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Gariepy et al.

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(54) **DISTRIBUTED HARDWARE ARCHITECTURE FOR UNMANNED VEHICLES**

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(51) **Int. Cl.**

G05D 1/00	(2006.01)
B60L 9/00	(2006.01)
B25J 5/00	(2006.01)

(52) **U.S. Cl.**
USPC **701/2**; 701/22; 318/568.12

(58) **Field of Classification Search**
USPC 700/245, 263, 297, 9; 701/2, 99; 713/300
See application file for complete search history.

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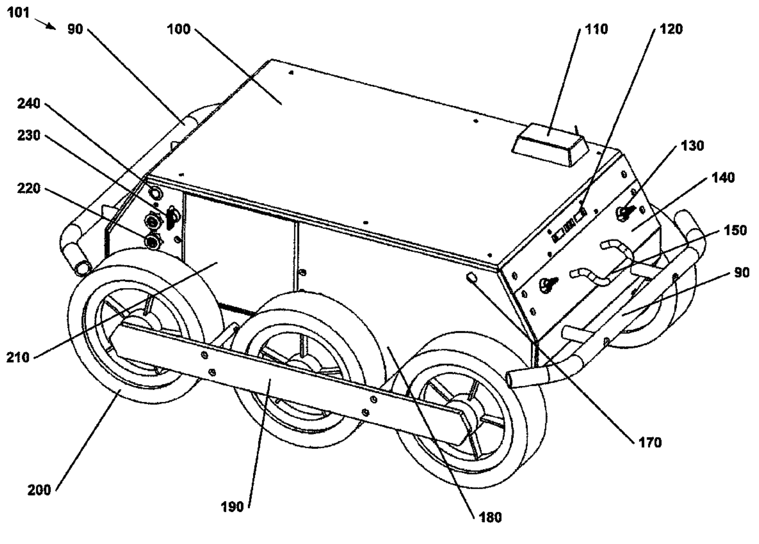
(57) **ABSTRACT**

A distributed hardware system for unmanned vehicles is provided, comprising a plurality of electronic hardware modules in communication via a vehicle control network. Each module is enabled to: communicate with one another, issue requests for information from a central control module, and transmit data over the network in a common format to perform respective tasks; and at least one of: independently sense one or more of: a respective status of the distributed hardware system and at least one respective environmental parameter; and independently control the respective function of a vehicle. A portion of the modules can enabled to: be removed and inserted from the distributed hardware system as plug and play modules; and determine when at least one of the modules is removed/inserted from the distributed hardware system and transition to a corresponding state. The system also includes a power management system which includes capacity monitoring and hot-swap capabilities.

16 Claims, 15 Drawing Sheets



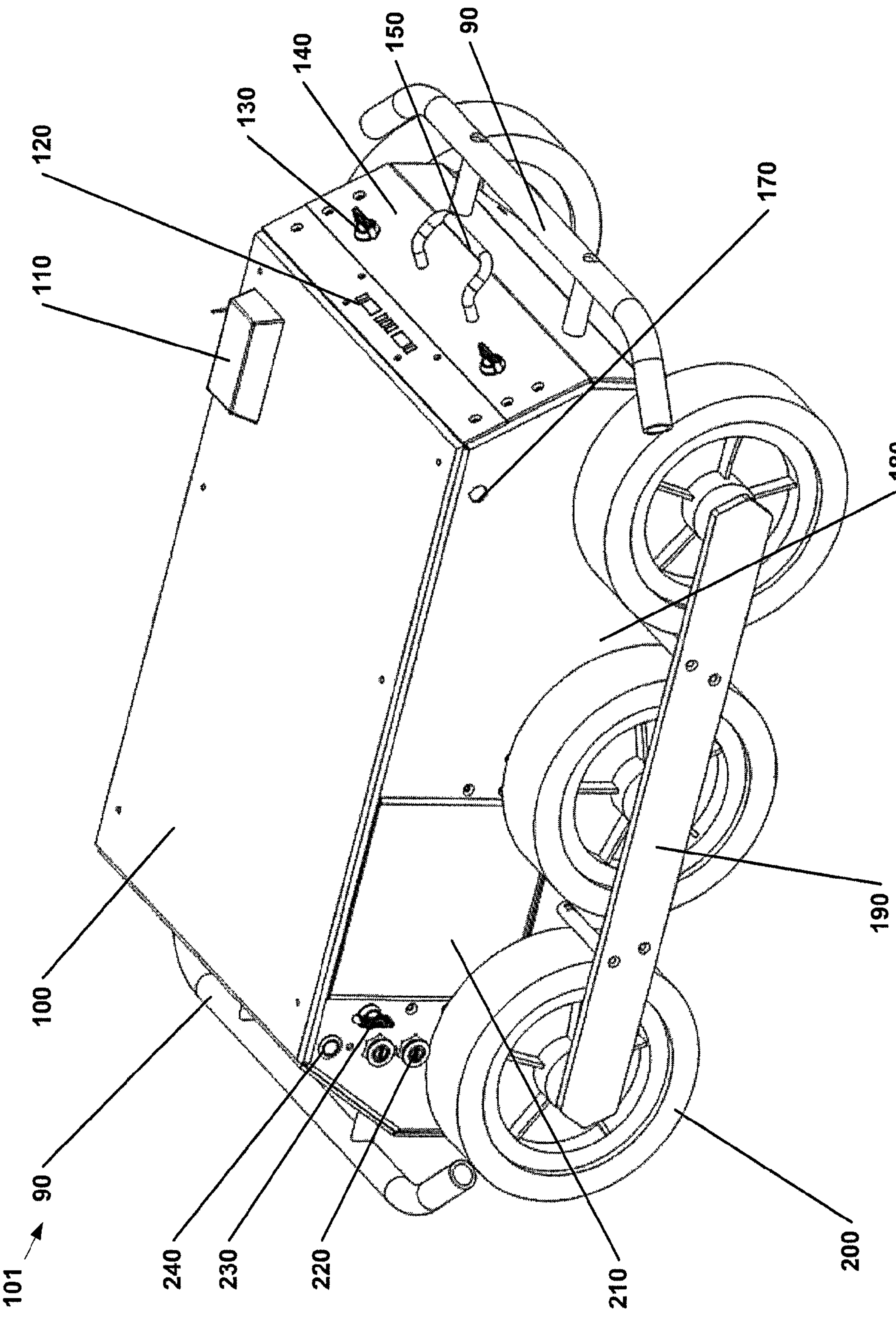


Fig. 1

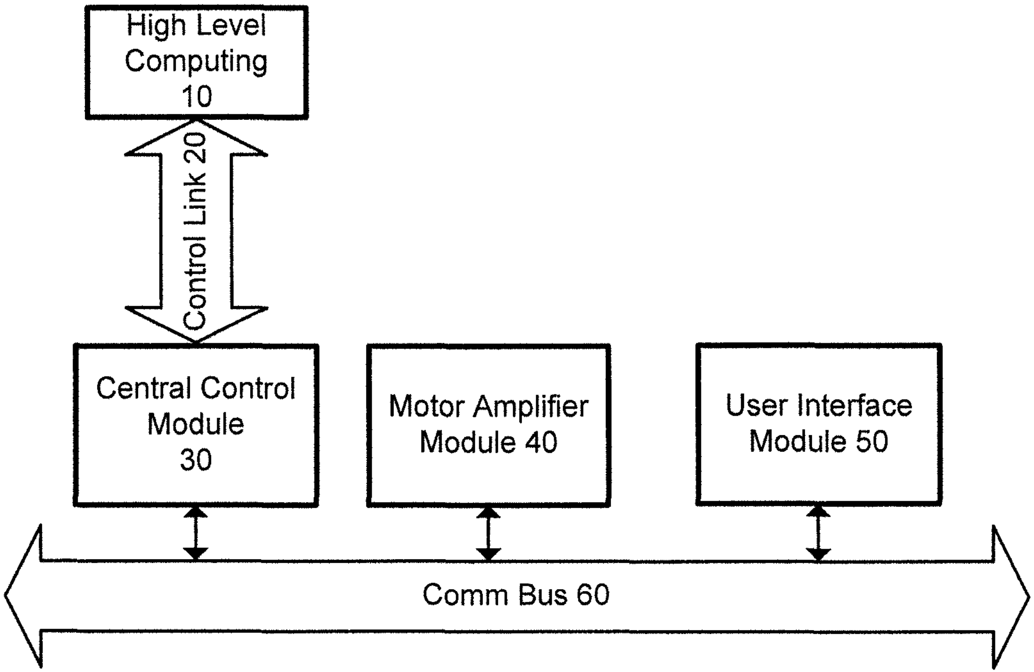

High Level Computing 10
Control Link 20
Central Control Module 30
Motor Amplifier Module 40
User Interface Module 50
Comm Bus 60

Fig. 2a

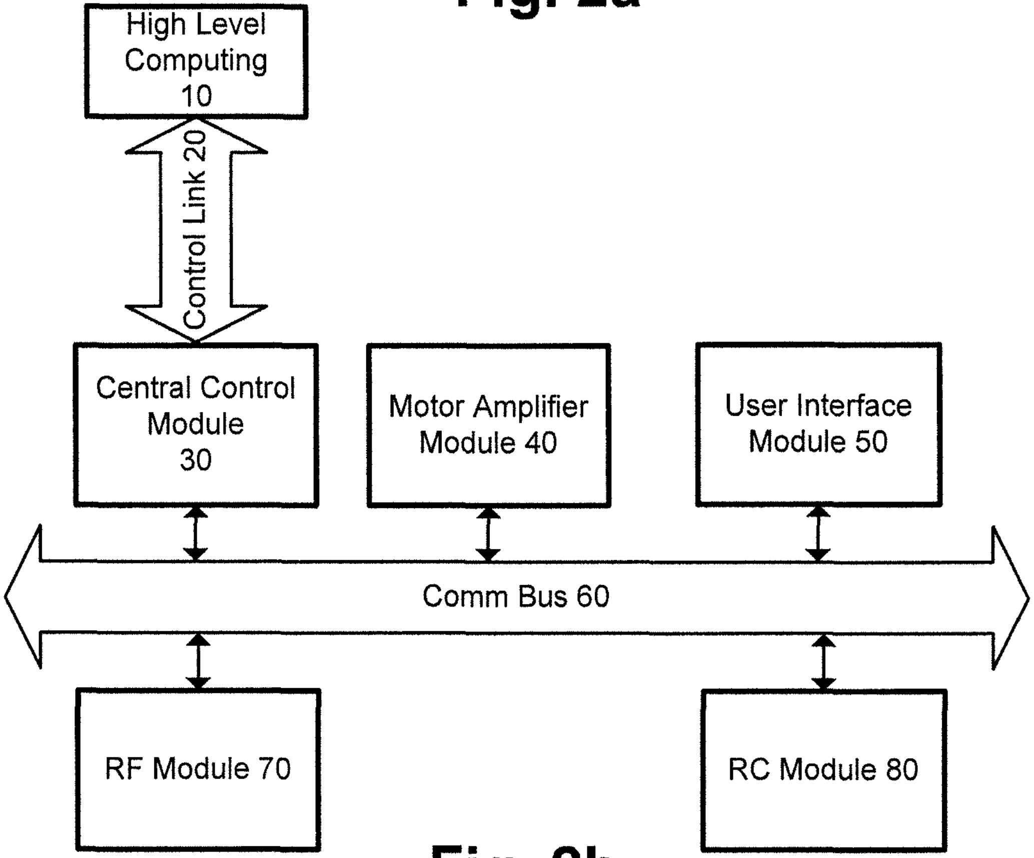

High Level Computing 10
Control Link 20
Central Control Module 30
Motor Amplifier Module 40
User Interface Module 50
Comm Bus 60
RF Module 70
RC Module 80

