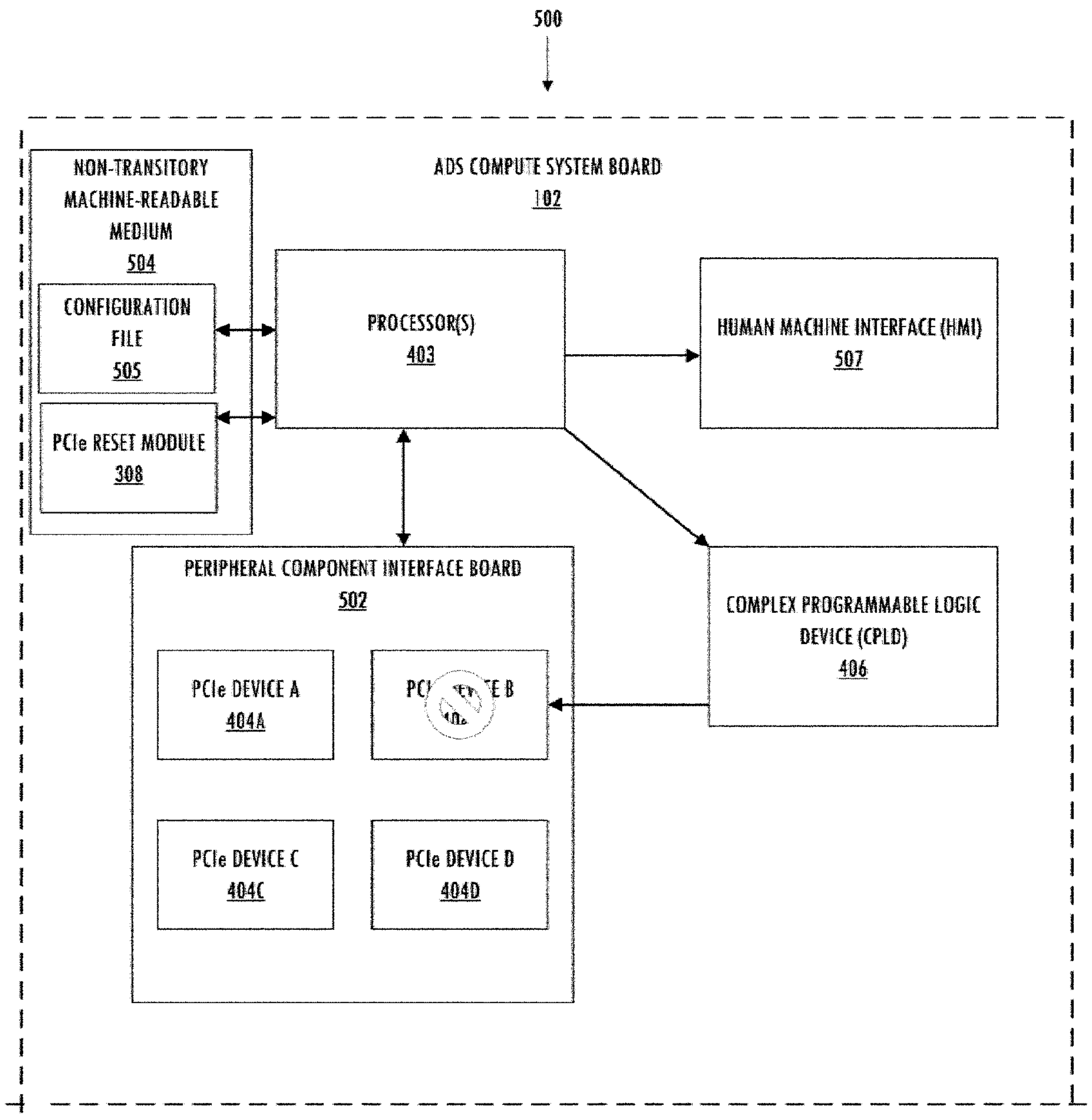

500
ADS COMPUTE SYSTEM BOARD
102
NON-TRANSITORY MACHINE-READABLE MEDIUM
504
CONFIGURATION FILE
505
PCIe RESET MODULE
308
PROCESSOR(S)
403
HUMAN MACHINE INTERFACE (HMI)
507
PERIPHERAL COMPONENT INTERFACE BOARD
502
COMPLEX PROGRAMMABLE LOGIC DEVICE (CPLD)
406
PCIe DEVICE A
404A
PCIe DEVICE B
404B
PCIe DEVICE C
404C
PCIe DEVICE D
404D

