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Cerchie et al.

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(54) **MULTI-MODE UNMANNED AND MANNED VEHICLE SYSTEMS AND METHODS**

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(65) **Prior Publication Data**

Assistant Examiner — Michael Kreiner

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Related U.S. Application Data

(62) Division of application No. 12/135,055, filed on Jun. 6, 2008, now Pat. No. 7,784,741, which is a division of application No. 11/388,026, filed on Mar. 22, 2006, now Pat. No. 7,624,943.

(57) **ABSTRACT**

(51) **Int. Cl.**

B64C 13/22 (2006.01)
B64C 13/00 (2006.01)

An apparatus for converting a manned aircraft of a type including at least one pilot control capable of manipulation to affect operation of the aircraft for unmanned flight operations includes first and second actuators, each configured to selectively provide movement or resistance to movement in a first manner including linear or rotational motion, first and second clutches, each configured to selectively couple movement of the associated actuator to or from the pilot control during flight, and a vehicle controller capable of being selectively enabled during flight to operate the pilot control actuators and clutches and thereby provide unmanned operation of the aircraft, or of being disabled, thereby providing for manned operation of the aircraft. The first actuator has a first scope describing a first amount of allowable movement, while the second actuator has a second scope larger than the first scope.

(52) **U.S. Cl.** **244/197**; 244/17.11; 244/76 R

(58) **Field of Classification Search** 244/17.11, 244/17.13, 75.1, 76 R, 189, 190, 194, 196, 244/197, 229

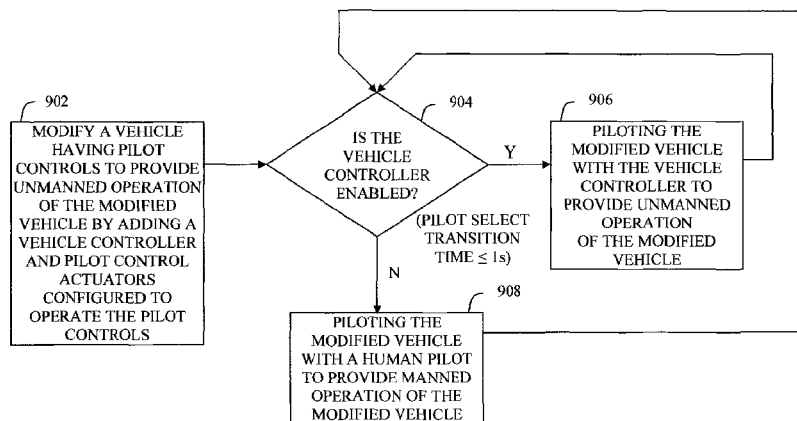
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10 Claims, 11 Drawing Sheets



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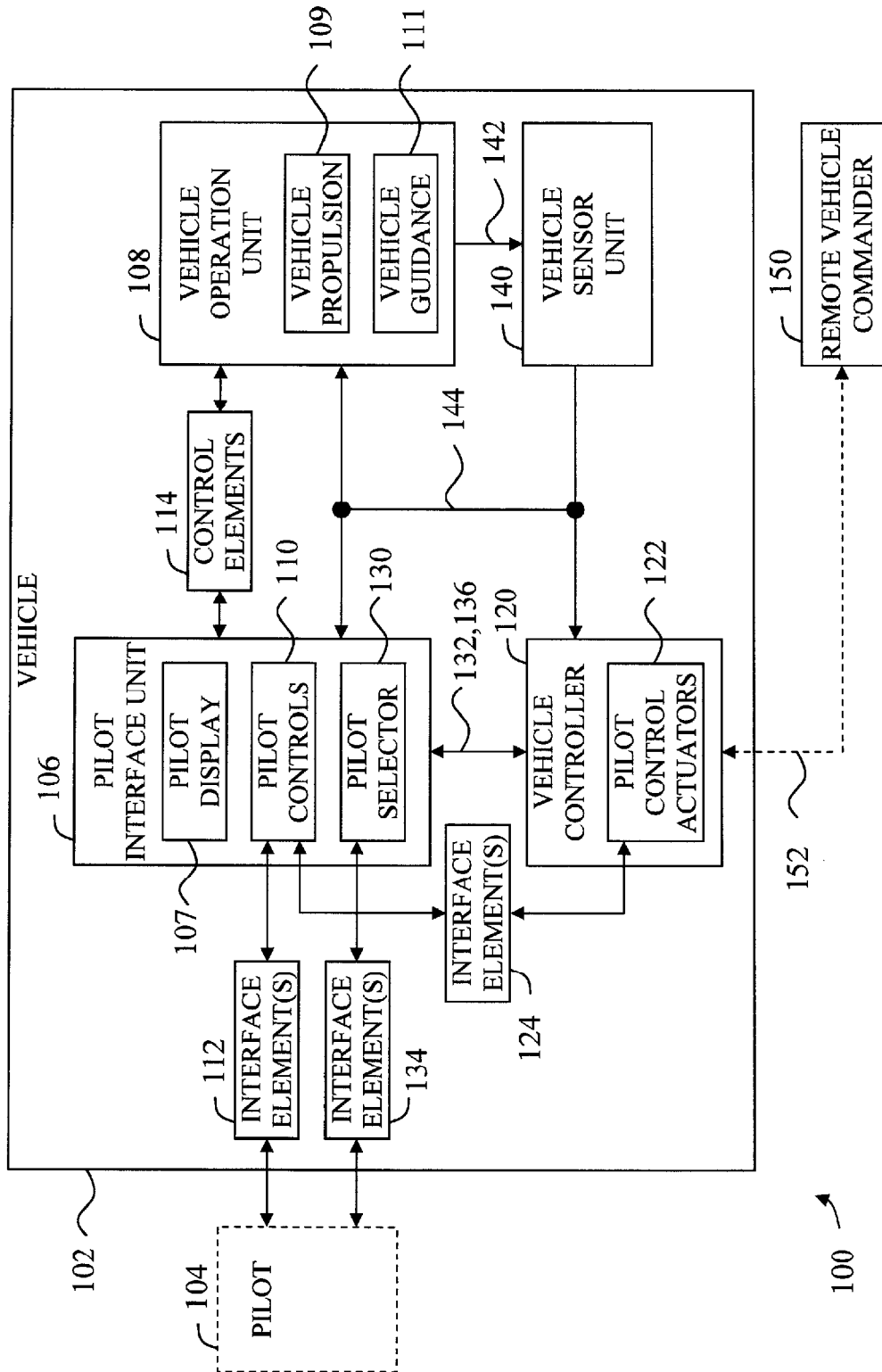