Fig. 2b

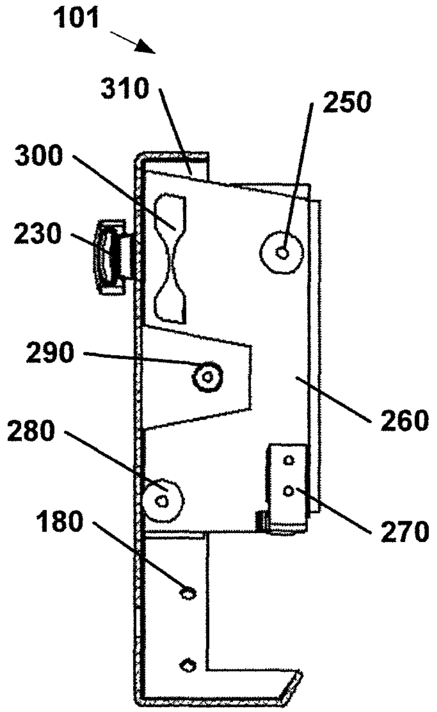


Fig. 3a

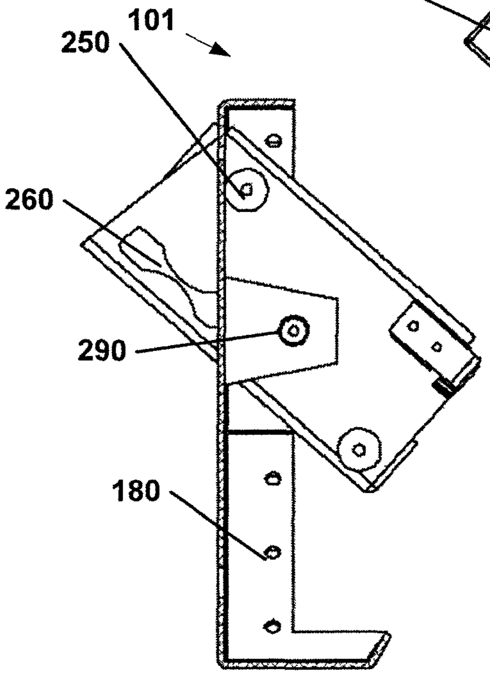


Fig. 3b

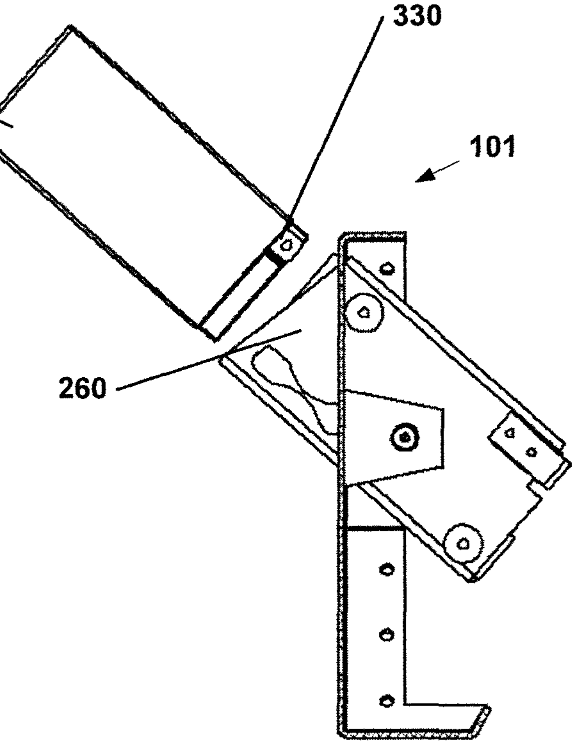


Fig. 3c

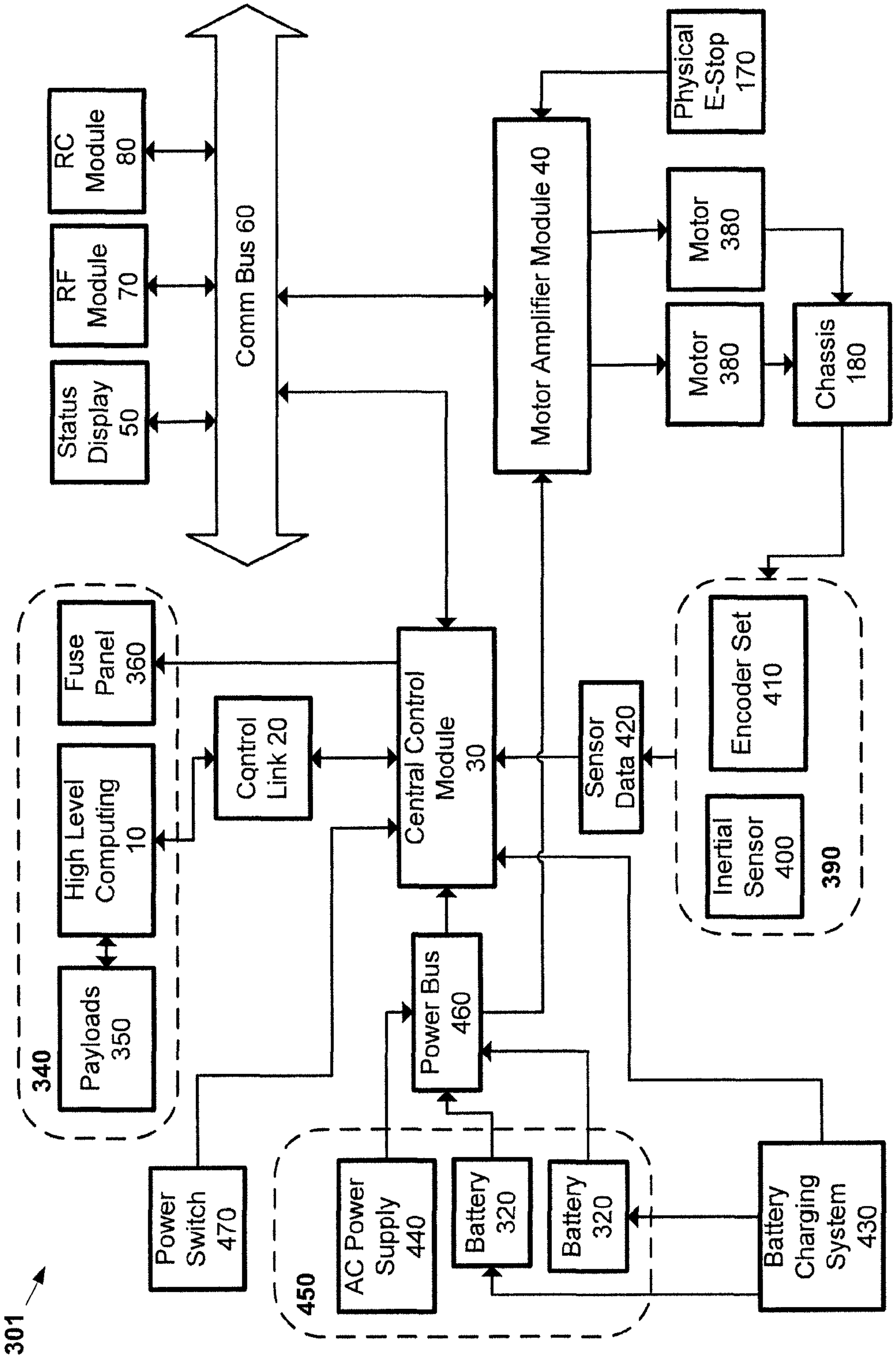

301
Status Display 50
RF Module 70
RC Module 80
Comm Bus 60
Physical E-Stop 170
Motor Amplifier Module 40
Motor 380
Motor 380
Chassis 180
340
Payloads 350
High Level Computing 10
Fuse Panel 360
Control Link 20
Central Control Module 30
Sensor Data 420
390
Inertial Sensor 400
Encoder Set 410
Power Bus 460
Power Switch 470
450
AC Power Supply 440
Battery 320
Battery 320
Battery Charging System 430

Fig. 4

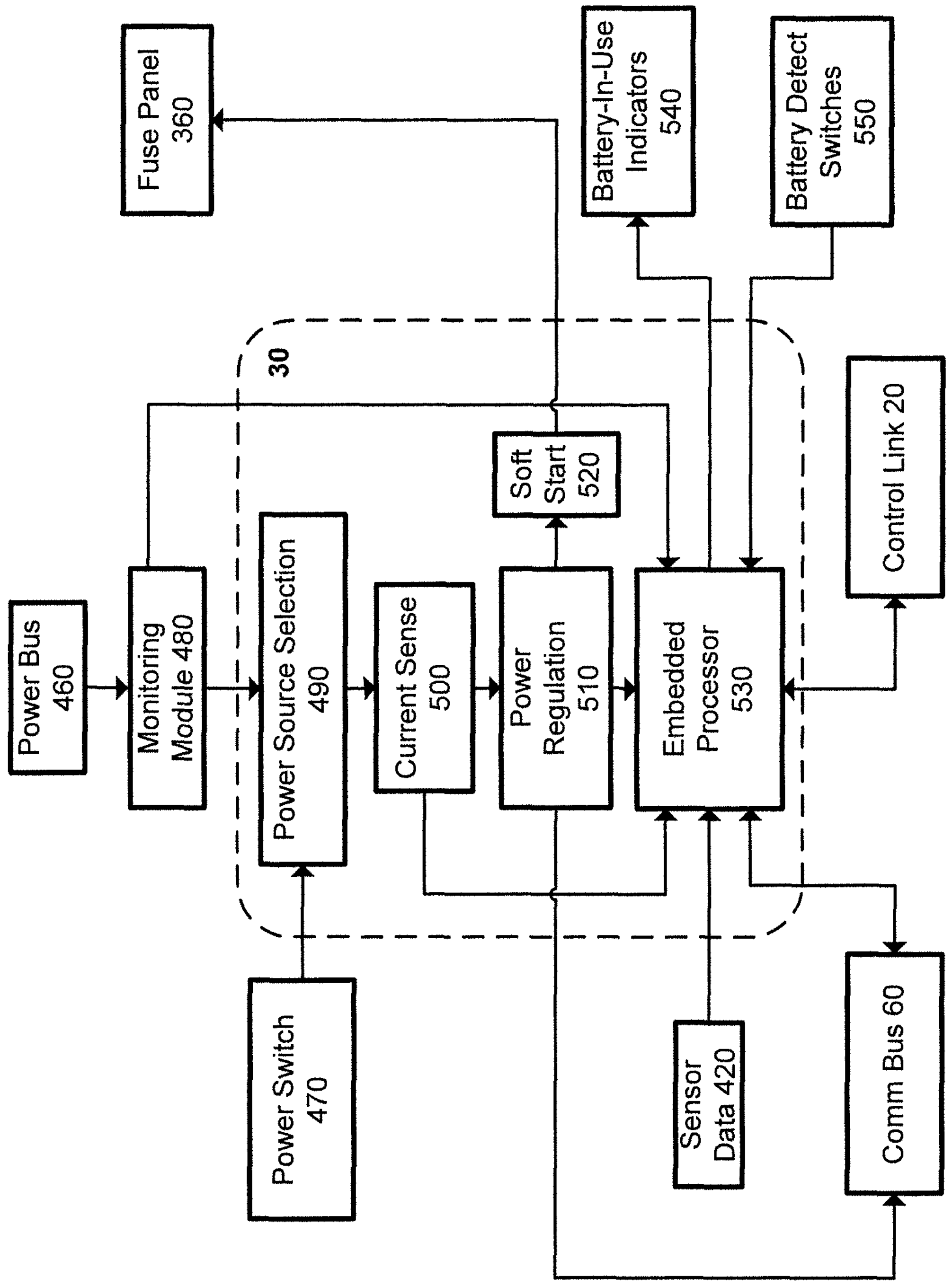

Fuse Panel 360
Battery-In-Use Indicators 540
Battery Detect Switches 550
30
Power Bus 460
Monitoring Module 480
Power Source Selection 490
Current Sense 500
Power Regulation 510
Soft Start 520
Embedded Processor 530
Control Link 20
Power Switch 470
Sensor Data 420
Comm Bus 60