FIG. 5B

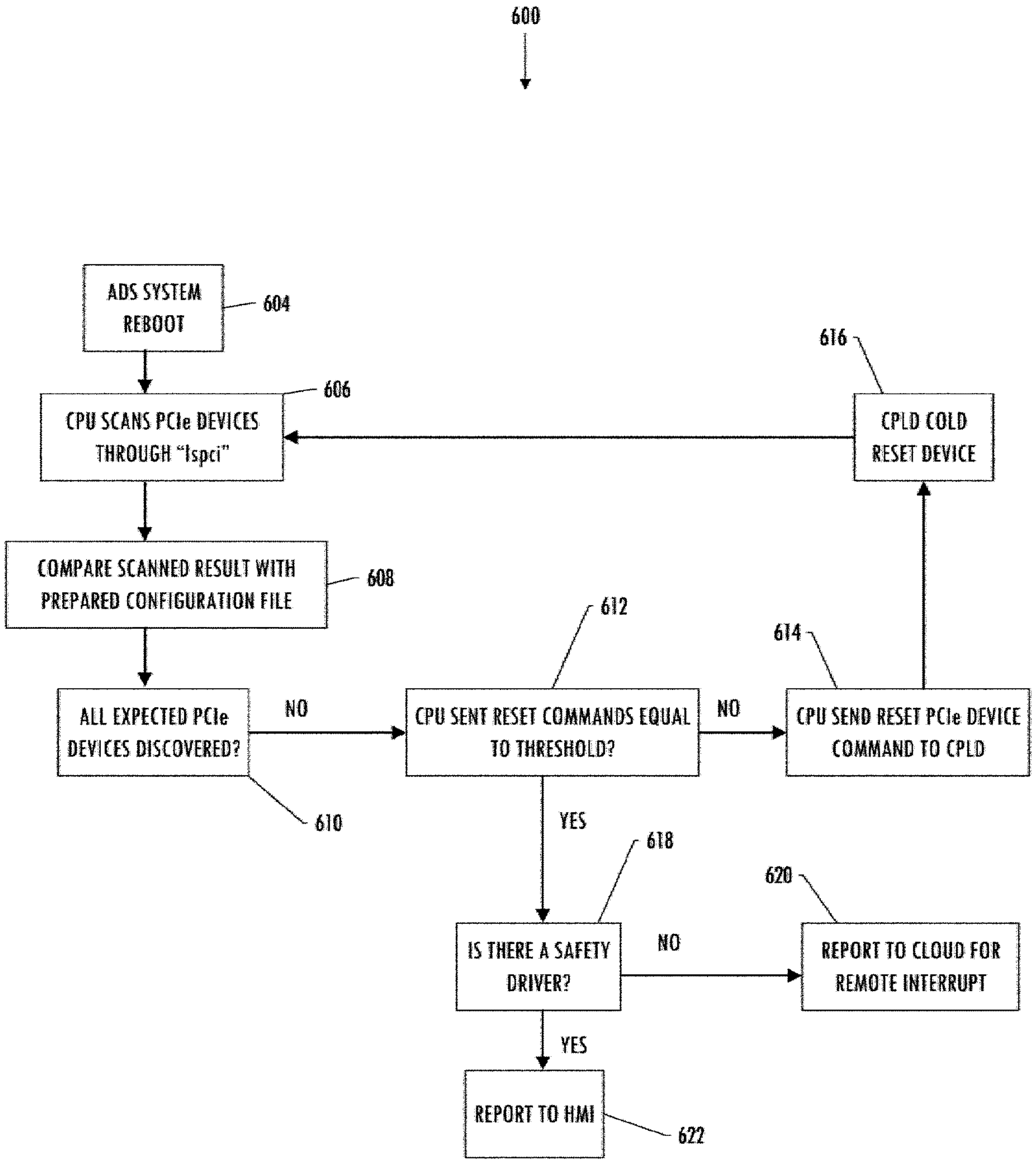

600
ADS SYSTEM REBOOT
604
CPU SCANS PCIe DEVICES THROUGH "lspci"
606
COMPARE SCANNED RESULT WITH PREPARED CONFIGURATION FILE
608
ALL EXPECTED PCIe DEVICES DISCOVERED?
610
NO
CPU SENT RESET COMMANDS EQUAL TO THRESHOLD?
612
NO
CPU SEND RESET PCIe DEVICE COMMAND TO CPLD
614
CPLD COLD RESET DEVICE
616
YES
IS THERE A SAFETY DRIVER?
618
NO
REPORT TO CLOUD FOR REMOTE INTERRUPT
620
YES
REPORT TO HMI
622

FIG. 6A

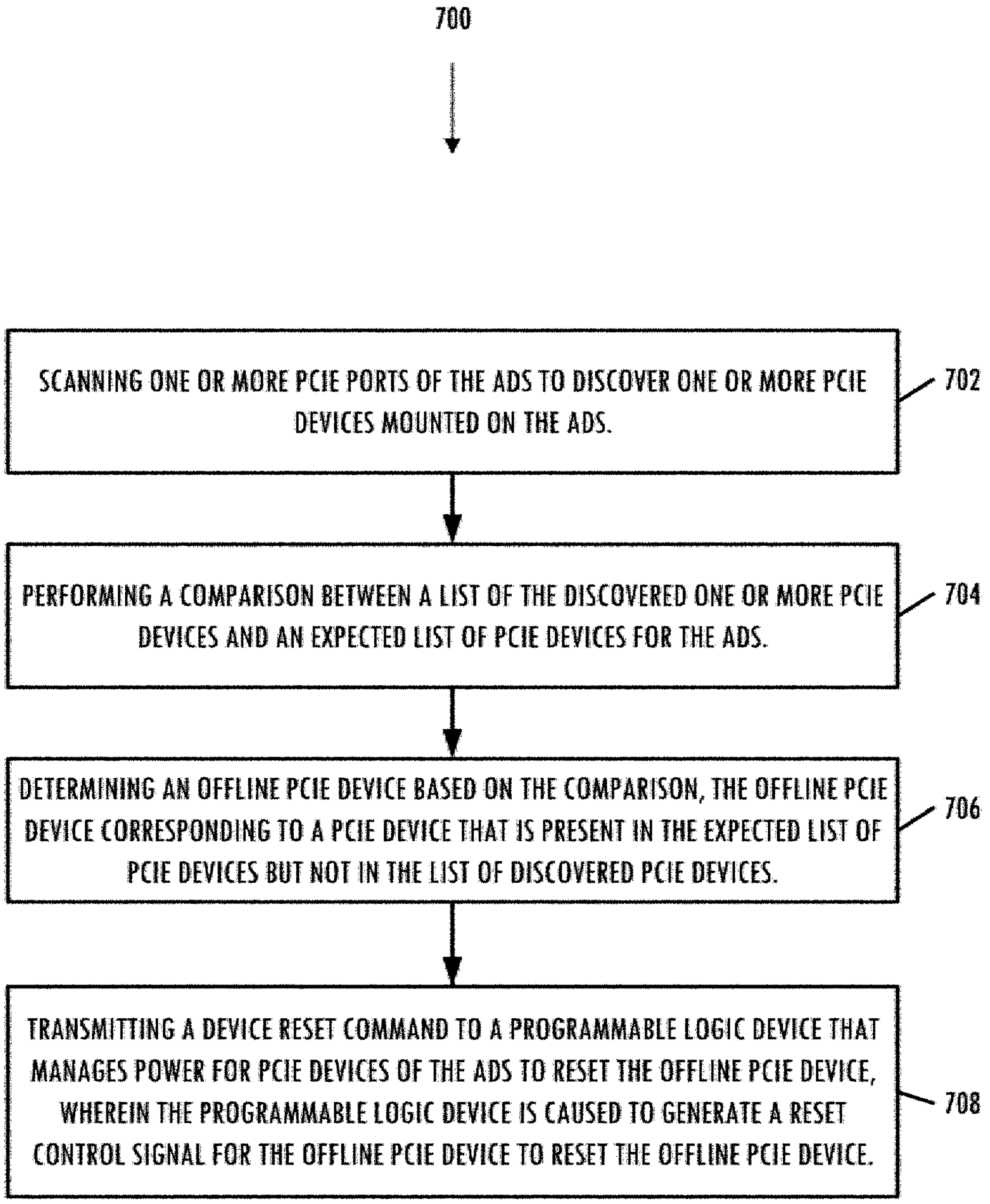
630

PCIe Port Number	Vendor ID	Device ID
Port 0	8086	4907
Port 1	1000	1185
Port 2	1000	1189
...	...	...
Port N	...	...