FIG 1

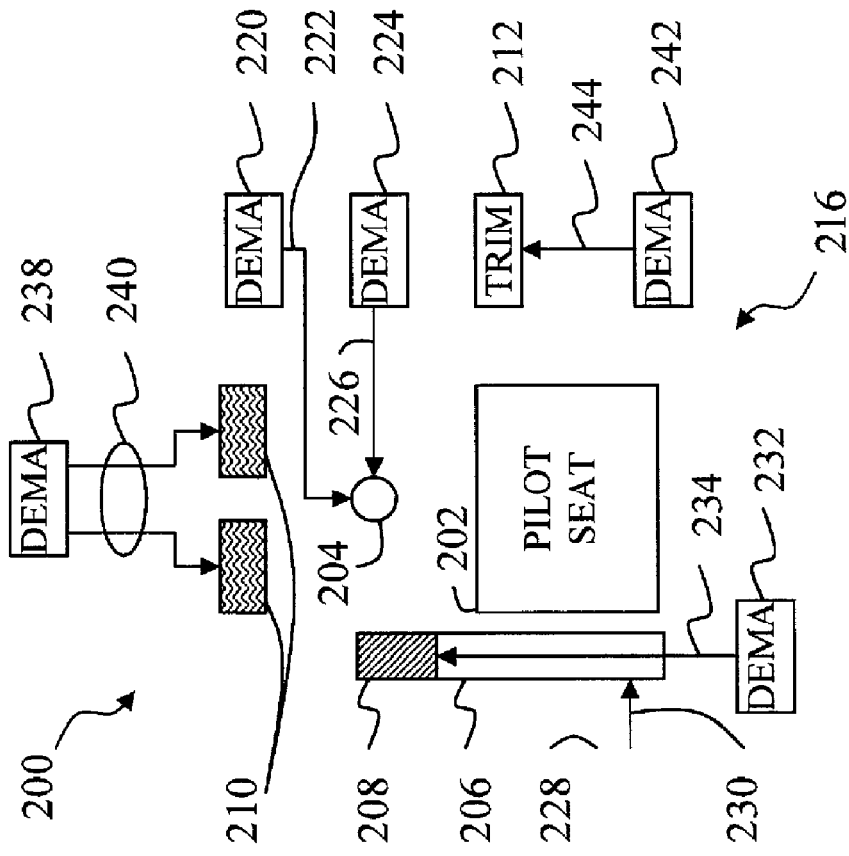


FIG 2

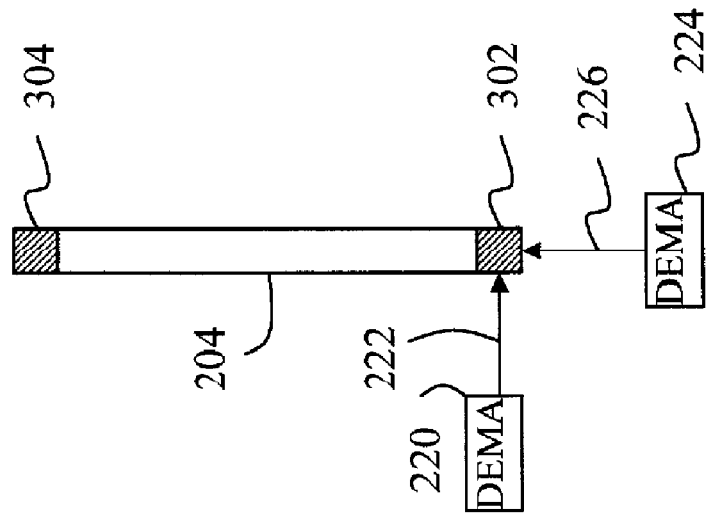


FIG 3

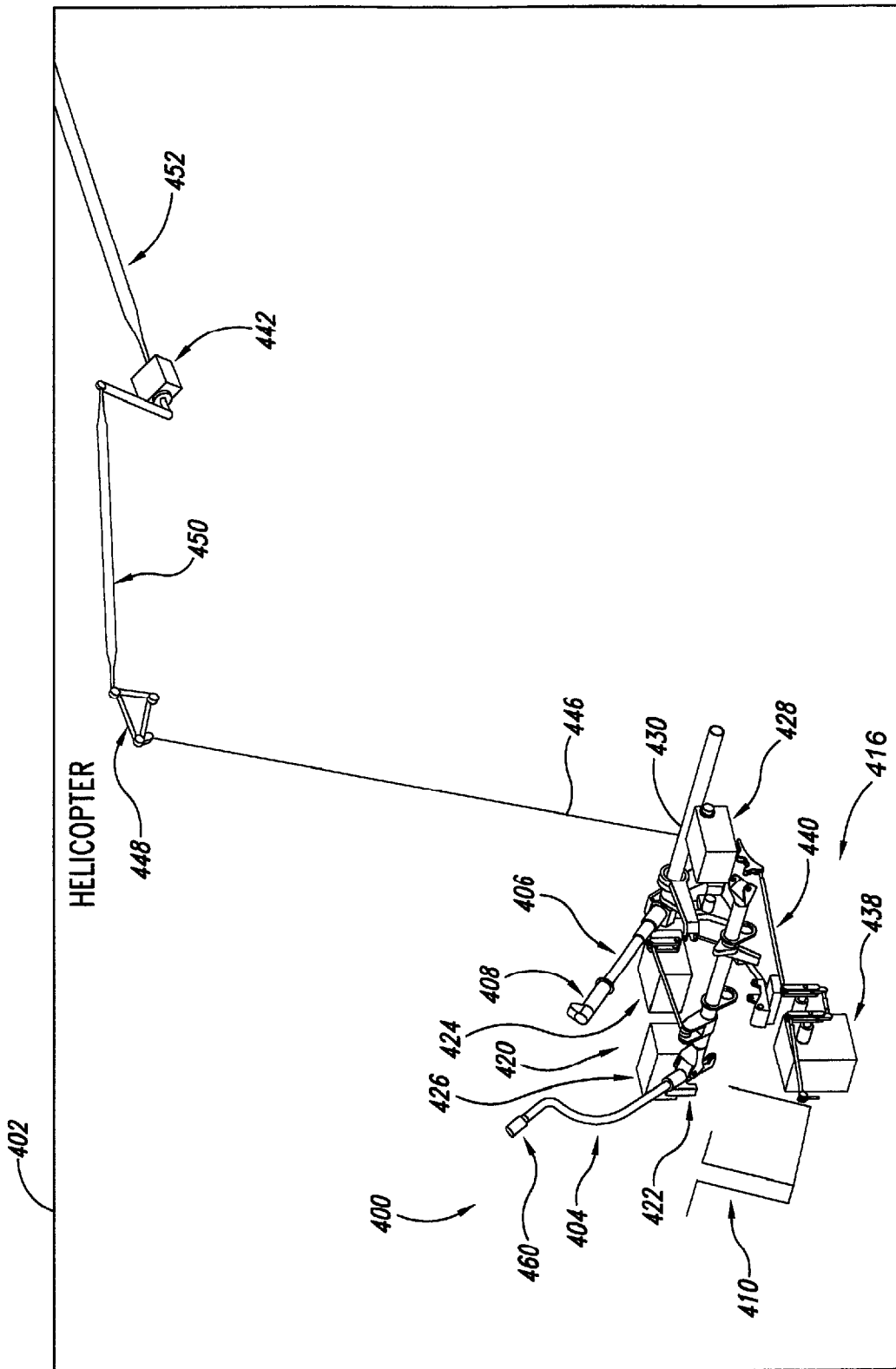