Fig. 5

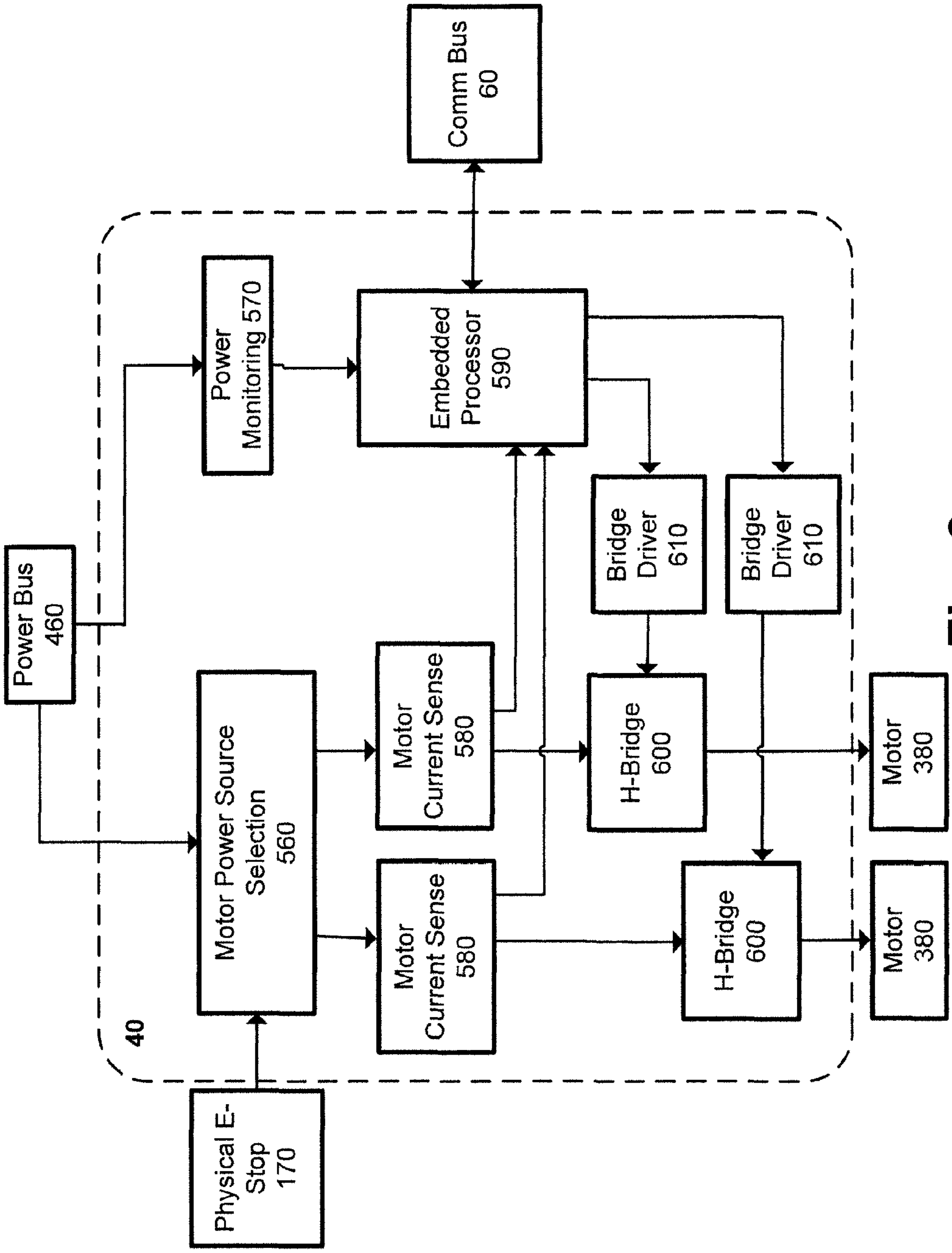

Comm Bus
60
Power Bus
460
Power
Monitoring 570
Embedded
Processor
590
Bridge
Driver
610
Bridge
Driver
610
Motor Power Source
Selection
560
Motor
Current Sense
580
Motor
Current Sense
580
H-Bridge
600
H-Bridge
600
Motor
380
Motor
380
40
Physical E-
Stop
170

Fig. 6

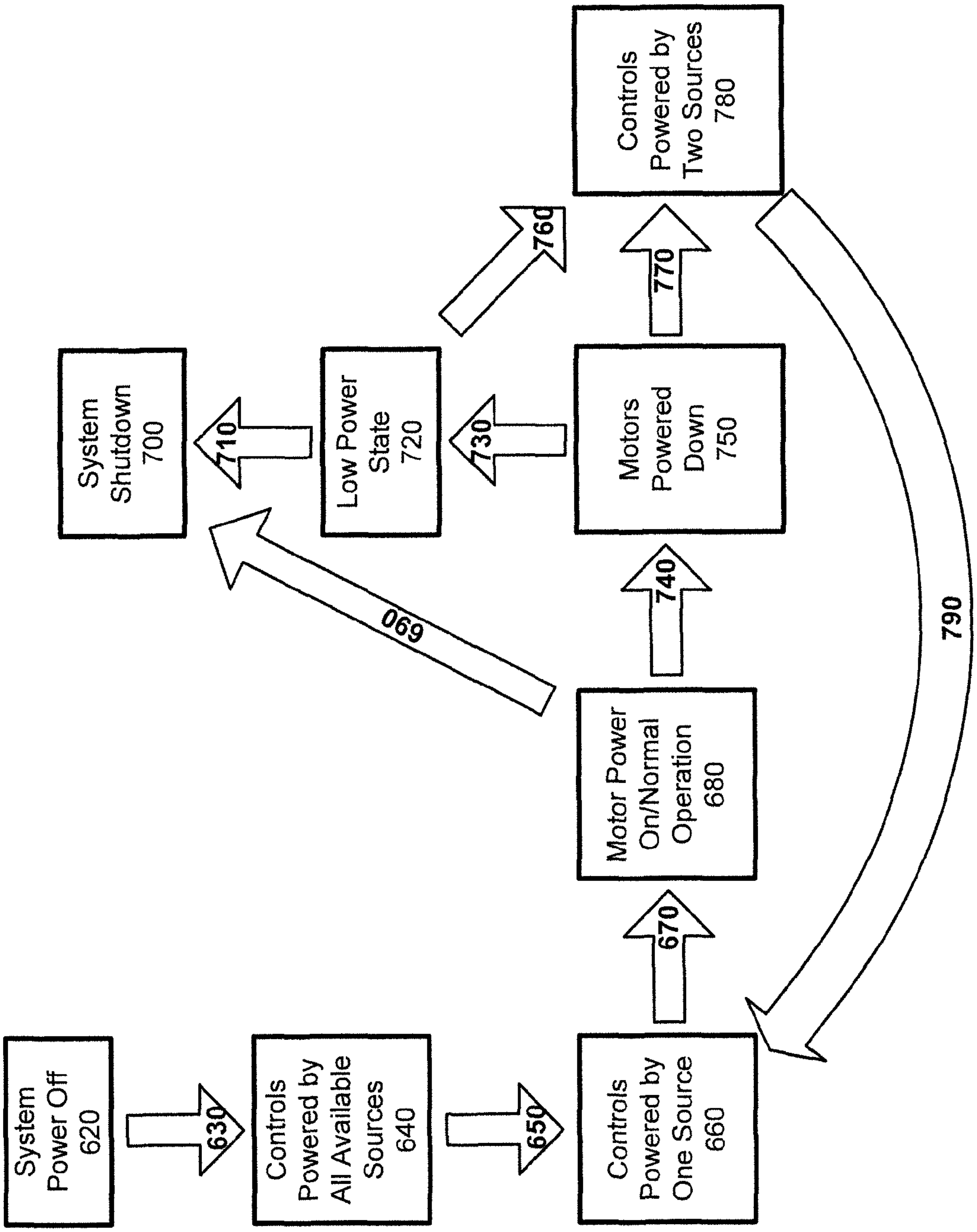

System Power Off 620
630
Controls Powered by All Available Sources 640
650
Controls Powered by One Source 660
670
Motor Power On/Normal Operation 680
690
740
Motors Powered Down 750
730
Low Power State 720
710
System Shutdown 700
760
770
Controls Powered by Two Sources 780
790