640

```
ADS@ads-system:~$ lspci
00:00.0 8086   4907
00:01.0 1000   1185
00:05.0 8776   5555
```

FIG. 6B


700
SCANNING ONE OR MORE PCIE PORTS OF THE ADS TO DISCOVER ONE OR MORE PCIE DEVICES MOUNTED ON THE ADS.
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PERFORMING A COMPARISON BETWEEN A LIST OF THE DISCOVERED ONE OR MORE PCIE DEVICES AND AN EXPECTED LIST OF PCIE DEVICES FOR THE ADS.
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708

FIG. 7

PERIPHERAL COMPONENT INTERCONNECT EXPRESS DEVICE RESET FOR AUTONOMOUS DRIVING SYSTEMS

CROSS-REFERENCE TO RELATED APPLICATION

This application is a National Stage of International Application No. PCT/CN2023/073342, filed Jan. 20, 2023, which is hereby incorporated by reference in its entirety.

TECHNICAL FIELD

Embodiments of the present disclosure relate generally to operating autonomous driving vehicles. More particularly, embodiments of the disclosure relate to resetting peripheral component interconnect express (PCIe) devices on autonomous driving systems.

BACKGROUND

Vehicles operating in an autonomous mode (e.g., driverless) can relieve occupants, especially the driver, from some driving-related responsibilities. When operating in an autonomous mode, the vehicle can navigate to various locations using onboard sensors, allowing the vehicle to travel with minimal human interaction or in some cases without any passengers.

Motion planning and control are critical operations in autonomous driving. However, conventional motion planning operations estimate the difficulty of completing a given path mainly from its curvature and speed, without considering the differences in features for different types of vehicles. The same motion planning and control is applied to all types of vehicles, which may not be accurate and smooth under some circumstances.

In order to accomplish autonomous driving, autonomous vehicles require vast amounts of precise and complex computing such as that used in machine learning techniques. These complex techniques require the use of peripheral equipment (such as PCIe devices), including processors such as graphics processing units (GPU), solid state drives (SSD), network interfaces cards (NIC), video capture cards, serial advanced technology attachment cards (SATA), or non-volatile memory express (NVMe) cards. These PCIe devices are mounted to the autonomous driving system (ADS) of the autonomous driving vehicle (ADV). Occasionally, a PCIe device may not be detected by a processor (e.g., central processing unit [CPU]) of the ADS and this can cause a safety issue in an ADV if the PCIe device is not reset.

Currently, PCIe devices are reset through a reboot of the ADS (which includes the entire autonomous driving system including the CPU and the PCIe devices mounted thereon) via a human safety driver. This process takes a significant amount of time (e.g., two minutes) and can cause significant safety issues.

Therefore, there is a need for an improved PCIe reset process for ADS in an ADV that reduces the amount of time it takes to reset offline PCIe devices, bring them back online, and minimize related safety issues.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the disclosure are illustrated by way of example and not limitation in the figures of the accompanying drawings in which like references indicate similar elements.

FIG. **1** is a block diagram illustrating a networked system, according to one embodiment.

FIG. **2** is a block diagram illustrating an example of an ADV, according to one embodiment.

FIGS. **3**A-**3**B are block diagrams illustrating an example of an ADS used with an ADV, according to one embodiment.

FIG. **4** is an illustration of an ADV with a block diagram illustrating various ADS components onboard, according to one embodiment.

FIGS. **5**A-**5**B are block diagrams of example systems for controlling PCIe devices on an ADS, according to one embodiment.

FIG. **6**A is an example flow diagram for controlling PCIe devices on an ADS, according to one embodiment.

FIG. **6**B illustrates an example configuration file and discovered PCIe device list, according to one embodiment.

FIG. **7** is an example flow diagram of a method for controlling PCIe devices on an ADS, according to one embodiment.

DETAILED DESCRIPTION

Various embodiments and aspects of the disclosure will be described with reference to details discussed below, and the accompanying drawings will illustrate the various embodiments. The following description and drawings are illustrative of the disclosure and are not to be construed as limiting the disclosure. Numerous specific details are described to provide a thorough understanding of various embodiments of the present disclosure. However, in certain instances, well-known or conventional details are not described in order to provide a concise discussion of embodiments of the present disclosure.

Reference in the specification to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in conjunction with the embodiment can be included in at least one embodiment of the disclosure. The appearances of the phrase "in one embodiment" in various places in the specification do not necessarily all refer to the same embodiment.

According to some embodiments, a computer-implemented method for controlling peripheral component interconnect express (PCIe) devices on an autonomous driving system (ADS) of an autonomous driving vehicle (ADV) is disclosed, the method comprising: scanning one or more PCIe ports of the ADS to discover one or more PCIe devices mounted on the ADS; performing a comparison between a list of the discovered one or more PCIe devices and an expected list of PCIe devices for the ADS; determining an offline PCIe device based on the comparison, the offline PCIe device corresponding to a PCIe device that is present in the expected list of PCIe devices but not in the list of discovered PCIe devices; and transmitting a device reset command to a programmable logic device that manages power for PCIe devices of the ADS to reset the offline PCIe device, wherein the programmable logic device is caused to generate a reset control signal for the offline PCIe device to reset the offline PCIe device.

According to some other embodiments, a non-transitory machine-readable medium for controlling PCIe devices on an ADS of an ADV is disclosed, the machine-readable medium having instructions stored therein, which when executed by a processor, cause the processor to perform operations, the operations comprising: scanning one or more PCIe ports of the ADS to discover one or more PCIe devices mounted on the ADS; performing a comparison between a list of the discovered one or more PCIe devices and an expected list of PCIe devices for the ADS; determining an offline PCIe device based on the comparison, the offline PCIe device corresponding to a PCIe device that is present in the expected list of PCIe devices but not in the list of discovered PCIe devices; and transmitting a device reset command to a programmable logic device that manages power for PCIe devices of the ADS to reset the offline PCIe device, wherein the programmable logic device is caused to generate a reset control signal for the offline PCIe device to reset the offline PCIe device.

According to still other embodiments, a system for controlling PCIe devices on an ADS of an ADV is disclosed, the system comprising: one or more processors; and a memory coupled to the one or more processors to store instructions, which when executed by the one or more processors, cause the one or more processors to: scan one or more PCIe ports of the ADS to discover one or more PCIe devices mounted on the ADS; perform a comparison between a list of the discovered one or more PCIe devices and an expected list of PCIe devices for the ADS; determine an offline PCIe device based on the comparison, the offline PCIe device corresponding to a PCIe device that is present in the expected list of PCIe devices but not in the list of discovered PCIe devices; and transmit a device reset command to a programmable logic device that manages power for PCIe devices of the ADS to reset the offline PCIe device, wherein the programmable logic device is caused to generate a reset control signal for the offline PCIe device to reset the offline PCIe device.