Fig. 4

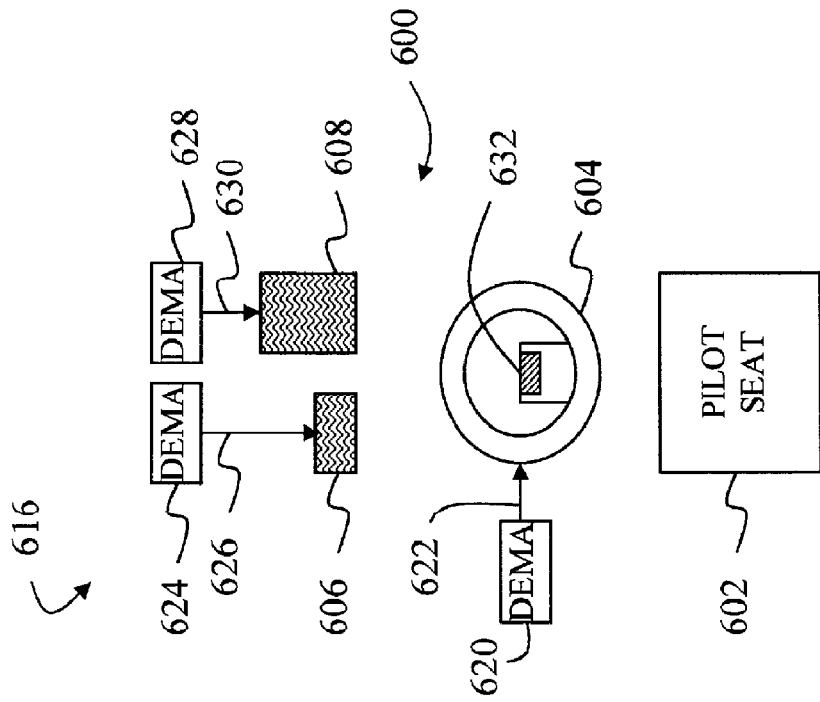


FIG 5

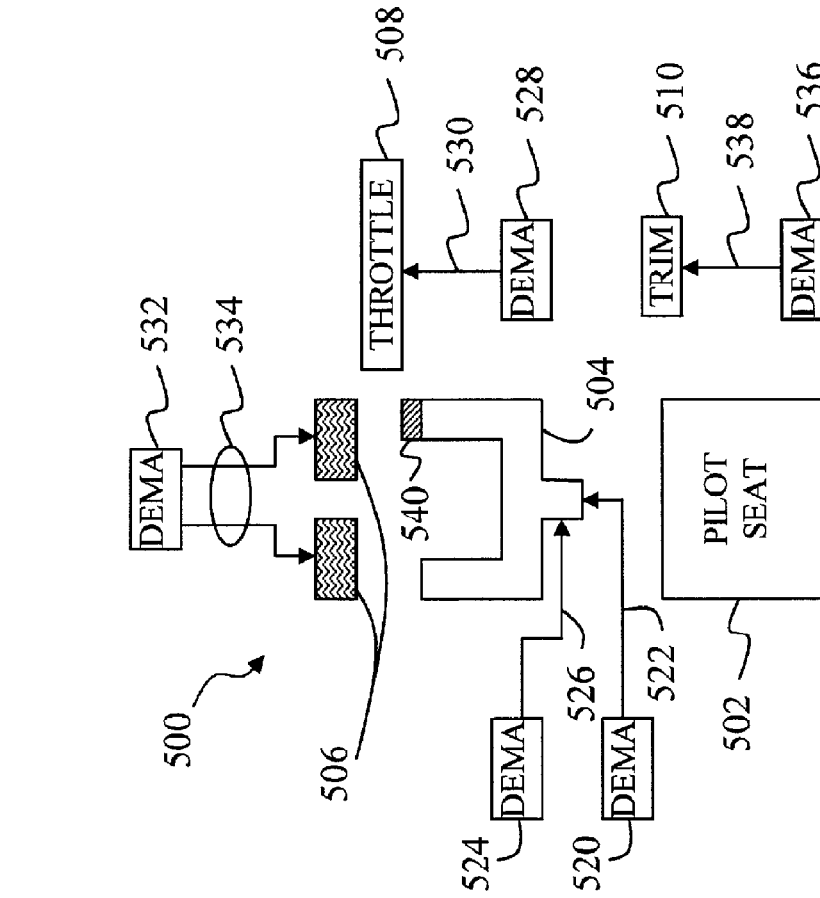
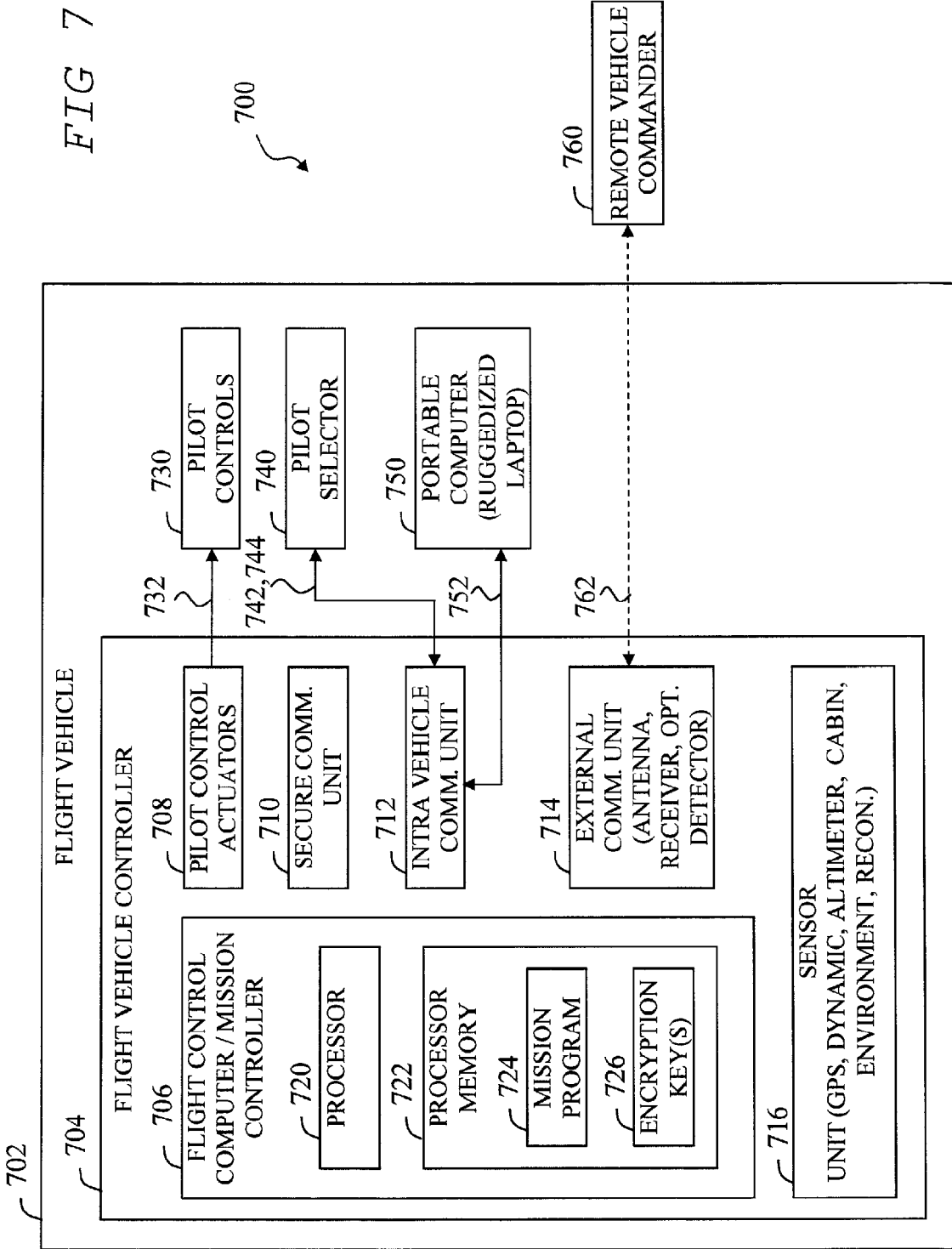