Fig. 7

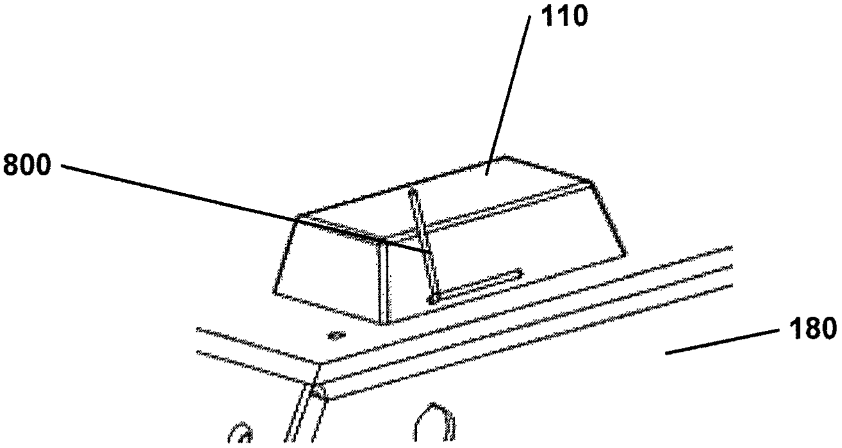


Fig. 8

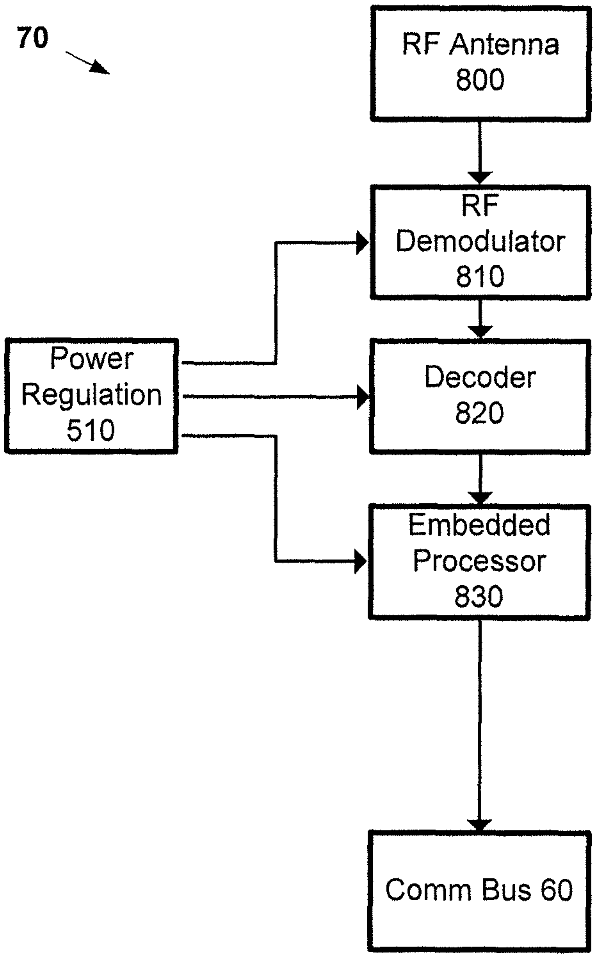

70
RF Antenna 800
RF Demodulator 810
Power Regulation 510
Decoder 820
Embedded Processor 830
Comm Bus 60

Fig. 9

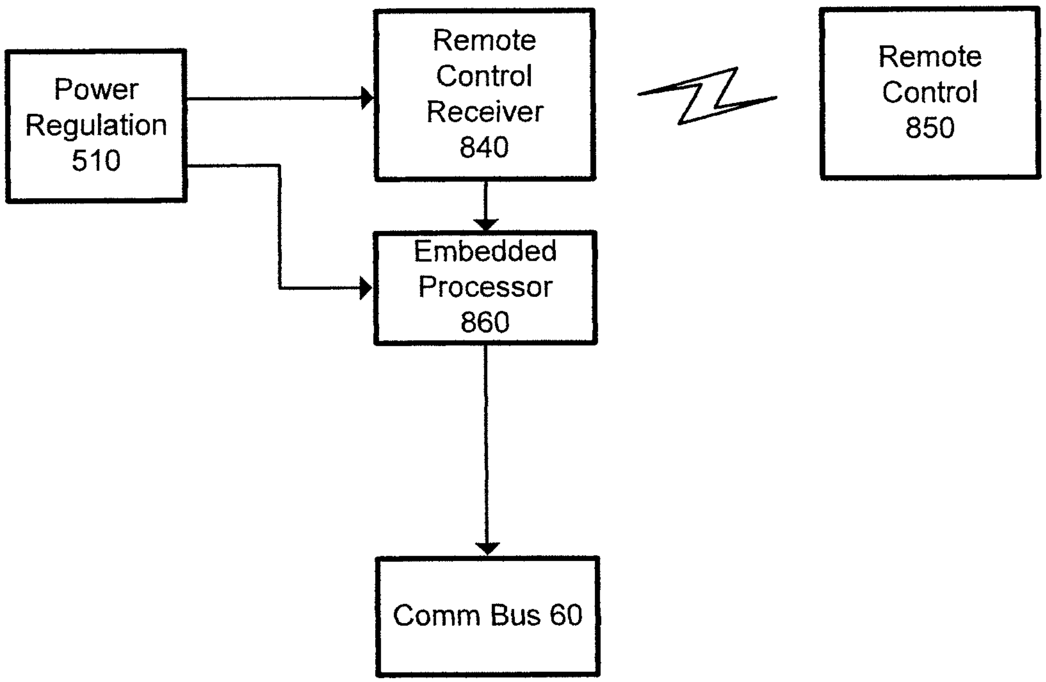

Power
Regulation
510
Remote
Control
Receiver
840
Remote
Control
850
Embedded
Processor
860
Comm Bus 60

Fig. 10

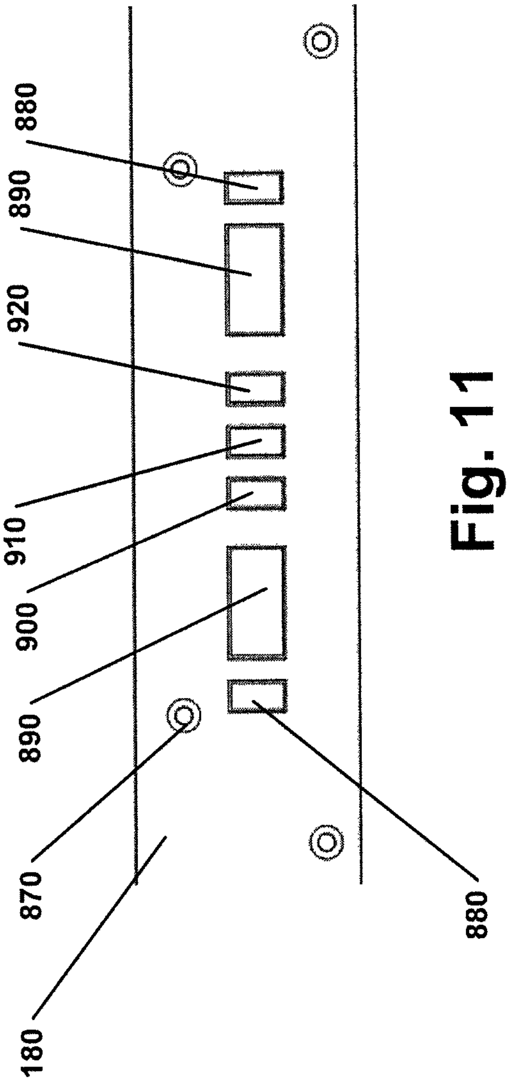


Fig. 11

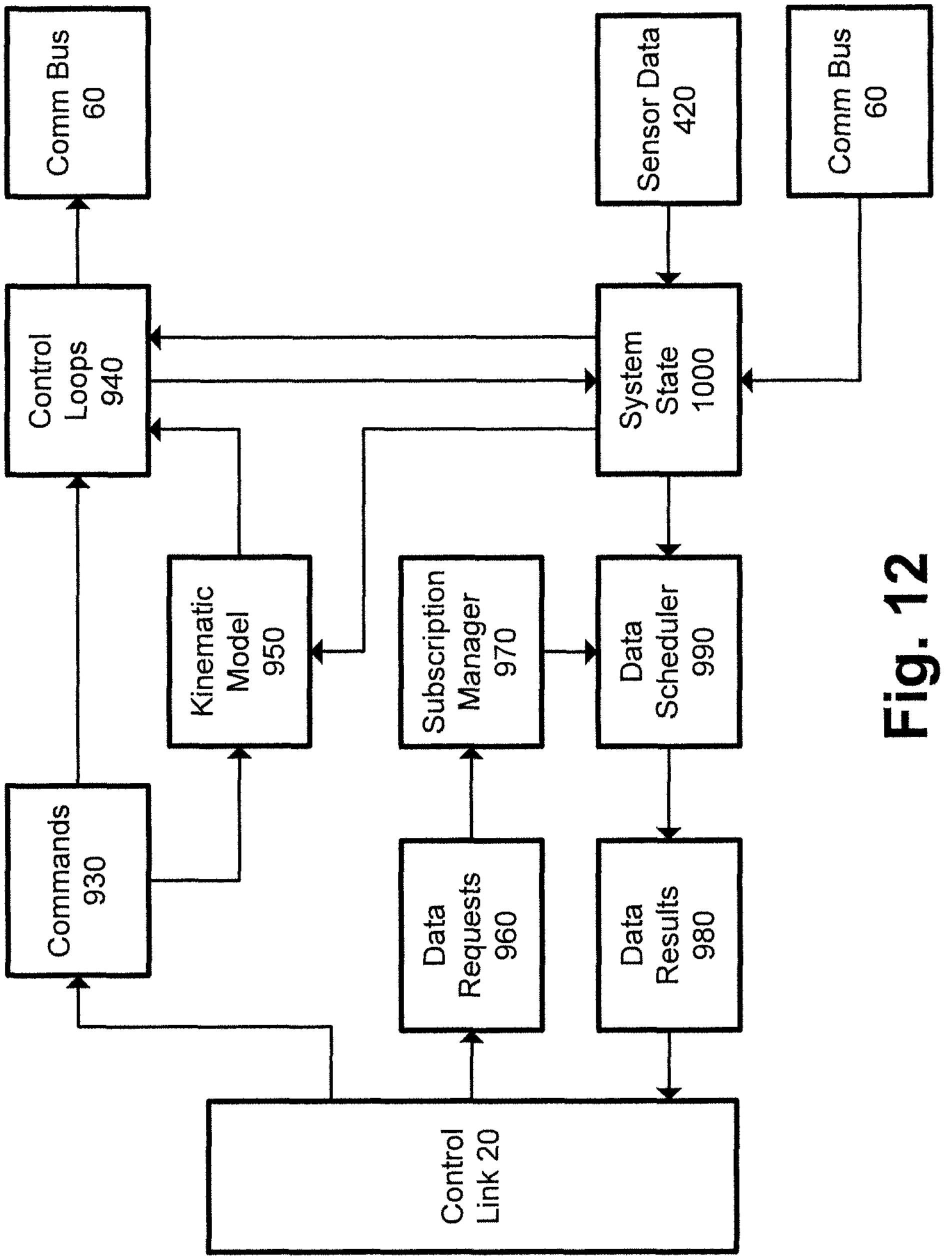

Control Link 20
Commands 930
Data Requests 960
Data Results 980
Kinematic Model 950
Subscription Manager 970
Data Scheduler 990
Control Loops 940
System State 1000
Comm Bus 60
Sensor Data 420
Comm Bus 60

Fig. 12

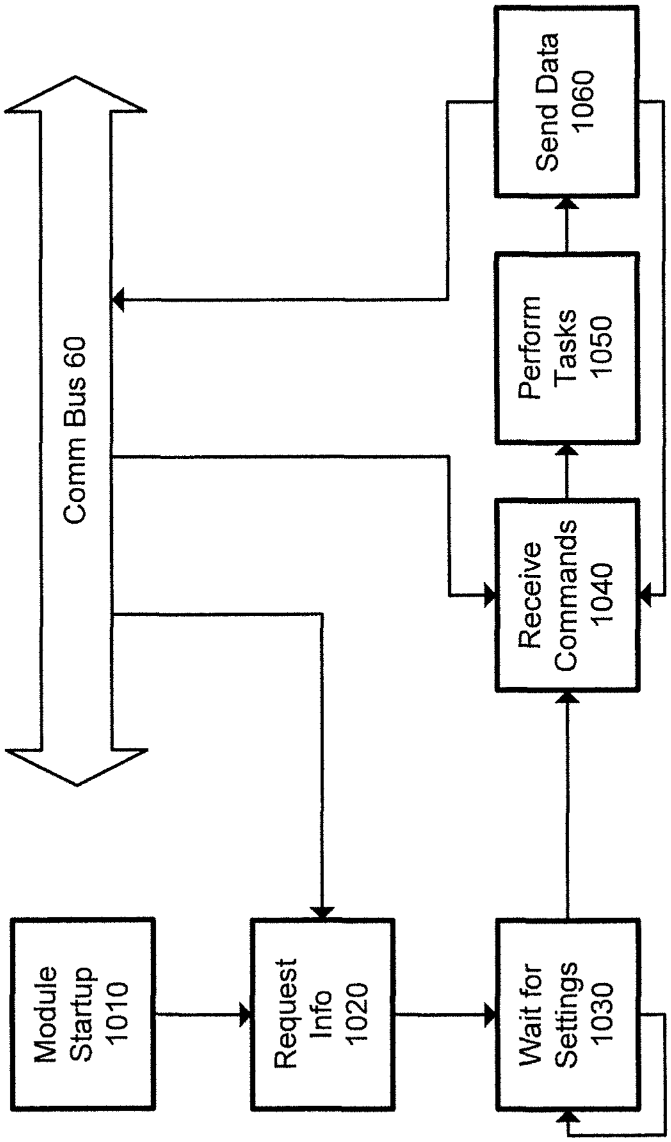

Comm Bus 60
Module Startup 1010
Request Info 1020
Wait for Settings 1030
Receive Commands 1040
Perform Tasks 1050
Send Data 1060