As described herein, the improved approach to PCIe device reset substantially reduces the time it takes to bring PCIe devices back online and allow the ADS to resume operations that include utilizing the PCIe devices mounted thereon. This disclosure will now turn to descriptions of the figures.

FIG. **1** is a block diagram illustrating an autonomous driving network configuration according to one embodiment of the disclosure. Referring to FIG. **1**, network configuration **100** includes ADV **101** that may be communicatively coupled to one or more servers **103-104** over a network **102**. Although there is one ADV shown, multiple ADVs can be coupled to each other and/or coupled to servers **103-104** over network **102**. Network **102** may be any type of networks such as a local area network (LAN), a wide area network (WAN) such as the Internet, a cellular network, a satellite network, or a combination thereof, wired or wireless. Server(s) **103-104** may be any kind of servers or a cluster of servers, such as Web or cloud servers, application servers, backend servers, or a combination thereof. Servers **103-104** may be data analytics servers, content servers, traffic information servers, map and point of interest (MPOI) servers, or location servers, etc. Servers **103-104** may also have the ability to remotely reset one or more devices on the ADS, such as one or more processors or one or more PCIe devices thereon.

An ADV refers to a vehicle that can be configured to operate in an autonomous mode in which the vehicle navigates through an environment with little or no input from a human driver. Such an ADV can include a sensor system having one or more sensors that are configured to detect information about the environment in which the vehicle operates. The vehicle and its associated controller(s) use the detected information to navigate through the environment. ADV **101** can operate in a manual mode, a full autonomous mode, or a partial autonomous mode.

In one embodiment, ADV **101** includes, but is not limited to, ADS **110**, vehicle control system **111**, wireless communication system **112**, user interface system **113**, and sensor system **115**. ADV **101** may further include certain common components included in ordinary vehicles, such as, an engine, wheels, steering wheel, transmission, etc., which may be controlled by vehicle control system **111** and/or ADS **110** using a variety of communication signals and/or commands, such as, for example, acceleration signals or commands, deceleration signals or commands, steering signals or commands, braking signals or commands, etc.

Components **110-115** may be communicatively coupled to each other via an interconnect, a bus, a network, or a combination thereof. For example, components **110-115** may be communicatively coupled to each other via a controller area network (CAN) bus. A CAN bus is a vehicle bus standard designed to allow microcontrollers and devices to communicate with each other in applications without a host computer. It is a message-based protocol, designed originally for multiplex electrical wiring within automobiles, but is also used in many other contexts.

Referring now to FIG. **2**, in one embodiment, sensor system **115** includes, but it is not limited to, one or more cameras **211**, global positioning system (GPS) unit **212**, inertial measurement unit (IMU) **213**, radar unit **214**, and a light detection and range (LIDAR) unit **215**. GPS system **212** may include a transceiver operable to provide information regarding the position of the ADV. IMU unit **213** may sense position and orientation changes of the ADV based on inertial acceleration. Radar unit **214** may represent a system that utilizes radio signals to sense objects within the local environment of the ADV. In some embodiments, in addition to sensing objects, radar unit **214** may additionally sense the speed and/or heading of the objects. LIDAR unit **215** may sense objects in the environment in which the ADV is located using lasers. LIDAR unit **215** could include one or more laser sources, a laser scanner, and one or more detectors, among other system components. Cameras **211** may include one or more devices to capture images of the environment surrounding the ADV. Cameras **211** may be still cameras and/or video cameras. A camera may be mechanically movable, for example, by mounting the camera on a rotating and/or tilting a platform.

Sensor system **115** may further include other sensors, such as, a sonar sensor, an infrared sensor, a steering sensor, a throttle sensor, a braking sensor, and an audio sensor (e.g., microphone). An audio sensor may be configured to capture sound from the environment surrounding the ADV. A steering sensor may be configured to sense the steering angle of a steering wheel, wheels of the vehicle, or a combination thereof. A throttle sensor and a braking sensor sense the throttle position and braking position of the vehicle, respectively. In some situations, a throttle sensor and a braking sensor may be integrated as an integrated throttle/braking sensor.

In one embodiment, vehicle control system **111** includes, but is not limited to, steering unit **201**, throttle unit **202** (also referred to as an acceleration unit), and braking unit **203**. Steering unit **201** is to adjust the direction or heading of the vehicle. Throttle unit **202** is to control the speed of the motor or engine that in turn controls the speed and acceleration of the vehicle. Braking unit **203** is to decelerate the vehicle by providing friction to slow the wheels or tires of the vehicle. Note that the components as shown in FIG. **2** may be implemented in hardware, software, or a combination thereof.

Referring back to FIG. **1**, wireless communication system **112** is to allow communication between ADV **101** and external systems, such as devices, sensors, other vehicles, etc. For example, wireless communication system **112** can wirelessly communicate with one or more devices directly or via a communication network, such as servers **103**-**104** over network **102**. Wireless communication system **112** can use any cellular communication network or a wireless local area network (WLAN), e.g., using WiFi to communicate with another component or system. Wireless communication system **112** could communicate directly with a device (e.g., a mobile device of a passenger, a display device, a speaker, electronic components on the ADS such as a PCIe device or processor within vehicle **101**), for example, using an infrared link, Bluetooth, etc. User interface system **113** may be part of peripheral devices implemented within vehicle **101** including, for example, a keyboard, a touch screen display device, a microphone, and a speaker, etc.

Some or all of the functions of ADV **101** may be controlled or managed by ADS **110**, especially when operating in an autonomous driving mode. ADS **110** includes the necessary hardware (e.g., processor(s), memory, storage) and software (e.g., operating system, planning and routing programs) to receive information from sensor system **115**, control system **111**, wireless communication system **112**, and/or user interface system **113**, process the received information, plan a route or path from a starting point to a destination point, and then drive vehicle **101** based on the planning and control information. Alternatively, ADS **110** may be integrated with vehicle control system **111**.

For example, a user as a passenger may specify a starting location and a destination of a trip, for example, via a user interface. ADS **110** obtains the trip related data. For example, ADS **110** may obtain location and route data from an MPOI server, which may be a part of servers **103**-**104**. The location server provides location services and the MPOI server provides map services and the POIs of certain locations. Alternatively, such location and MPOI information may be cached locally in a persistent storage device of ADS **110**.