FIG 6



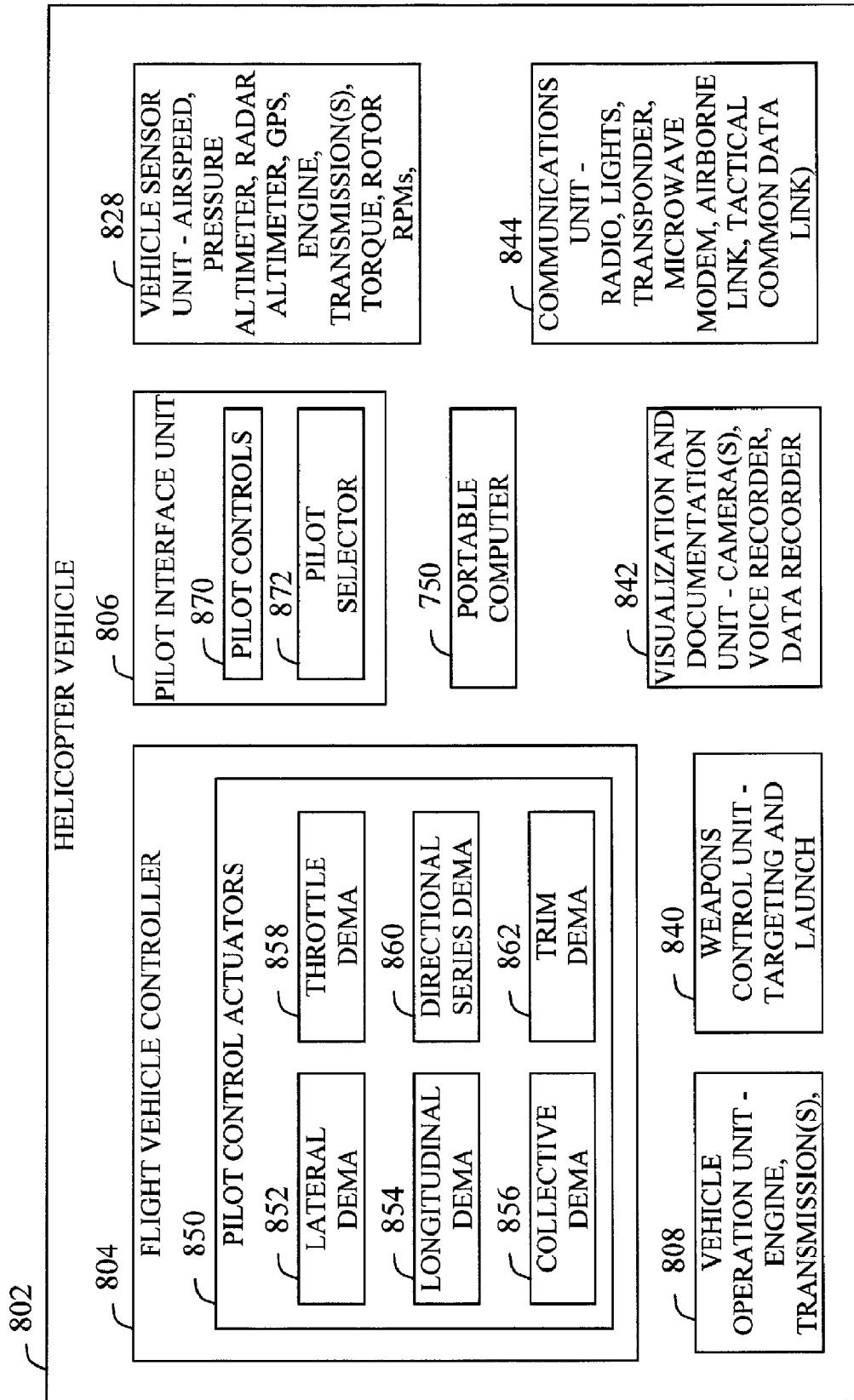


FIG 8

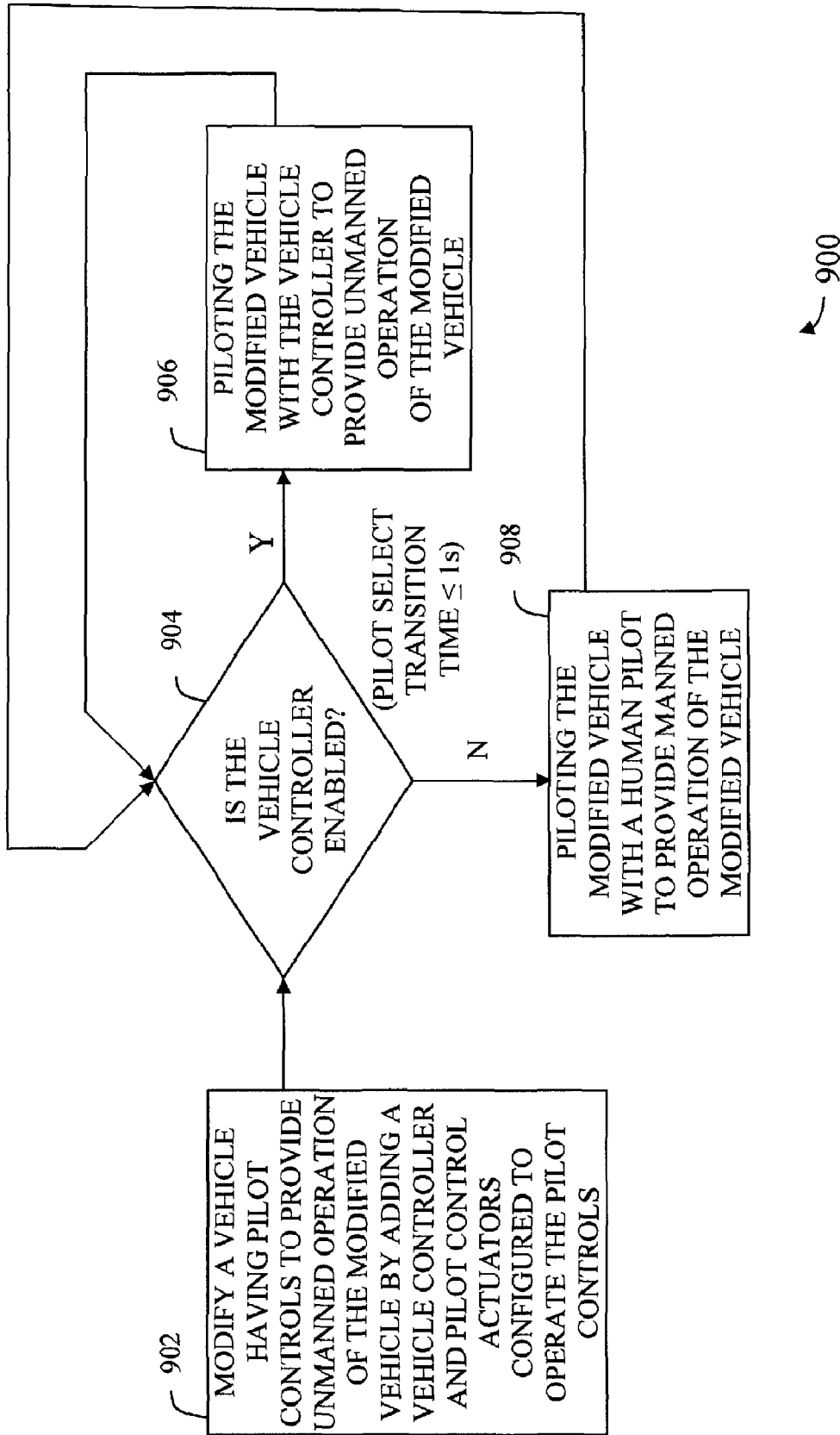


FIG 9

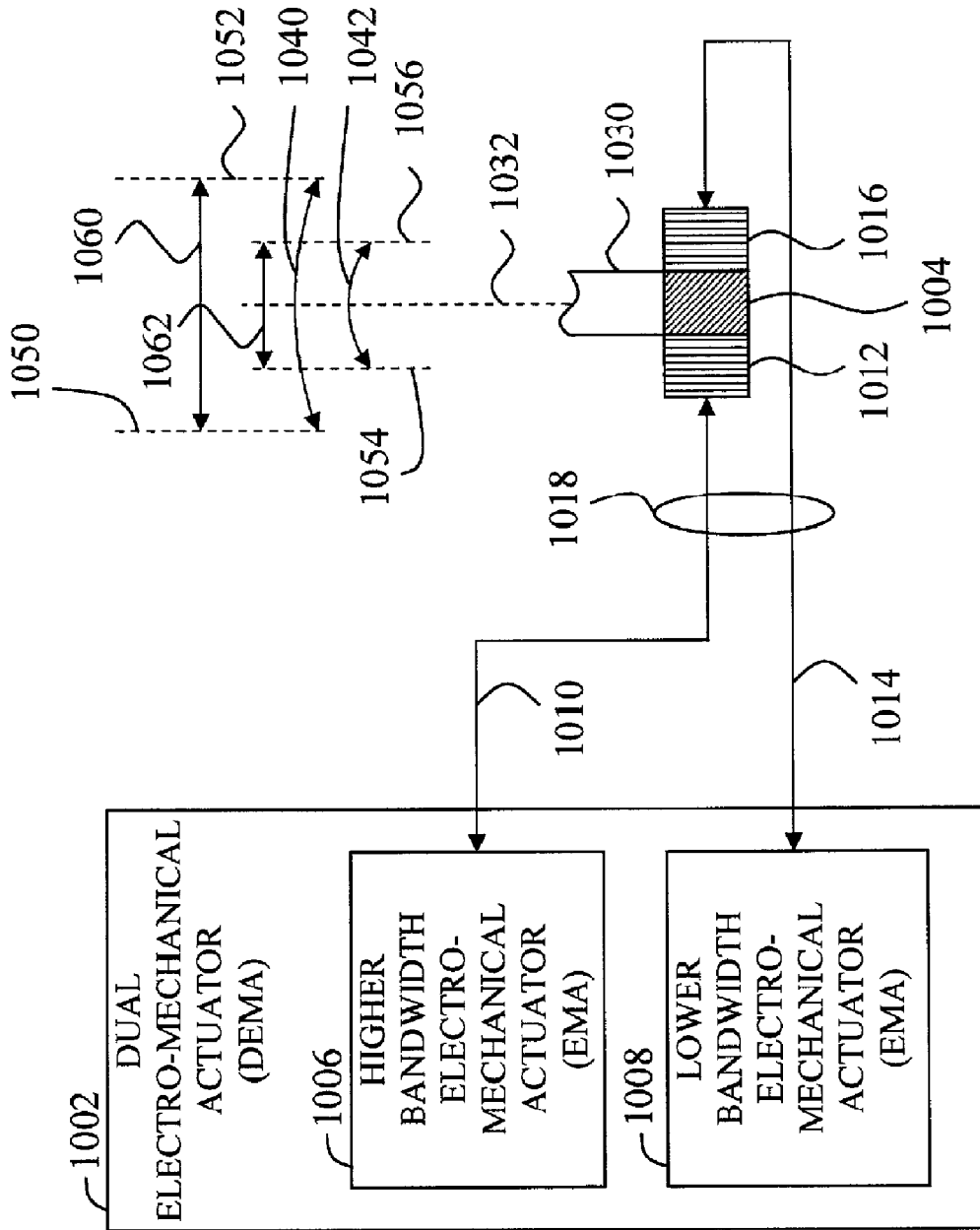


FIG 10

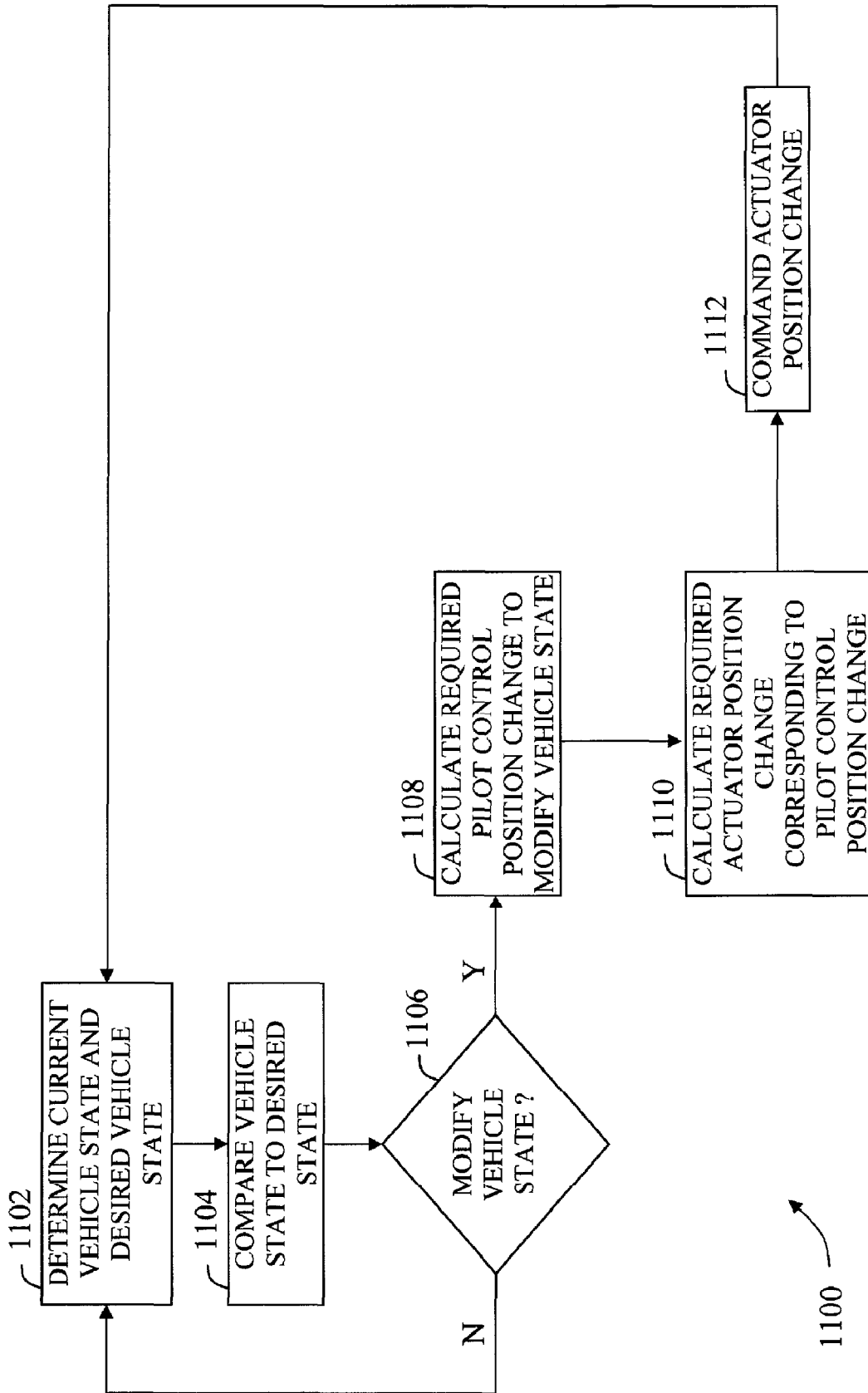


FIG 11

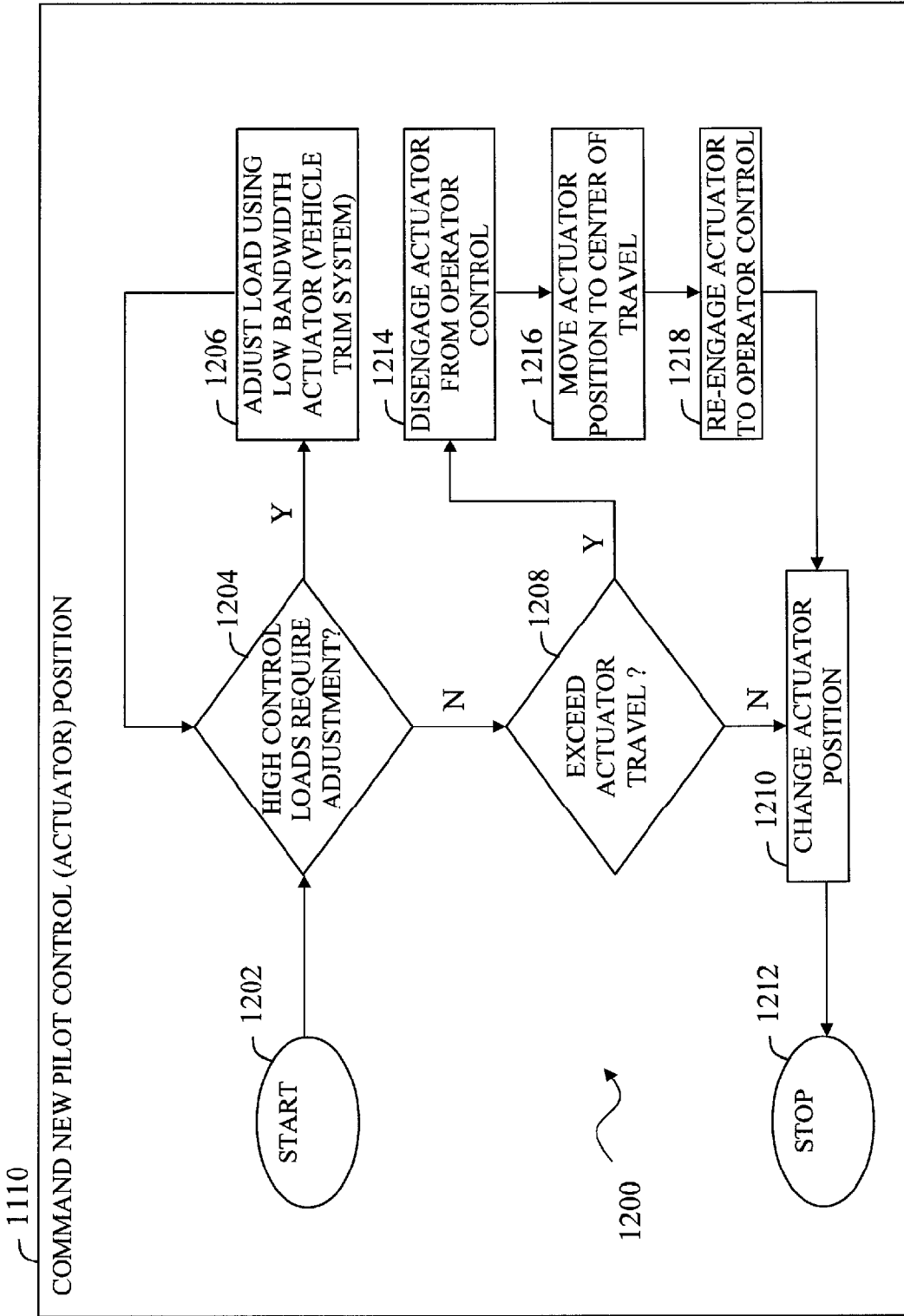


FIG 12

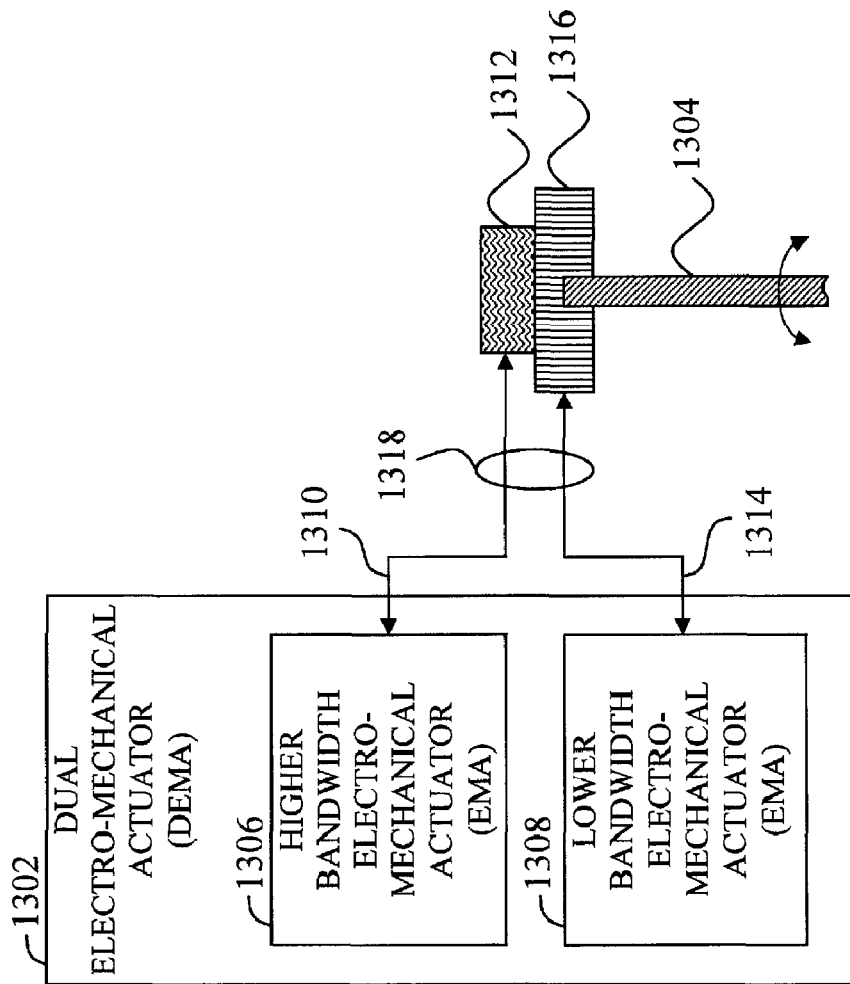


FIG 13

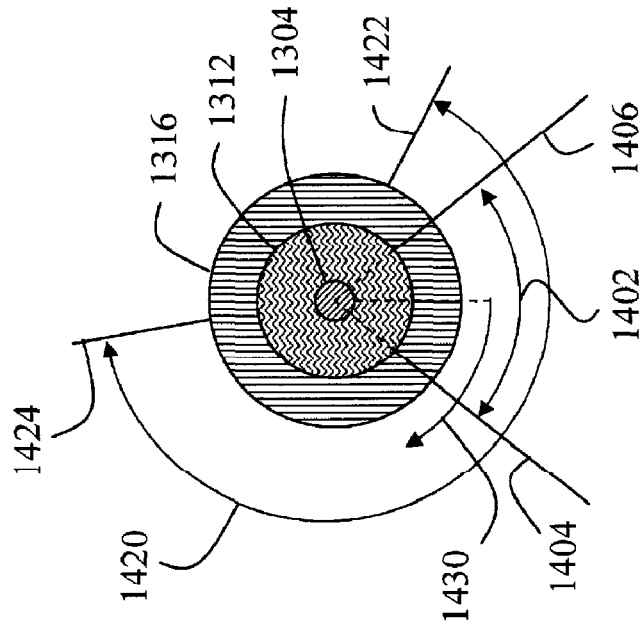


FIG 14

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MULTI-MODE UNMANNED AND MANNED VEHICLE SYSTEMS AND METHODS

RELATED APPLICATIONS

This application is a divisional of U.S. patent application Ser. No. 12/135,055, filed Jun. 6, 2008, now U.S. Pat. No. 7,784,741, issued Aug. 31, 2010, which is a divisional of U.S. patent application Ser. No. 11/388,026, filed Mar. 22, 2006, now U.S. Pat. No. 7,624,943, issued Dec. 1, 2009, both of which are incorporated herein by reference.

TECHNICAL FIELD

The present invention relates generally to vehicles, and more particularly, to multi-mode unmanned and manned vehicle systems and methods.

RELATED ART

Unmanned vehicles may be used for various applications in which a human pilot is either not available or where the parameters of a particular mission profile makes it undesirable to use a human pilot. There is a current trend in aviation towards the use of unmanned aerial vehicles (UAVs). Pilotless, or drone aircraft, have long been used successfully for various missions, including reconnaissance and/or engagement of an enemy force. Many unmanned vehicle development projects start from such baseline aircraft and proceed