Fig. 13

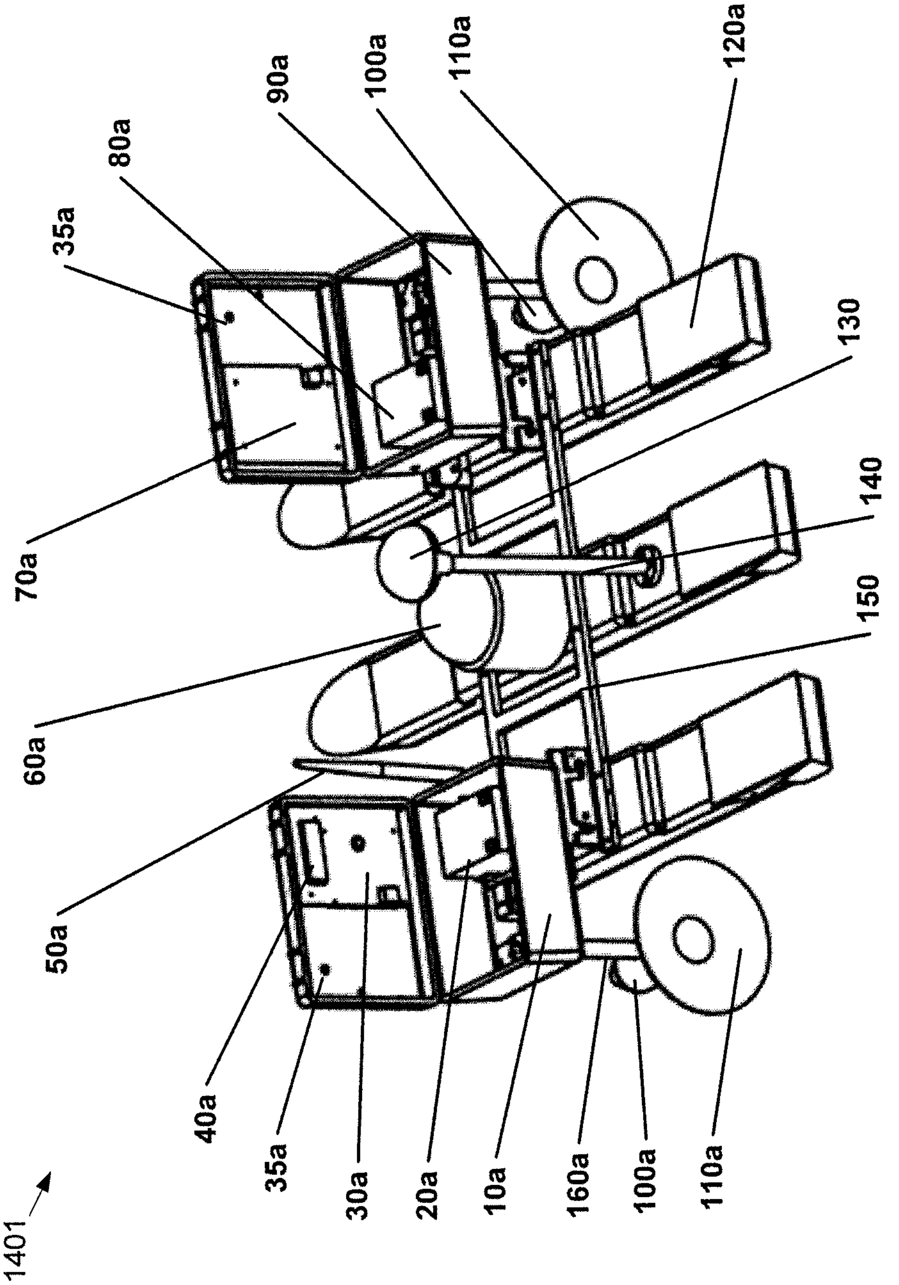

1401
40a
35a
30a
20a
10a
160a
100a
110a
50a
60a
70a
35a
80a
90a
100a
110a
120a
130
140
150

Fig. 14

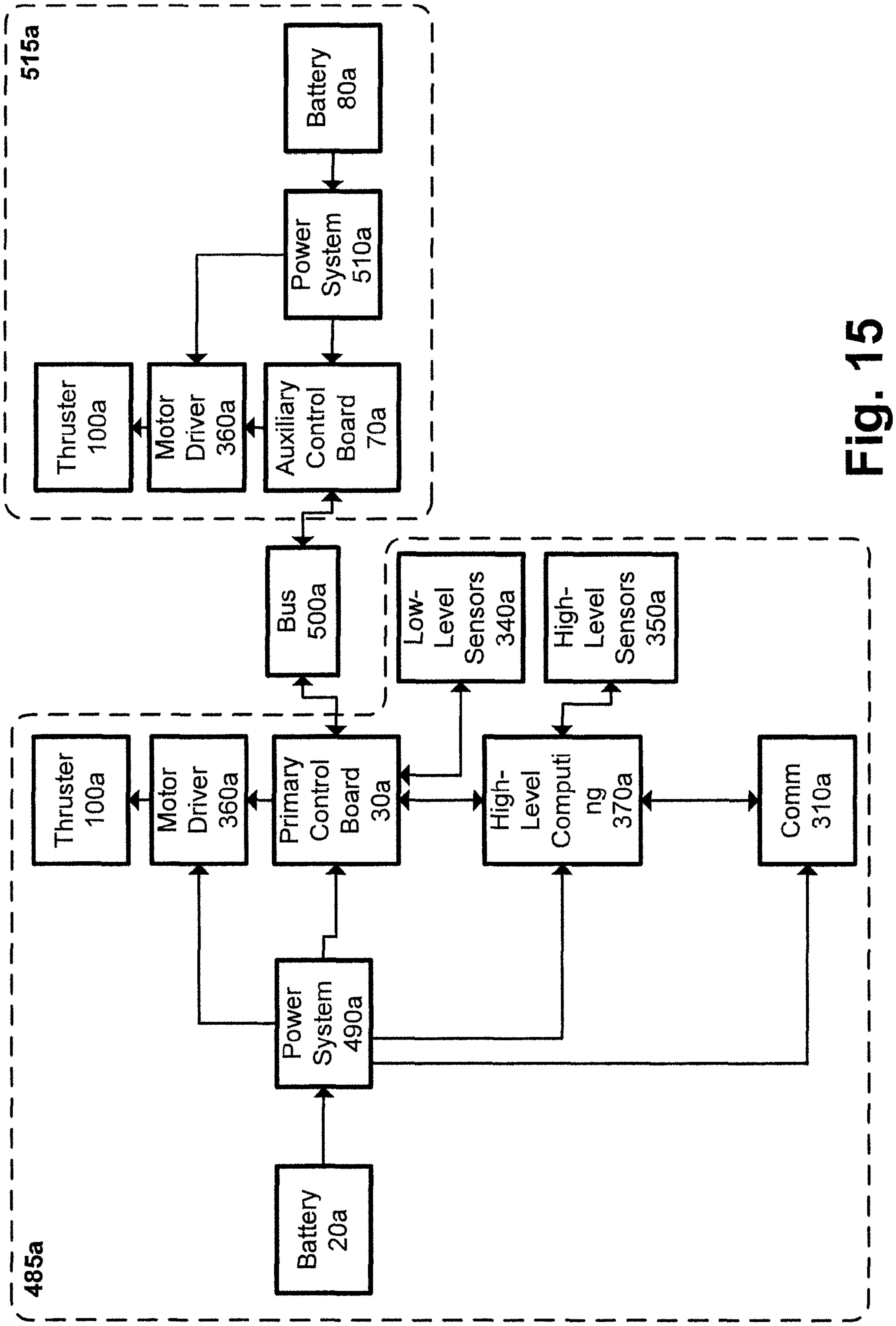

515a
Battery 80a
Power System 510a
Auxiliary Control Board 70a
Motor Driver 360a
Thruster 100a
Bus 500a
Low-Level Sensors 340a
High-Level Sensors 350a
485a
Battery 20a
Power System 490a
Primary Control Board 30a
Motor Driver 360a
Thruster 100a
High-Level Computing 370a
Comm 310a

Fig. 15

DISTRIBUTED HARDWARE ARCHITECTURE FOR UNMANNED VEHICLES

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application claims priority from U.S. Patent Application No. 61/282,991 filed on May 5, 2010, the contents being incorporated herein by reference.

FIELD

The specification relates generally to unmanned vehicles ("UVs"), and specifically to a distributed hardware architecture which can provide unmanned vehicles with a high degree of reliability and upgradeability.

BACKGROUND

Autonomous unmanned vehicle systems have existed in research labs for decades, and are now seeing increasing use outside of these controlled environments. Systems which were considered reliable from an experimental standpoint are now viewed as quite fragile when they are subjected to harsh environmental conditions and intensive use. They were originally only operated by those who designed them; they are now being placed in the hands of less technically adept individuals. Though many industrial or military grade UVs exist which can operate in such settings, they tend to be prohibitively expensive for most users.

Additionally, these systems were originally developed in a custom or low-production volume manner, where careful attention could be paid to individual units as they are constructed. As unmanned systems begin to be mass-produced, key components will need to be easily upgradable, without requiring major system architecture changes for each improvement. At the moment, the nature of many UVs precludes this. Many fully-closed systems exist wherein upgrades can only be performed by the manufacturer. Likewise, a great number of "modular" robotics platforms and hardware are on the market, but such hardware often requires a significant amount of effort by the user to integrate; they are not "plug-and-play".

It is therefore desirable to implement a hardware system architecture which is robust to failure, easy to use, and easily upgradeable as design improvements are made.

SUMMARY

It is an object of the present invention to increase the robustness and ease of use of unmanned vehicles. As well, it is a further object to allow unmanned vehicles to be upgraded easily by the user, without requiring hardware to be returned to the manufacturer or the user to possess highly technical skills.

The present invention is comprised of an unmanned vehicle platform with a set of components which are known to be applicable by those skilled in the art. These components may include actuators such as DC drive motors, pan/tilt sensor mounts, or standalone manipulator devices. Components may also include sensing modules such as scanning laser rangefinders, passive environmental sensors, inertial measurement units, drive encoders, camera assemblies, and global positioning systems. Finally, computing and communication modules such as processors, memory, 802.11 transceivers, point-to-point wireless control hardware, and hardwired user interfaces may also be included.

Each component is mounted either external to or within a vehicle platform, depending on specific component requirements. Sensors such as cameras or laser rangefinders tend to be mounted externally, while inertial measurement units, drive systems, and computational hardware can be mounted internally. The vehicle platform should be constructed to protect any internally mounted devices from harsh environmental conditions. Methods for this protection are well known to those in the field of electromechanical design.