While ADV **101** is moving along the route, ADS **110** may also obtain real-time traffic information from a traffic information system or server (TIS). Note that servers **103**-**104** may be operated by a third party entity. Alternatively, the functionalities of servers **103**-**104** may be integrated with ADS **110**. Based on the real-time traffic information, MPOI information, and location information, as well as real-time local environment data detected or sensed by sensor system **115** (e.g., obstacles, objects, nearby vehicles), ADS **110** can plan an optimal route and drive vehicle **101**, for example, via control system **111**, according to the planned route to reach the specified destination safely and efficiently.

FIGS. **3**A and **3**B are block diagrams illustrating an example of an autonomous driving system used with an ADV according to one embodiment. System **300** may be implemented as a part of ADV **101** of FIG. **1** including, but is not limited to, ADS **110**, control system **111**, and sensor system **115**. Referring to FIGS. **3**A-**3**B, ADS **110** includes, but is not limited to, localization module **301**, perception module **302**, prediction module **303**, decision module **304**, planning module **305**, control module **306**, routing module **307**, and PCIe Reset Module **308**.

Some or all of modules **301**-**308** may be implemented in software, hardware, or a combination thereof. For example, these modules may be installed in persistent storage device **352**, loaded into memory **351**, and executed by one or more processors (not shown). Note that some or all of these modules may be communicatively coupled to or integrated with some or all modules of vehicle control system **111** of FIG. **2**. Some of modules **301**-**308** may be integrated together as an integrated module.

Localization module **301** determines a current location of ADV **101** (e.g., leveraging GPS unit **212**) and manages any data related to a trip or route of a user. Localization module **301** (also referred to as a map and route module) manages any data related to a trip or route of a user. A user may log in and specify a starting location and a destination of a trip, for example, via a user interface. Localization module **301** communicates with other components of ADV **101**, such as map and route data **311**, to obtain the trip related data. For example, localization module **301** may obtain location and route data from a location server and a map and POI (MPOI) server. A location server provides location services and an MPOI server provides map services and the POIs of certain locations, which may be cached as part of map and route data **311**. While ADV **101** is moving along the route, localization module **301** may also obtain real-time traffic information from a traffic information system or server.

Based on the sensor data provided by sensor system **115** and localization information obtained by localization module **301**, a perception of the surrounding environment is determined by perception module **302**. The perception information may represent what an ordinary driver would perceive surrounding a vehicle in which the driver is driving. The perception can include the lane configuration, traffic light signals, a relative position of another vehicle, a pedestrian, a building, crosswalk, or other traffic related signs (e.g., stop signs, yield signs), etc., for example, in a form of an object. The lane configuration includes information describing a lane or lanes, such as, for example, a shape of the lane (e.g., straight or curvature), a width of the lane, how many lanes in a road, one-way or two-way lane, merging or splitting lanes, exiting lane, etc.

Perception module **302** may include a computer vision system or functionalities of a computer vision system to process and analyze images captured by one or more cameras in order to identify objects and/or features in the environment of the ADV. The objects can include traffic signals, roadway boundaries, other vehicles, pedestrians, and/or obstacles, etc. The computer vision system may use an object recognition algorithm, video tracking, and other computer vision techniques. In some embodiments, the computer vision system can map an environment, track objects, and estimate the speed of objects, etc. Perception module **302** can also detect objects based on other sensors data provided by other sensors such as a radar and/or LIDAR.

For each of the objects, prediction module **303** predicts what the object will behave under the circumstances. The prediction is performed based on the perception data perceiving the driving environment at the point in time in view of a set of map/route information **311** and traffic rules **312**. For example, if the object is a vehicle at an opposing direction and the current driving environment includes an intersection, prediction module **303** will predict whether the vehicle will likely move straight forward or make a turn. If the perception data indicates that the intersection has no traffic light, prediction module **303** may predict that the vehicle may have to fully stop prior to enter the intersection. If the perception data indicates that the vehicle is currently at a left-turn only lane or a right-turn only lane, prediction module **303** may predict that the vehicle will more likely make a left turn or right turn respectively.

For each of the objects, decision module **304** makes a decision regarding how to handle the object. For example, for a particular object (e.g., another vehicle in a crossing route) as well as its metadata describing the object (e.g., a speed, direction, turning angle), decision module **304** decides how to encounter the object (e.g., overtake, yield, stop, pass). Decision module **304** may make such decisions according to a set of rules such as traffic rules or driving rules **312**, which may be stored in persistent storage device **352**.

Routing module **307** is configured to provide one or more routes or paths from a starting point to a destination point. For a given trip from a start location to a destination location, for example, received from a user, routing module **307** obtains route and map information **311** and determines all possible routes or paths from the starting location to reach the destination location. Routing module **307** may generate a reference line in a form of a topographic map for each of the routes it determines from the starting location to reach the destination location. A reference line refers to an ideal route or path without any interference from others such as other vehicles, obstacles, or traffic condition. That is, if there is no other vehicle, pedestrians, or obstacles on the road, an ADV should exactly or closely follows the reference line. The topographic maps are then provided to decision module **304** and/or planning module **305**. Decision module **304** and/or planning module **305** examine all of the possible routes to select and modify one of the most optimal routes in view of other data provided by other modules such as traffic conditions from localization module **301**, driving environment perceived by perception module **302**, and traffic condition predicted by prediction module **303**. The actual path or route for controlling the ADV may be close to or different from the reference line provided by routing module **307** dependent upon the specific driving environment at the point in time.

Based on a decision for each of the objects perceived, planning module **305** plans a path or route for the ADV, as well as driving parameters (e.g., distance, speed, and/or turning angle), using a reference line provided by routing module **307** as a basis. That is, for a given object, decision module **304** decides what to do with the object, while planning module **305** determines how to do it. For example, for a given object, decision module **304** may decide to pass the object, while planning module **305** may determine whether to pass on the left side or right side of the object. Planning and control data is generated by planning module **305** including information describing how vehicle **101** would move in a next moving cycle (e.g., next route/path segment). For example, the planning and control data may instruct vehicle **101** to move 10 meters at a speed of 30 miles per hour (mph), then change to a right lane at the speed of 25 mph.

Based on the planning and control data, control module **306** controls and drives the ADV, by sending proper commands or signals to vehicle control system **111**, according to a route or path defined by the planning and control data. The planning and control data include sufficient information to drive the vehicle from a first point to a second point of a route or path using appropriate vehicle settings or driving parameters (e.g., throttle, braking, steering commands) at different points in time along the path or route.