to develop not only the unmanned attributes of a vehicle, but the vehicle itself. This approach increases the cost of development, whereas, there is a growing market for low-cost UAVs. Therefore, in view of these issues and others, there remains a need in the art for a more cost effective approach to the development and deployment of unmanned vehicles.

SUMMARY

In accordance with the present disclosure, a vehicle is provided that is capable of unmanned operation while preserving a manned operational capability. In this manner, the unmanned operation becomes a new mission capability for the manned vehicle, thereby providing a lower cost approach for developing the unmanned vehicle. This approach has been proven on a single rotor MDHI MD530F helicopter (MD Helicopters, Inc. of Mesa, Ariz., USA), and may be extended to various other manned vehicle types. Basing a new unmanned vehicle development on an existing manned vehicle platform enables the new unmanned vehicle to use all of the existing manned vehicle options to effectively accelerate development of the unmanned vehicle at a very low cost, ensures that the logistics and maintenance of the vehicle are virtually the same and that improvements to the vehicle platform benefit both modes, and that traditionally manned vehicle manufacturers are able to quickly enter the unmanned vehicle markets. Pairing both manned and unmanned operation of a vehicle in this manner provides an attractive domestic and foreign market approach.

More specifically, in accordance with an embodiment of the present invention, an apparatus for converting a manned aircraft for unmanned flight, the aircraft including at least one pilot control capable of manipulation to affect operation of the aircraft, the apparatus comprising a first actuator configured to selectively provide at least one of movement and resistance to movement in a first manner, including at least one of linear and rotational motion, and having a first scope describing a first amount of allowable movement, a first

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clutch configured to selectively couple movement of the first actuator to the pilot control, a second actuator configured to selectively provide at least one of movement and resistance to movement in the first manner and having a second scope larger than the first scope, a second clutch operatively coupled to the pilot control and configured to selectively couple movement of the second actuator to the pilot control, and a vehicle controller. The vehicle controller is capable of being selectively enabled to operate the pilot control actuators and clutches to selectively manipulate the pilot control providing unmanned operation of the aircraft, and to be disabled, providing manned operation of the aircraft.

In accordance with another embodiment of the present invention, a helicopter includes a plurality of pilot controls configured for operation of the helicopter by a pilot for manned operation, a plurality of dual pilot control actuators, a vehicle controller configured to operate the pilot control actuators, and a pilot selector configured to enable or disable the vehicle controller during manned or unmanned operation of the helicopter. The pilot controls are capable of manipulation to affect operation of the helicopter, and each dual pilot control actuator is configured for operation of a pilot control and includes a first actuator, a first clutch, a second actuator, and a second clutch. The first actuator is configured to selectively provide at least one of movement and resistance to movement in a first manner, including at least one of linear and rotational motion, and having a first scope describing a first amount of allowable movement. The first clutch is configured to selectively couple movement of the first actuator to the pilot control, the second actuator is configured to selectively provide at least one of movement and resistance to movement in the first manner, and has a second scope that is larger than the first scope. The second clutch is operatively coupled to the pilot control and configured to selectively couple movement of the second actuator to the pilot control. The vehicle controller is configured to operate each dual pilot control actuator, where the vehicle controller is selectively enabled to provide unmanned operation of the helicopter and selectively disabled to provide manned operation of the helicopter. The vehicle controller is configured to receive command information from a computer in the helicopter or a remote operator separated from the helicopter.