The platform itself can incorporate one of many possible methods of moving through the environment. It can be an unmanned surface vehicle capable of navigating over water, an unmanned ground vehicle based on an existing manned vehicle chassis, a custom unmanned ground vehicle, or any other type of unmanned chassis known to the field. In an exemplary implementation, the platform is a custom all-electric 6×6 off-road chassis driven by brushed DC motors. However, in other implementations the platform can comprise any suitable platform including but not limited to unmanned vehicles, manned vehicles, aquatic vehicles, amphibious vehicles, aeronautic vehicles any other suitable vehicle, and/or a combination, or the like. In the off-road chassis implementation, steering can be achieved by a method which is known as "differential drive" to those skilled in the art. The entirety of the internal electronics and drive train is protected from the environment.

Key in the invention is the use of a managed power system to improve robustness and usability. As well as applying known methods to estimate power usage and battery capacity, the managed power system can be enabled to allow users to perform a tool less "hot-swap" of batteries if desired, allowing system runtime to be extended indefinitely with only intermittent interruptions to operation by battery changes and no interruptions to sensor or computational power.

The system also separates key hardware such as communications devices, power amplifiers, user interface hardware, and control processors into discrete modules linked via a central vehicle control network. An example implementation of this control network uses the well-known CAN (Controller Area Network) standard, which is commonly used in the automotive and aerospace sector. Each module can communicate with any other module on the network, and the network is structured such that the highest priority messages always make it to their recipients without requiring retransmission.

These discrete modules can be upgraded in the field without requiring manufacturer service. Additionally, since they exchange information in a common, well-defined manner, users do not have to modify any of the modules in a system when upgrading

An aspect of the specification provides a distributed hardware system for controlling a vehicle, comprising: a network; a central control module for controlling the distributed hardware system; a plurality of electronic hardware modules in communication with the central control module via the network, each of the plurality of electronic hardware modules enabled to: communicate with one another via the network; issue requests for information from the central control module via network; transmit data over the network in a common format to perform tasks respective to a respective function; and at least one of: independently sense one or more of: a respective status of the distributed hardware system and at least one respective environmental parameter; and

independently control the respective function of the vehicle, and at least a portion of the plurality of electronic hardware modules enabled to: be removed and inserted from the distributed hardware system as plug and play modules; and determine when at least one of the plurality of electronic hardware modules is removed or inserted from the distributed hardware system and transition to a corresponding state.

The distributed hardware system can further comprise at least one power source. The at least one power source can comprise at least two batteries and respective battery bins enabled to independently open such that a hot swap of a respective battery can be performed.

The control module can be enabled to control power to each of the plurality of electronic hardware modules. The distributed hardware system can further comprise at least a first power source powering the distributed hardware system and a second power source, wherein one or more of the control module and at least one of the plurality of electronic hardware modules can be further enabled to: determine that the first power source is no longer able to power the distributed hardware system; and implement a power down transition in the distributed hardware system such that powering of the distributed hardware system is switched to the second power source and a hot swap sequence can be implemented to remove the first power source and insert a third power source. The power down transition can comprise a motor power down transition. The one or more of the control module and at least one of the plurality of electronic hardware modules can be further enabled to enter a low power state until the hot swap sequence occurs.

The distributed hardware system can further comprise at least one sensor for sensing at least one of the respective status of the distributed hardware system and the at least one respective environmental parameter, wherein a respective one of the plurality of electronic hardware modules can be enabled for communication with the at least one sensor.

At least one of the plurality of electronic hardware modules can comprise a motor amplifier module for controlling a motor of the vehicle.

At least one of the plurality of electronic hardware modules can comprise a radio frequency (RF) module enabled to receive command data from a remote control system, translate the command data to the common format and communicate translated command data over the network.

At least one of the plurality of electronic hardware modules can comprise a remote control receiver enabled to receive command data from an off-the-shelf remote control receiver, translate the command data to the common format and communicate translated commands over the network.

At least one of the plurality of electronic hardware modules can comprise a user interface module enabled to at least one of receive command data from an input device and convey system data to a user.

The network can comprise at least one of a vehicle control network and a communication bus.

The distributed hardware system can further comprise at least one of a battery charging system and at least one motor.

The central control module can be enabled to communicate with a high level computing system via a control link.

The central control module can be enabled to store at least one of: system state information received from the plurality of electronic hardware modules; setting data; setpoint data; and a combination thereof.

BRIEF DESCRIPTIONS OF THE DRAWINGS

For a better understanding of the various implementations described herein and to show more clearly how they may be carried into effect, reference will now be made, by way of example only, to the accompanying drawings in which:

FIG. **1** depicts external characteristics features of an unmanned vehicle platform, according to non-limiting implementations.

FIGS. **2***a* and **2***b* depict two possible arrangements of internal modules of the unmanned vehicle platform of FIG. **1**, according to non-limiting implementations.

FIG. **3** is a depiction of a possible hot-swap capable battery receptacle

FIG. **4** depicts configuration of electronic modules and device network of the unmanned vehicle platform of FIG. **1**, according to non-limiting implementations

FIG. **5** depicts a configuration of a central control module of the unmanned vehicle platform of FIG. **1**, according to non-limiting implementations.

FIG. **6** depicts a configuration of a motor amplifier module of the unmanned vehicle platform, according to non-limiting implementations.

FIG. **7** depicts a process flow for a power management system that can be implemented by the unmanned vehicle platform of FIG. **1**, according to non-limiting implementations.

FIG. **8** depicts a remote receiver module mounted to chassis **180** of the unmanned vehicle platform of FIG. **1**, according to non-limiting implementations.

FIG. **9** depicts a configuration of an RF module of the unmanned vehicle platform of FIG. **1**, according to non-limiting implementations.

FIG. **10** depicts a configuration of a remote receiver module of the unmanned vehicle platform of FIG. **1**, according to non-limiting implementations.

FIG. **11** depicts a status display of the unmanned vehicle platform of FIG. **1**, according to non-limiting implementations.

FIG. **12** depicts an example program layout of vehicle control firmware of each module attached to the unmanned vehicle platform of FIG. **1** via a central vehicle control network, according to non-limiting implementations.

FIG. **13** depicts another example program layout of vehicle control firmware of each module attached to the unmanned vehicle platform of FIG. **1** via a central vehicle control network, according to non-limiting implementations.

FIG. **14** depicts an aquatic unmanned platform **1401**, according to non-limiting implementations.

FIG. **15** depicts an electrical architecture of the unmanned aquatic vehicle of FIG. **14**, according to non-limiting implementations

DETAILED DESCRIPTION

FIG. **1** depicts external features of an unmanned vehicle platform **101**, according to non-limiting implementations. A chassis **180** and supporting external members **190** house or otherwise provide stable mounting points for sensors, computing systems, and other devices. Unmanned vehicle platform **101** is enabled to track trajectories by way of actuating a set of wheels **200**, which in non-limiting depicted implementations are arranged in a differential-drive configuration. Devices may be mounted within the chassis **180** or external to it, on removable and modular plates **100** or affixed to bumpers **90**.

For ease of access to devices mounted within the chassis, drawers **140** are securable from opening using, for example, a set of latches **130**, and may be opened via handles **150**, springs, or the like. Bumpers **90** may be designed to provide an ergonomic carrying method for the combination of the platform and any other attached devices. Batteries are accessible externally via the battery bays **210** which may incorporate a battery bay latch **230**. In some implementations, if users do not wish to remove batteries for charging, they may be charged while still in the platform via charge connectors **220**.

Unmanned vehicle platform **101** can comprise a set of controls mounted directly to the chassis. In depicted example implementations, unmanned vehicle platform **101** is enabled for activation/deactivation via a latching pushbutton **240** and can be emergency stopped manually via a safety pushbutton **170**. Any other suitable method of controlling unmanned vehicle platform **101** is within the scope of present implementations, including but not limited to issuing commands from a computing system mounted within the drawers **140** and/or by sending commands to a remote control receiver module **110**. A degree of feedback on the state of the system of the unmanned vehicle platform **101** can be provided via a status display **120**.

Internally, unmanned vehicle platform **101** can comprise a plurality of possible operational modules, each of which may provide unmanned vehicle platform **101** with a different set of capabilities. FIGS. **2***a* and **2***b* shows two possible arrangements of internal modules. FIG. **2***a* depicts a central control module **30** connected to a motor amplifier module **40** and a user interface module **50** by way of a vehicle control network **60**. Vehicle control network **60** can comprise any suitable network hardware and topology, including but not limited to a communication bus (e.g. as depicted), the "CANBus" standard (which can used for its speed and robustness to noise), or the like. Any other suitable network hardware and topology is within the scope of present implementations, including any suitable network hardware and topology commonly in use.

Modules **30**, **40**, **50** can also be enabled to receive commands from other systems not on the vehicle control network **60**. For example, in non-limiting exemplary implementations, the central control module **30** can be connected via a control link **20** to a high-level computing system **10**, over which it reports status, sends sensor data, and receives commands. The embodiment as shown uses a wired serial point-to-point connection as the control link **20** and an off-the-shelf laptop computer as the high-level computing system **10**, but the system is not restricted to these choices. For example, the control link **20** could be a radio modem and the high-level computing system **10** could be a rack-mounted server. It is appreciated that any suitable control link and/or computing system is within the scope of present implementations.

FIG. **2***b* is similar to FIG. **2***a*, with like elements having like numbers, however the arrangement of modules of FIG. **2***b* further comprises an RF (radio frequency) module **70** enabled to receive wireless emergency stop commands and an RC (radio control/radio receiver) module **80** enabled to transform signals from (for example) off-the-shelf radio control receivers to forms which are compatible with the vehicle control network **60**. Expanding the platform capabilities in this way does not necessitate any changes to the rest of unmanned vehicle platform **101**.

Attention is now directed to FIGS. **3***a*, **3***b* and **3***c* depicts a toolless battery change process/sequence, according to non-limiting implementations; FIG. **3***a* depicts a battery bin **260** in a closed position, FIG. **3***b* depicts the battery bin **260** in an open position, and FIG. **3***c* depicts the battery bin **260** in the open position with a battery **320** external to the battery bin **260**. With reference to FIG. **3***a*, the battery bin **260** is secured to the chassis **180** via pivots **290**. The battery bin **260** incorporates integrated terminals **270** which elastically deform under the weight of the battery to maintain electrical connectivity. Also mounted to the battery bin **260** are two mechanical stops **250**, **280** which constrain the pivoting of the battery bin **260** by contacting the chassis **180**. A battery bay latch **230** may be used to lock the battery bin **260** in the closed position by engaging with a latch slot **300**. Additionally, this battery bay latch **230** may include a sensor on it to allow the central control module **30** to determine when the battery bay **260** is opened or closed. If this is the case, the battery bay latch **230** is designed such that it cannot be closed when the battery bay **260** is open. Finally, a spring assembly **310** may add to the force keeping the battery terminals **330** mated with the integrated terminals **270** when the battery bin **260** is closed.

The battery **320** is removed by releasing the battery bay latch **230** and manually pivoting the battery bin **260** until the opening mechanical stop **250** makes contact with the chassis **180**, as in FIG. **3***b*. When the battery bay latch **230** includes a sensor capable of monitoring its state, the central control module **30** can execute appropriate instructions to handle the opening event (for example, as described below with reference to FIG. **7**). The battery bin **260** may also be opened by a spring assembly or by other automated means. The battery **320** is then removed, as in FIG. **3***c*. The removal process itself can be dependent on the battery form factor. In exemplary implementations, the removal process can take the form of a manually actuated pull strap.