In one embodiment, the planning phase is performed in a number of planning cycles, also referred to as driving cycles, such as, for example, in every time interval of 100 milliseconds (ms). For each of the planning cycles or driving cycles, one or more control commands will be issued based on the planning and control data. That is, for every 100 ms, planning module **305** plans a next route segment or path segment, for example, including a target position and the

time required for the ADV to reach the target position. Alternatively, planning module **305** may further specify the specific speed, direction, and/or steering angle, etc. In one embodiment, planning module **305** plans a route segment or path segment for the next predetermined period of time such as 5 seconds. For each planning cycle, planning module **305** plans a target position for the current cycle (e.g., next 5 seconds) based on a target position planned in a previous cycle. Control module **306** then generates one or more control commands (e.g., throttle, brake, steering control commands) based on the planning and control data of the current cycle.

Note that decision module **304** and planning module **305** may be integrated as an integrated module. Decision module **304**/planning module **305** may include a navigation system or functionalities of a navigation system to determine a driving path for the ADV. For example, the navigation system may determine a series of speeds and directional headings to affect movement of the ADV along a path that substantially avoids perceived obstacles while generally advancing the ADV along a roadway-based path leading to an ultimate destination. The destination may be set according to user inputs via user interface system **113**. The navigation system may update the driving path dynamically while the ADV is in operation. The navigation system can incorporate data from a GPS system and one or more maps so as to determine the driving path for the ADV.

In one embodiment, the PCIe reset module **308** is configured to reset PCIe devices mounted on the ADS compute board that are non-responsive or offline. FIGS. **4-7** provide further detail on the operation of the PCIe reset module **308**.

FIG. **4** illustrates a top view of an example ADV **101** and a block diagram of some of the components that make up or interact with the PCIe reset module **308** above. For example, in some embodiments, the PCIe reset module **308** is software or an integrated circuit configured to perform the steps described herein. In some embodiments, the ADV **101** includes an ADS **110** having one or more processors **403** and one or more PCIe devices **404** mounted thereon. The ADS further includes a programmable logic device (e.g., complex programmable logic device (CPLD) **406**) that manages power for the PCIe devices **404** of the ADS **110**. As shown in FIG. **4**, these components are in communication with one another and are a part of the ADV **101** and are used to (at least partially) control the ADV.

FIG. **5**A illustrates a block diagram of a system **500** for controlling PCIe devices on an ADS of an ADV. In some implementations, the system **500** includes one or more processors **403** and a non-transitory machine-readable medium **504**, such as a memory. In some implementations, the memory is coupled to the one or more processors **403** to store instructions (e.g., PCIe reset module **308**), which when executed by the one or more processors **403**, cause the one or more processors **403** to perform various functions. In some implementations, execution of the instructions cause the one or more processors **403** to scan one or more PCIe ports of the ADS **110** to discover one or more PCIe devices **404**A-**404**D mounted on the ADS **110**. For example, the ADS **110** may include a peripheral component interface board **502** that has mounted thereon one or more PCIe devices, such as, for example, PCIe device A **404**A, PCIe device B **404**B, PCIe device C **404**C, and PCIe device D **404**D. Execution of the instructions cause the one or more processors **403** to scan the PCIe ports on the peripheral component interface board **502** to identify the PCIe devices.

In some embodiments, the one or more PCIe devices includes one or more of: a graphics processing unit (GPU), a solid state drive (SSD), a network interface card (NIC), a video capture card, a serial advanced technology attachment (SATA) card, a non-volatile memory express (NVMe) card, or any other suitable PCIe device.

In some implementations, execution of the instructions causes the one or more processors **403** to create a list of discovered one or more PCIe devices discovered while scanning the PCIe ports. The list of discovered one or more PCIe devices may include all of the PCIe devices mounted on the peripheral component interface board **502** or the list could include less, based on whether any of the PCIe devices **404** are offline. For example, as shown in FIG. **5**B, PCIe device B **404**B is indicated as being offline. As such, the list of discovered one or more PCIe devices would include PCIe device A **404**A, PCIe device C **404**C, and PCIe device D **404**D, but PCIe device B **404**B would not be included on the list. Furthermore, the one or more processors **403** are caused, by execution of the instructions, to perform a comparison between the list of the discovered one or more PCIe devices and an expected list of PCIe devices for the ADS. In some implementations, the expected list of PCIe devices can be stored in a configuration file **505** stored in persistent storage, such as persistent storage device **352** of FIG. **3**A, and loaded to the non-transitory machine-readable medium **504** of the ADS **110** for access by the one or more processors **403**.

In some implementations, the one or more processors **403** are caused to determine an offline PCIe device (e.g., PCIe device B **404**B in the example above and shown in FIG. **5**B) based on the comparison, the offline PCIe device corresponding to a PCIe device that is present in the expected list of PCIe devices but not in the list of discovered PCIe devices. The ADS **110** includes a programmable logic device, such as CPLD **406**. The CPLD is used to control or manage power and other features of the PCIe devices **404** on the ADS. In order to reset the offline PCIe device, the one or more processors **403** are caused to transmit a device reset command to the programmable logic device (e.g., CPLD **406**) to reset the offline PCIe device. After receiving the device reset command from the one or more processors, the programmable logic device is caused to generate a reset control signal for the offline PCIe device to reset the offline PCIe device.

Referring to FIG. **5**B, and using the example above where PCIe device B **404**B is offline and not listed in the list of discovered one or more PCIe devices, the one or more processors **403** is caused to transmit a device reset command to the CPLD **406** to reset the PCIe device B **404**B. In some cases, the offline PCIe device will not immediately restart and may need additional restart attempts. FIG. **6**A below describes the process of additional restart attempts. In some embodiments, the ADS includes a human machine interface (HMI) **507** that allows an operator of the ADV to interact with the ADV and its component features, including the ADS. In some embodiments, as described further below, the offline PCIe device will not reset in response to the CPLD reset control signal, and a message will be displayed to the operator via the HMI **507**. The operator may then manually reset the PCIe device via the HMI.

FIG. **6**A is a flow chart **600** of an example process for restarting an offline PCIe device, such as offline PCIe device B **404**B shown in FIG. **5**B above. In some embodiments, the ADV is powered on and the ADS performs a system reboot **604**. Following reboot, the one or more processors **403** (e.g., CPU) scans **606** the PCIe ports for PCIe devices through, for example, the lspci Unix command. lspci is a command on Unix-like operating systems that outputs detailed information about all PCI buses and devices in the system. In some

embodiments, other PCI devices scanning and detection methodologies are used for other operating systems (OSs), such as, PCI scanning utility for windows OS. In some embodiments, one or more processors **403** (e.g., CPU) scans **606** the PCIe ports for PCIe devices periodically or in response to failure/unexpected events, e.g., PCIe reset failures or when processors **403** fail to communicate some PCIe devices. Similar to the procedure described above with respect to FIGS. **5**A and **5**B, the CPU then compares **608** the scanned result with a list of expected PCIe devices on a prepared configuration file stored in memory. The CPU then determines whether all expected PCIe devices were discovered by comparing the discovered PCIe devices list to the prepared configuration file **610**.