The battery **320** is replaced by reversing the process. The battery **320** is slid into the battery bin **260** until the battery terminals **330** mate with the integrated terminals **270**. The battery bin **260** is then pivoted closed until the closing mechanical stop **280** makes contact with the chassis **180**. Finally, the battery bin **260** is secured with the battery bay latch **230**. If the battery bay latch **230** includes a sensor capable of monitoring its state, the central control module **30** can now execute appropriate instructions to handle the closing event.

FIG. **4** depicts a system **301** of electronic modules and device network of unmanned vehicle platform **101**, according to non-limiting implementations. The central control module **30** is powered by a power bus **460** which itself is fed from a plurality of power sources which may include one or more batteries **320** and/or an AC power supply **440** or the like. Batteries **320** used in unmanned vehicle platform **101** can be recharged without being removed by the battery charging system **430**. The battery charging system **430** can indicate to the central control module **30** when the batteries **320** are being charged.

The central control module **30** can be enabled to shut off or turn on any subset of the available power sources, while the platform's power switch **470** shuts off all available power sources. The central control module **30** is further enabled to power the fuse panel **360**, any internal modules **50**, **70**, **80**, low-level sensors **390** and portions of the motor amplifier module **40**. Incorporated into the low-level sensors **390** are a number of control feedback sensors which can be used to perform platform state estimation. Control feedback sensors can include but are not limited to inertial sensors **400** and encoders **410**, where the encoders **410** can use any suitable sensing methods (e.g. optical, magnetic, mechanical or the like). In the latter case, the encoders **410** can be physically connected to the drive train of the chassis **180**, providing a direct observation of various speeds within the drive train. These feedback sensors **400** and encoders **410** may be used to improve the trajectory tracking performance of the unmanned vehicle platform **101** and/or may be restricted to observing changes in a state of the unmanned vehicle platform **101**.

The payload bay **340** is generally comprised of components that a user interacts with during operation of the unmanned vehicle platform **101**. In depicted implementations, the payload bay **340** contains the high-level computing system **10**, the fuse panel **360** and a plurality of payloads **350**.

Payloads **350** can comprise additional sensors, additional actuators, communications devices, additional computing hardware, and any other suitable equipment, including equipment that can commonly be found on other unmanned vehicle platforms.

The high-level computing system **10** is connected using appropriate interfaces to the payloads **350**. The fuse panel **360** routes power from the central control module **30** to the high-level computing system **10** and the payloads **350**, and may have multiple fused connectors for a variety of different voltage levels and current ratings. Any suitable software can be deployed to the high-level computing system **10**.

The central control module **30** communicates via the vehicle control network **60** with secondary modules **40**, **50**, **70**, **80** as appropriate. Communications may happen sporadically or at a regular frequency. When the latter, one or more modules can be enabled to require a given message frequency to remain operational, which can improve the safety of the unmanned vehicle platform **101**. For example, such an implementation can be useful when receiving commands via the remote receiver module **80**, monitoring remote switches via the RF module **50** and/or commanding motor motion via the motor amplifier module **40**. However, such a requirement on message frequency can be less useful with other modules such as the user interface module **70**. Furthermore, it is appreciated that use of the phrases “require” and “requirement” refer only to particular implementations and the given message frequency remaining operational is to be construed as being required in all implementations and/or to be unduly limiting.

FIG. **5** depicts a configuration of a central control module **30** of the unmanned vehicle platform **101**, according to non-limiting implementations. The main components of the central control module comprise a power source selection module **490**, a power regulation module **510** and an embedded processor **530**. The power source selection module **490** is enabled to select which of the available power sources within the power bus **460** is fed into the power regulation module **510**. This selection is done based on the information made available by the monitoring module **480**. The power regulation module **510** powers the embedded processor **530**, the fuse panel **360** (including devices powered by the fuse panel), and any other devices which are connected to the vehicle control network **60**.

As well, the battery detect switches **550** enable the power source selection module **490** to determine if the user is removing a battery **320** or if they have recently replaced one. With such information, the power source selection module **490** can minimize system downtime by ensuring that the unmanned vehicle platform **101** and/or the system **301** is powered from a reliable power source at all times. Optional display indicators, such as the status panel **120** and/or the battery-in-use indicators **540** can indicate which subset of power sources are being used at any given time.

A soft start module **520** may be used to limit the inrush current into the fuse panel **360** and other devices powered by the power regulation module **510**. The status of each power source in the power bus **460** is monitored using corresponding monitoring modules **480**. The monitoring modules **480** may retrieve any subset of temperature, voltage and current draw data or the like. The monitoring module **480** may also use this data to estimate the health of each power source in the power bus **460**. This data can also report to the embedded processor **530** so that it can reduce power draw when necessary. The data may also be forwarded to the high level computing system **10** or retransmitted along the vehicle control network **60**.

Each monitoring module **480** can be enabled to shut off power from its associated power source. There may also be a separate current sense module **500** that reports current draw data to the embedded processor **530**. A power switch **470** is used to shut off all available power sources. The embedded processor **530** also collects sensor data **520** from a plurality of sensors, which may include, but is not limited to, devices such as a tilt-compensated compass, IR rangefinders, angular rate gyros, and wheel encoders.

FIG. **6** depicts a configuration of a motor amplifier module **40** of the unmanned vehicle platform **101**, according to non-limiting implementations. The motor amplifier module **40** comprises an embedded processor **590**, a motor power source selection module **560** and any suitable ancillary components, for example any suitable ancillary components that can be determined according to electrical design principles. The embedded processor **590** can communicate with the central control module **30** and other modules in the system **301** using the vehicle control network **60**. The power regulation module **510** located in the central control module **30** provides the power necessary to run the embedded processor **590**. This power is transmitted along the same path as the vehicle control network **60**. The embedded processor **590** can read battery voltages using the power monitoring system **570** and motor current draw using the current sense modules **580**.

These measurements can be used for platform health monitoring, or can be incorporated further into the platform control system **301** to allow for more precise control strategies. The motors **380** are powered by sources selected by the motor power source selection module **560**. Power to each motor **380** is controlled by the embedded processor **590**. The embedded processor **590** can use any suitable strategy to regulate the power to each motor **380**. In exemplary implementations, as depicted, each motor **380** is driven by an H-bridge circuit **600** which is controlled by a bridge driver **610**. Each bridge driver **610** is in turn controlled by the embedded processor **590**.

A physical E-stop **170** can be used to cut off power to parts of the system **301**, if necessary, providing a robust safety system which is not dependent at all on firmware. For example the physical E-stop **170** can be monitored by the motor power selection module **560**. When the physical E-stop **170** is activated, the motor power selection module **560** can shut off all power to the H-bridge circuits **600** and by extension halts the motors **380**.

FIG. **7** depicts a process flow for a managing a power bus **460** that can be implemented by the unmanned vehicle platform **101**, according to non-limiting implementations. The unmanned vehicle platform **101** starts in a power off state **620**. When the main power switch **470** is turned on, a power-on transition occurs **630** and the central control module **30**, as well as every other device powered by the power regulation module **510**, is powered on. For a period of time, the electronics are powered by all available power sources **640**. After a period of time, the embedded processor **530** instructs the power source selection module **490** to choose a single power source and a power source selection transition **650** occurs.

In the single-power state **660**, the central control module **30**, and every other device powered by the power regulation module **510**, is powered by a single power source (e.g. a first battery of batteries **320**). In some configurations the system **301** will remain powered by a secondary power source, such as a second battery of batteries **320**, in addition to a source such as an AC power supply **440** in case the primary source is suddenly removed. After the power source selection transition **650** occurs, the motor power source selection module **560** turns on the power source to power the motors and a motor power transition **670** occurs. Once the motor power transition **670** has been completed, the unmanned vehicle platform **101** has entered its normal operation state **680**.

A number of situations can cause the unmanned vehicle platform **101** to leave the normal operation state **680**. Such situations may include the triggering of the battery detect switch **550**, the battery state-of-charge dropping below a preset threshold, or the user swapping out a current power source/battery **320**. If one of these situations occurs, the unmanned vehicle platform **101** leaves the normal operation state **680** and a motor power down transition **740** occurs. During the motor power down transition **740**, the motor power source selection module **560** shuts down all power to the motors **380** and the system **301** then transitions into the motors powered down state **750**. If the motor power down transition **740** occurred due to a low state-of-charge on the batteries **320** then the vehicle will undergo a state transition **730** to a low-power state **720**.

In the low power state, the unmanned vehicle platform **101** waits until the charge on the battery **320** reaches a critically low level and another transition **710** occurs to a shut down state **700**. The user may add a fresh battery **320** or an additional power source such as an AC power supply **440** to prevent the system **301** from entering the shut down state **700**. In this case, the system **301** switches the new power source on, undergoes a recovery transition **760**, and is powered by both the old and the new power source for a period of time **790**. From this state, the system **301** would return to being powered by one source **660** by shutting the old source off and will eventually return to normal operation **680** as it did when first starting up.

In the situation where the unmanned vehicle platform **101** undergoes a motor power down transition **740** because the battery detect switch **550** had been triggered or the user is swapping out the current power source, a secondary power source transition **770** occurs and the unmanned vehicle platform **101** is powered by two power sources for a period of time **790**. From this state **790**, the unmanned vehicle platform **101** would shut off the old power source and return to being powered by one source **660**. The unmanned vehicle platform **101** would then return to the normal operation state **680** as it did when first starting. If the user removes the only available power source, a shutdown transition **690** occurs and the unmanned vehicle platform **101** enters the shut down state **700** immediately.

FIG. **8** depicts detail of a remote receiver module **110** mounted to the chassis **180**, according to non-limiting implementations. The remote receiver module **110** can comprise any suitable remote receivers, including but not limited to remote receivers enabled to improve performance, for example by altering an enclosure composition, adding external antennas **800** or the like.

FIG. **9** depicts a configuration of the RF module **70** of the unmanned vehicle platform **101**, according to non-limiting implementations, which enables direct wireless control of the central control module **30**. The RF module **70** comprises an RF antenna **800** that provides a modulated signal to the RF demodulator **810**. The RF demodulator **810** sends out a string of data, as received by the antenna **800**, to the decoder **820**. The decoder **820** reads a serial bit stream and translates the data to a parallel bus. The parallel bus is read in by the embedded processor **830**. The embedded processor **830** then encodes the data and communicates the encoded data over the vehicle control network **60**. The entirety of this module is powered by the power regulation module **510**. This configuration is only an example and the specifics of details such as modulation, frequency, and power are not to be construed as being particularly limiting.

FIG. **10** depicts a configuration of the remote receiver module **80** of the unmanned vehicle platform **101**, according to non-limiting implementations. Remote receiver module **80** is enabled to translate data from, for example, off-the-shelf remote receivers to a common format, which enables many off-the-shelf remote receivers to be integrated with the unmanned vehicle platform **101** without changing the firmware or electrical system of the central control module **30**. Such data can be transmitted over a 2.4 GHz band, or any other suitable radio band, or the like. The remote receiver module **80** can comprise (for example) an off-the-shelf remote control receiver **840** and an embedded processor **860**. The remote control receiver **840** and the embedded processor **860** are powered by the power regulation module **510**. The remote control receiver **840** demodulates transmissions sent by the remote control transmitter **850**. The remote control transmitter **850** can be handheld, stationary, or in any other physical configuration.

The remote control receiver **840** forwards the demodulated transmission to the embedded processor **860**. The demodulated transmission can consist of servo pulses, pulse width modulation signals, a serial bit stream, or any other number of transmission formats as known to those skilled in the art, or the like. The embedded processor **860** interprets the demodulated transmission and reformats the received data into a form which can be transmitted on the vehicle control network **60**. The embedded processor **860** can also be enabled to conduct some filtering on the demodulated transmission. Such filtering can comprise detecting when the remote control transmitter **850** is out of range of the remote control receiver **840**. Similarly, such filtering could also serve to reject invalid transmissions and reduce noise.

FIG. **11** depicts a status display **120** of the unmanned vehicle platform **101**, according to non-limiting implementations, mounted on an exemplary chassis **180** by mechanical hardware **870**. The status display **120** can be positioned in any suitable manner, for example such that it is visible to users from the exterior of the chassis **180**. In exemplary depicted non-limiting implementations, indicator lights **880**-**920** are mounted to a single printed circuit board. Furthermore, the user interface module **50** can comprise the status display **120**. Exemplary functions of the indicator lights **880**-**920** include, but are not limited to: indicating the presence of main electronics power **900**, indication of communications failure **910**, indication of use of power source selection **880**, depiction of the state of charge of an onboard power source **890**, depiction of overall system status **920** or the like.

The user interface module **50** can also be enabled receive inputs, and the portion of the chassis **180** to which the status display **120** is mounted can be enabled for quick replacement to match different physical layouts of the status display **120** can optionally incorporate input devices such as mode switches or adjustment knobs or the like.

FIG. **12** depicts a program layout of vehicle control firmware of the unmanned vehicle platform **101**, according to non-limiting implementations. The control link **20** provides full-duplex serial communication to the system **301**, including error detection. The system **301** of unmanned vehicle platform **101** can receive messages which make up commands **930** or data requests **960**. Commands **930** can affect vehicle settings and setpoints directly or can be pre-processed by additional modules such as built-in vehicle kinematic models **950**. Vehicle settings and setpoints can be verified by a set of control loops **940** before being sent to secondary modules via the vehicle control network **60**. The control loops **940** may also be capable of providing some degree of autonomy, for example when the sensor data **420** includes appropriate information. Settings and setpoints can be stored in a central system state **1000**. System state **1000** also contains data received from other modules located on the vehicle control network **60**. Sensor data **420** may be raw data as received from the hardware, or filtered via analog and/or digital means.

The system **301** of the unmanned vehicle platform **101** can be monitored remotely by issuing data requests **960**. Data requests **960** can be structured to require immediate responses from the system **301**, or can be subscriptions for periodic updates of specific data. The management of the varied requests and subscriptions can be handled by a subscription manager **970**. The subscription manager **970** is queried by a data scheduler **990** which uses this subscription information and the system state **1000** to produce data **980** for the control link **20**. In this way, data **980** can thus be produced for the device on the other end of the control link **20** without continual requests for such data, thereby lowering the inbound bandwidth requirements.

FIG. **13** depicts a control flow within each module attached to the vehicle control network **60** of the unmanned vehicle platform **101**, according to non-limiting implementations. Upon module start-up **1010**, a given module issues requests for information **1020** from the central control module **30** via the vehicle control network **60**. For the user interface module **50**, this information may be system status, while for the motor amplifier module **40**, this information may be safety limits. The given module may then wait for this information to be provided in a loop **1030** or may continue execution.

For non-critical information, the given module may not need to wait, but can continue on and process the information as it arrives. A loop is then entered, wherein the given module receives updated information and commands **1040**, performs a variety of tasks **1050**, and then transmits information over the vehicle control network **60**. Depending on the specifics of the vehicle control network **60**, each module may need to specifically address the outgoing data (in the case of a Serial Peripheral Interconnect (SPI), for example), or may be able to send it out as a broadcast, receivable by any module that requires such data (in the case of CAN). The implementation of the loop can be performed in any suitable manner, including but not limited to using a busy-wait structure, hardware timer interrupts, or one of many more complex scheduling strategies used by computer operating systems.

Referring briefly back to FIG. **1**, it is appreciated that the unmanned vehicle platform **101** comprises a wheeled land vehicle. However, in other type of vehicles are within the scope of present implementations. For example, while the unmanned vehicle platform **101** is an unmanned platform, systems and modules described herein can be included in unmanned vehicles, manned vehicles, aquatic vehicles, amphibious vehicles, aeronautic vehicles any other suitable vehicle, and/or a combination, or the like.

For example, attention is next directed to FIG. **14** which depicts an aquatic unmanned platform **1401**, according to non-limiting implementations. The aquatic unmanned platform **1401** comprises a hull **120***a* and attached framework **150***a* which provides a stable buoyant platform upon which the rest of the aquatic unmanned platform **1401** is mounted. A primary electrical enclosure **10***a* comprises the primary control board **30***a* and a primary battery **20***a*, while an auxiliary electrical enclosure **90***a* holds the auxiliary control board **70***a* and an auxiliary battery **80***a*. Attached via shafts **160***a* to both enclosures **10***a*, **90***a* are thruster assemblies **100***a* with appropriate propellers **110***a* for propelling the aquatic unmanned platform **1401** through an aquatic environment. A status display **40***a* and a long-range bidirectional communications system **50***a* can each be attached to the primary electrical enclosure **10***a*. A plurality of additional sensors such as a camera system **60***a* and a GPS system **130***a* may also be emplaced on the hull **120***a*. Sensors **60***a*, **130***a* may be mounted on mounts **140***a* if required. It is otherwise appreciated that aquatic unmanned platform **1401** comprises a control system similar to the system **301**, and suitable associated modules.

In particular attention is directed to FIG. **15** which depicts an electrical architecture of unmanned aquatic vehicle **1401**, according to non-limiting implementations and represent an alternative architecture of parts of system **301**. Separate control modules **485***a*, **515***a* are electrically connected via a suitable vehicle control network **500***a*. In each module **485***a*, **515***a* comprises a motor driver **36***a***0** and its associated thruster **100***a*. A primary module **485***a* is powered by a battery **2***a* which has its power filtered, monitored, and distributed by a power system **490***a*. Control of the system is done by the primary control board **30***a*, which itself receives information from low-level sensors **340***a* and communicates with other control modules via the vehicle control network **500***a*. The primary control board **30***a* can interface with the user and other sensors in any suitable manner. Auxiliary module **515***a* comprises a dedicated battery **80** and power system **510***a*, and is controlled aria an auxiliary control board **70***a*, which itself responds to commands over the vehicle control network **500***a*. Each power system **490***a*, **510***a* is enabled for self-monitoring and safety limiting, and can provide status updates as required to the relevant control board **30***a*, **70***a* of FIG. **14**.

Those skilled in the art will appreciate that in some implementations, the functionality of system **301** can be implemented using pre-programmed hardware or firmware elements (e.g., application specific integrated circuits (ASICs), electrically erasable programmable read-only memories (EEPROMs), etc.), or other related components. In other implementations, the functionality of system **301** can be achieved using a computing apparatus that has access to a code memory (not shown) which stores computer-readable program code for operation of the computing apparatus. The computer-readable program code could be stored on a computer readable storage medium which is fixed, tangible and readable directly by these components, (e.g., removable diskette, CD-ROM, ROM, fixed disk, USB drive). Furthermore, it is appreciated that the computer-readable program can be stored as a computer program product comprising a computer usable medium. Further, a persistent storage device can comprise the computer readable program code. It is yet further appreciated that the computer-readable program code and/or computer usable medium can comprise a non-transitory computer-readable program code and/or non-transitory computer usable medium. Alternatively, the computer-readable program code could be stored remotely but transmittable to these components via a modem or other interface device connected to a network (including, without limitation, the Internet) over a transmission medium. The transmission medium can be either a non-mobile medium (e.g., optical and/or digital and/or analog communications lines) or a mobile medium (e.g., microwave, infrared, free-space optical or other transmission schemes) or a combination thereof.

While the foregoing written description enables one of ordinary skill to make and use what is considered presently to be the best mode thereof, those of ordinary skill will understand and appreciate the existence of variations, combinations, and equivalents of the specific embodiment, method, and examples herein. The present specification should therefore not be limited by the above described embodiment, method, and examples, but by all embodiments and methods within the scope and spirit of the claims appended hereto.

What is claimed is:

1. A distributed hardware system for controlling a vehicle, comprising:

a network;

a central control module for controlling the distributed hardware system;

a plurality of electronic hardware modules in communication with the central control module via the network, each of the plurality of electronic hardware modules enabled to:

communicate with one another via the network;

issue requests for information from the central control module via network;

transmit data over the network in a common format to perform tasks respective to a respective function; and at least one of:

independently sense one or more of a respective status of the distributed hardware system and at least one respective environmental parameter; and

independently control the respective function of the vehicle, and at least a portion of the plurality of electronic hardware modules enabled to:

be physically removed and physically inserted from the distributed hardware system as plug and play modules; and

determine when at least one of the plurality of electronic hardware modules is physically removed or physically inserted from the distributed hardware system and transition to a corresponding state.

2. The distributed hardware system of claim **1**, further comprising at least one power source.

3. The distributed hardware system of claim **2**, wherein the at least one power source comprises at least two batteries and respective battery bins enabled to independently open such that a hot swap of a respective battery can be performed.

4. The distributed hardware system of claim **1**, wherein the control module is enabled to control power to each of the plurality of electronic hardware modules.

5. The distributed hardware system of claim **4**, further comprising at least a first power source powering the distributed hardware system and a second power source, wherein one or more of the control module and at least one of the plurality of electronic hardware modules is further enabled to:

determine that the first power source is no longer able to power the distributed hardware system; and

implement a power down transition in the distributed hardware system such that powering of the distributed hardware system is switched to the second power source and a hot swap sequence can be implemented to remove the first power source and insert a third power source.

6. The distributed hardware system of claim **5**, wherein the power down transition comprises a motor power down transition.

7. The distributed hardware system of claim **5**, wherein the one or more of the control module and at least one of the plurality of electronic hardware modules is further enabled to enter a low power state until the hot swap sequence occurs.

8. The distributed hardware system of claim **1**, further comprising at least one sensor for sensing at least one of the respective status of the distributed hardware system and the at least one respective environmental parameter, wherein a respective one of the plurality of electronic hardware modules is enabled for communication with the at least one sensor.

9. The distributed hardware system of claim **1**, wherein at least one of the plurality of electronic hardware modules comprises a motor amplifier module for controlling a motor of the vehicle.

10. The distributed hardware system of claim **1**, wherein at least one of the plurality of electronic hardware modules comprises a radio frequency (RF) module enabled to receive command data from a remote control system, translate the command data to the common format and communicate translated command data over the network.

11. The distributed hardware system of claim **1**, wherein at least one of the plurality of electronic hardware modules comprises a remote control receiver enabled to receive command data from an off-the-shelf remote control receiver, translate the command data to the common format and communicate translated commands over the network.

12. The distributed hardware system of claim **1**, wherein at least one of the plurality of electronic hardware modules comprises a user interface module enabled to at least one of receive command data from an input device and convey system data to a user.

13. The distributed hardware system of claim **1**, wherein the network comprises at least one of a vehicle control network and a communication bus.

14. The distributed hardware system of claim **1**, further comprising at least one of a battery charging system and at least one motor.

15. The distributed hardware system of claim **1**, wherein the central control module is enabled to communicate with a high level computing system via a control link.

16. The distributed hardware system of claim **1**, wherein the central control module is enabled to store at least one of:

system state information received from the plurality of electronic hardware modules;

setting data;

setpoint data; and

a combination thereof.

* * * * *