However, if at least one of the expected PCIe devices is not on the discovered list of PCIe devices, the CPU first determines how many reset commands it has sent **612** already for the offline PCIe device in a given period of time, and determines whether the number of reset commands already sent in the given period of time is less than or equal to a predefined threshold. The predefined threshold can be any suitable threshold based on the acceptable number of reset attempts for a given PCIe device. If the number of reset commands sent by the CPU is less than the predefined threshold, then the CPU will send a device reset command **614** to the CPLD device. The CPLD device receives the device reset command from the CPU and thereafter transmits **616** a reset control signal for the offline PCIe device to reset. The process the CPU follows if the number of reset commands sent by the CPU is equal to the predefined threshold is described further below.

In some embodiments, after the CPLD has sent the reset control signal to the offline PCIe device to reset, the CPU is caused to scan **606** to discover the one or more PCIe devices again. The CPU is further caused to determine a new list of discovered PCIe devices discovered thereby and compare **608** the new list of discovered PCIe devices to the expected list of PCIe devices in the configuration file. Next, the CPU is caused to determine **610** whether the offline PCIe device is discovered after the reset control signal from the programmable logic device. If the previously offline PCIe device is now on the discovered list of PCIe devices, the CPU operations end for this iteration. If the offline PCIe device is not present in the new list of discovered PCIe devices, the CPU again determines **612** if the number of device reset commands that has been sent for the offline PCIe device during a given period of time is equal to or less than the predefined threshold. If the number of device reset commands has reached the predefined threshold, then the CPU is further caused to determine whether an operator (e.g., a safety driver) is onboard the ADV **618**. If the operator or safety driver is onboard the ADV (e.g., detected by a weight sensor at a driver's seat), the CPU is further caused to report **622** a restart failure of the offline PCIe device to a human machine interface (HMI) of the ADS so that the offline PCIe device can be reviewed for failure or restarted manually by the operator.

In one embodiment, if an operator or safety driver is not onboard the ADV, the CPU is further caused to report **620** a restart failure of the offline PCIe device to a remote computer (e.g., cloud server **103** shown in FIG. **1**) in communication with the ADV for remote restart (e.g., remote interrupt) of the PCIe device.

FIG. **6**B illustrates an example configuration file **630** and example discovered PCIe device list **640**. As illustrated, the configuration file **640** includes PCIe devices expected on ports 0, 1, 2 . . . , N. As indicated by the discovered PCIe device list **640**, the discovered PCIe devices were found on ports 0, 1, and 5. No PCIe devices were discovered on Port 2. As detailed herein, the CPU would compare the discovered list **640** list to the expected list in the configuration file and send a device reset command to the programmable logic device (e.g., a CPLD) to reset the PCIe device on port 2.

FIG. **7** illustrates a flow chart of an example computer-implemented method **700** for controlling PCIe devices on an ADS of an ADV. Process **700** may be performed by processing logic which may include software, hardware, or a combination thereof. For example, process **700** may be performed by PCIe reset module **308** of FIG. **3**A. In block **702**, the method **700** includes scanning one or more PCIe ports of the ADS to discover one or more PCIe devices mounted on the ADS. In block **704**, the method includes performing a comparison between a list of the discovered one or more PCIe devices and an expected list of PCIe devices for the ADS. In block **706**, the method includes determining an offline PCIe device based on the comparison, the offline PCIe device corresponding to a PCIe device that is present in the expected list of PCIe devices but not in the list of discovered PCIe devices. In block **708**, the method includes transmitting a device reset command to a programmable logic device that manages power for PCIe devices of the ADS to reset the offline PCIe device, wherein the programmable logic device is caused to generate a reset control signal for the offline PCIe device to reset the offline PCIe device.

Note that some or all of the components as shown and described above may be implemented in software, hardware, or a combination thereof. For example, such components can be implemented as software installed and stored in a persistent storage device, which can be loaded and executed in a memory by a processor (not shown) to carry out the processes or operations described throughout this application. Alternatively, such components can be implemented as executable code programmed or embedded into dedicated hardware such as an integrated circuit (e.g., an application specific IC or ASIC), a digital signal processor (DSP), or a field programmable gate array (FPGA), which can be accessed via a corresponding driver and/or operating system from an application. Furthermore, such components can be implemented as specific hardware logic in a processor or processor core as part of an instruction set accessible by a software component via one or more specific instructions.

Some portions of the preceding detailed descriptions have been presented in terms of algorithms and symbolic representations of operations on data bits within a computer memory. These algorithmic descriptions and representations are the ways used by those skilled in the data processing arts to most effectively convey the substance of their work to others skilled in the art. An algorithm is here, and generally, conceived to be a self-consistent sequence of operations leading to a desired result. The operations are those requiring physical manipulations of physical quantities.

It should be borne in mind, however, that all of these and similar terms are to be associated with the appropriate physical quantities and are merely convenient labels applied to these quantities. Unless specifically stated otherwise as apparent from the above discussion, it is appreciated that throughout the description, discussions utilizing terms such as those set forth in the claims below, refer to the action and processes of a computer system, or similar electronic computing device, that manipulates and transforms data represented as physical (electronic) quantities within the computer system's registers and memories into other data similarly represented as physical quantities within the computer system memories or registers or other such information storage, transmission or display devices.

Embodiments of the disclosure also relate to an apparatus for performing the operations herein. Such a computer program is stored in a non-transitory computer readable medium. A machine-readable medium includes any mechanism for storing information in a form readable by a machine (e.g., a computer). For example, a machine-readable (e.g., computer-readable) medium includes a machine (e.g., a computer) readable storage medium (e.g., read only memory ("ROM"), random access memory ("RAM"), magnetic disk storage media, optical storage media, flash memory devices).

The processes or methods depicted in the preceding figures may be performed by processing logic that comprises hardware (e.g. circuitry, dedicated logic, etc.), software (e.g., embodied on a non-transitory computer readable medium), or a combination of both. Although the processes or methods are described above in terms of some sequential operations, it should be appreciated that some of the operations described may be performed in a different order. Moreover, some operations may be performed in parallel rather than sequentially.

Embodiments of the present disclosure are not described with reference to any particular programming language. It will be appreciated that a variety of programming languages may be used to implement the teachings of embodiments of the disclosure as described herein.

In the foregoing specification, embodiments of the disclosure have been described with reference to specific exemplary embodiments thereof. It will be evident that various modifications may be made thereto without departing from the broader spirit and scope of the disclosure as set forth in the following claims. The specification and drawings are, accordingly, to be regarded in an illustrative sense rather than a restrictive sense.

What is claimed is:

1. A computer-implemented method for controlling peripheral component interconnect express (PCIe) devices on an autonomous driving system (ADS) of an autonomous driving vehicle (ADV), the method comprising:

scanning one or more PCIe ports of the ADS to discover one or more PCIe devices mounted on the ADS;

performing a comparison between a list of the discovered one or more PCIe devices and an expected list of PCIe devices for the ADS;

determining an offline PCIe device based on the comparison, the offline PCIe device corresponding to a PCIe device that is present in the expected list of PCIe devices but not in the list of the discovered PCIe devices; and

transmitting a device reset command to a programmable logic device that manages power for PCIe devices of the ADS to reset the offline PCIe device.

2. The method of claim **1**, wherein the programmable logic device is configured to generate and send a reset control signal for the offline PCIe device to reset the offline PCIe device.

3. The method of claim **2**, further comprising:

scanning to discover the one or more PCIe devices again after the reset control signal is sent by the programmable logic device;

determining a new list of discovered PCIe devices;

comparing the new list of discovered PCIe devices to the expected list of PCIe devices; and determining whether the offline PCIe device is discovered after the reset control signal from the programmable logic device.

4. The method of claim 3, further comprising, in response to the offline PCIe device not being present in the new list of discovered PCIe devices, determining if a number of device reset commands that has been sent for the offline PCIe device during a given period of time is equal to or less than a predefined threshold.

5. The method of claim 4, further comprising, if the number of device reset commands is less than the predefined threshold, transmitting the device reset command to the programmable logic device again to reset the offline PCIe device.

6. The method of claim 5, further comprising, if the number of device reset commands is equal to the predefined threshold, determining whether an operator is onboard the ADV.

7. The method of claim 6, further comprising, in response to an operator being onboard the ADV, reporting a restart failure of the offline PCIe device to a human machine interface (HMI) of the ADS, such that the offline PCIe device can be reviewed for failure or restarted manually by the operator.

8. The method of claim 6, further comprising, in response to an operator not being onboard the ADV, reporting a restart failure of the offline PCIe device to a remote computer in communication with the ADV for remote restart of the offline PCIe device.

9. The method of claim 1, wherein the one or more PCIe devices comprise one or more of: a graphics processing unit (GPU), a solid state drive (SSD), a network interface card (NIC), a video capture card, a serial advanced technology attachment (SATA) card, or non-volatile memory express (NVMe) card.

10. A non-transitory machine-readable medium for controlling peripheral component interconnect express (PCIe) devices on an autonomous driving system (ADS) of an autonomous driving vehicle (ADV), the machine-readable medium having instructions stored therein, which when executed by a processor, cause the processor to perform operations, the operations comprising:

scanning one or more PCIe ports of the ADS to discover one or more PCIe devices mounted on the ADS;

performing a comparison between a list of the discovered one or more PCIe devices and an expected list of PCIe devices for the ADS;

determining an offline PCIe device based on the comparison, the offline PCIe device corresponding to a PCIe device that is present in the expected list of PCIe devices but not in the list of discovered PCIe devices; and

transmitting a device reset command to a programmable logic device that manages power for PCIe devices of the ADS to reset the offline PCIe device.

11. The non-transitory machine-readable medium of claim 10, wherein the programmable logic device is caused to generate and send a reset control signal for the offline PCIe device to reset the offline PCIe device.

12. The non-transitory machine-readable medium of claim 11, wherein the operations further comprise:

scanning to discover the one or more PCIe devices again after the reset control signal is sent by the programmable logic device;

determining a new list of discovered PCIe devices discovered by the processor;

comparing the new list of discovered PCIe devices to the expected list of PCIe devices; and

determining whether the offline PCIe device is discovered after the reset control signal from the programmable logic device.

13. The non-transitory machine-readable medium of claim 12, wherein in response to the offline PCIe device not being present in the new list of the discovered PCIe devices, the operations further comprise determining if a number of device reset commands that has been sent for the offline PCIe device during a given period of time is equal to or less than a predefined threshold.

14. The non-transitory machine-readable medium of claim 13, wherein if the number of device reset commands is less than the predefined threshold, the operations further comprise transmitting the device reset command to the programmable logic device again to reset the offline PCIe device.

15. The non-transitory machine-readable medium of claim 14, wherein if the number of device reset commands is equal to the predefined threshold, the operations further comprise determining whether an operator is onboard the ADV.

16. The non-transitory machine-readable medium of claim 15, wherein in response to an operator being onboard the ADV, the operations further comprise reporting a restart failure of the offline PCIe device to a human machine interface (HMI) of the ADS so that the offline PCIe device can be reviewed for failure or restarted manually by the operator.

17. The non-transitory machine-readable medium of claim 15, wherein in response to an operator not being onboard the ADV, the operations further comprise reporting a restart failure of the offline PCIe device to a remote computer in communication with the ADV for remote restart of the offline PCIe device.

18. The non-transitory machine-readable medium of claim 10, wherein the one or more PCIe devices comprise one or more of: a graphics processing unit (GPU), a solid state drive (SSD), a network interface card (NIC), a video capture card, a serial advanced technology attachment (SATA) card, or non-volatile memory express (NVMe) card.

19. A system for controlling peripheral component interconnect express (PCIe) devices on an autonomous driving system (ADS) of an autonomous driving vehicle (ADV), the system comprising:

one or more processors; and

a memory coupled to the one or more processors to store instructions, which when executed by the one or more processors, cause the one or more processors to:

scan one or more PCIe ports of the ADS to discover one or more PCIe devices mounted on the ADS;

perform a comparison between a list of the discovered one or more PCIe devices and an expected list of PCIe devices for the ADS;

determine an offline PCIe device based on the comparison, the offline PCIe device corresponding to a PCIe device that is present in the expected list of PCIe devices but not in the list of the discovered PCIe devices; and

transmit a device reset command to a programmable logic device that manages power for PCIe devices of the ADS to reset the offline PCIe device.

20. The system of claim 19, wherein the programmable logic device is configured to generate a reset control signal for the offline PCIe device to reset the offline PCIe device.

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