In accordance with another embodiment of the present invention, a method of piloting a vehicle includes the operations of modifying an aircraft configured for operation by a pilot for manned operation and having at least one pilot control to include a vehicle controller and at least a first pilot control actuator and a second pilot control actuator in a dual actuator configuration, detecting whether the vehicle controller is enabled, sensing at least one aircraft property, computing a vehicle controller response based on the at least one sensed property, and piloting the modified aircraft using the vehicle controller by operating the at least two pilot control actuator according to the vehicle controller response when the vehicle controller is enabled. The at least two pilot control actuators are operatively coupled with the at least one pilot control to provide an enhanced bandwidth capability.

In accordance with another embodiment of the present invention, a helicopter includes a means for controlling the operation of the helicopter by a pilot for manned operation, a means for actuating each controlling means using a means for selectively engaging each means for actuating, and a means for operating each actuating means. Each means for controlling is capable of manipulation to affect operation of the helicopter, and each means for actuating is configured to manipulate at least one controlling means. Each means for actuating includes a first actuator having partial authority and

a second actuator having full authority, the bandwidth of the first actuator being higher than the bandwidth of the second actuator to provide an enhanced bandwidth capability, and each means for operating being configured to operate at least one actuating means. The operating means is selectively enabled to provide unmanned operation of the helicopter and disabled to provide manned operation of the helicopter.

The scope of the present invention is defined by the claims, which are incorporated into this section by reference. A more complete understanding of embodiments of the present invention will be afforded to those skilled in the art, as well as a realization of additional advantages thereof, by a consideration of the following detailed description. Reference will be made to the appended sheets of drawings that will first be described briefly.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a functional block diagram of an example embodiment of a vehicle system in accordance with the present invention.

FIG. 2 is a schematic plan view of a portion of an example embodiment of a helicopter vehicle pilot position including pilot controls in accordance with the present invention.

FIG. 3 is a schematic side elevation view of an example embodiment of a helicopter cyclic pilot control in accordance with the present invention.

FIG. 4 is a partial perspective view of a portion of a helicopter vehicle pilot position including pilot controls according to an embodiment of the present invention.

FIG. 5 is a schematic plan view of a portion of an airplane vehicle pilot position including pilot controls according to an embodiment of the present invention.

FIG. 6 is a schematic plan view of a portion of an automobile vehicle pilot position including pilot controls according to an embodiment of the present invention.

FIG. 7 is a functional block diagram of a flight system according to an embodiment of the present invention.

FIG. 8 is a functional block diagram of a helicopter vehicle according to an embodiment of the present invention.

FIG. 9 is a flow diagram of a multi-mode unmanned and manned vehicle piloting method according to an embodiment of the present invention.

FIG. 10 is a schematic and functional block diagram of an exemplary dual electromechanical actuator (DEMA) operatively coupled to an interface element according to an embodiment of the present invention.

FIG. 11 is an operation flow diagram of an unmanned operation corresponding to piloting the modified vehicle using the vehicle controller according to an embodiment of the present invention.

FIG. 12 is an actuator positioning flow diagram according to an embodiment of the present invention.

FIG. 13 is a schematic and functional block diagram of an exemplary dual electromechanical actuator operatively coupled to an interface element according to an embodiment of the present invention.

FIG. 14 is a schematic end view of a first clutch, a second clutch and an interface element according to an embodiment of the present invention.

Embodiments of the present invention and their advantages are best understood by referring to the detailed description that follows. In the drawings, like reference numerals are used to identify like elements illustrated in one or more of the figures thereof.

DETAILED DESCRIPTION

One or more embodiments of the present invention are drawn to one or more systems and/or methods related to a

vehicle controlled alternately by a pilot and a vehicle controller. In accordance with one or more embodiments of the present invention, a manned vehicle, such as a helicopter configured for operation by a human pilot, may be converted for operation as an unmanned helicopter while maintaining the ability to fly the helicopter in a manned pilot mode. In this manner, the vehicle controller may be disengaged so that the vehicle may be piloted by a human pilot. Alternatively, the vehicle controller may be engaged so that the vehicle may be piloted by the vehicle controller.

Similarly, one or more associated vehicle systems (e.g., weapons and/or surveillance systems) may be controlled alternately by the pilot and the vehicle controller. Therefore, at least four modes of operation are possible: 1) manned piloting of the vehicle and manned operation of associated vehicle systems for a completely manned operation of both the vehicle and associated vehicle systems, 2) manned piloting of the vehicle and unmanned operation of the associated vehicle systems for a partially manned operation of the vehicle and associated vehicle systems, 3) unmanned piloting of the vehicle and manned operation of one or more associated vehicle systems for a partially manned operation of the vehicle and associated vehicle systems, and 4) unmanned piloting of the vehicle and unmanned operation of the associated vehicle systems for a completely unmanned operation of the vehicle.

Transition between these modes of operation may occur during operation of the vehicle or from a non-operational state without limitation. In these different operating modes, a pilot or passenger may be involved to a varying degree throughout a particular mission or mission segment in order to supplement and/or replace one or more human operators and/or pilots. Further, a ground-based operator and/or pilot may be used to pilot the vehicle and/or operate one or more associated vehicle systems. Although reference is made to aircraft including helicopters and airplanes, other applications of embodiments of the present invention may include any manned vehicle, including spacecraft, airships, automobiles, trucks, boats, and/or hovercraft.

FIG. 1 illustrates a vehicle system 100 according to an embodiment of the present invention. System 100 may include a vehicle 102 capable of manned operation by a pilot 104, where vehicle 102 is converted for unmanned operation while retaining the manned operational capability.

Vehicle 102 may include a pilot interface unit 106 and a vehicle operation unit 108. Pilot interface unit 106 may include one or more pilot displays 107 and/or one or more pilot controls 110 for use in operation of vehicle 102, and vehicle operation unit 108 may include the vehicle propulsion 109 and vehicle guidance 111 systems and/or mechanisms to provide directed movement of vehicle 102.

Pilot 104 may read or observe data on display 107 to receive information, including the state, location, and/or performance of vehicle 102. Display 107 may include a Head's Up Display (HUD) and/or a monitor, such as a Cathode Ray Tube (CRT), a Liquid Crystal Display (LCD), and/or other display apparatus that provides visual and/or auditory information to pilot 104 and/or other passengers on vehicle 102. By manipulation of one or more pilot accessible interface elements or portions 112 of pilot controls 110, pilot 104 supplies commands to and may receive feedback from the vehicle operation unit 108 for controlling the operation of vehicle 102. For example, element 112 may include a lever, control arm, a grip, a foot pedal, a toggle, a button, or other mechanism for interfacing with a pilot or vehicle operator, so that manipulation of element 112 may include the pilot pulling, pushing, rotating, moving, or resisting movement of ele-

ment **112**. In this manner, pilot interface unit **106** may communicate the pilot commands to and receive feedback from vehicle operation unit **108** through various mechanical and/or electrical control elements **114**, which may include one or more pushrods, levers, solenoids, gears, pulleys, belts, clutches, and/or command and control systems, alone or in combination.

According to one embodiment, vehicle **102** includes a vehicle controller **120** that may interface with and/or include a plurality of pilot control actuators **122** enabled to selectively provide mechanical movement of pilot controls **110** through a mechanical and/or electrical connection comprising one or more interface elements or linkages **124**, in order to provide operation of the vehicle **102**. Alternatively, pilot control actuators **122** may provide a resistance to movement to pilot controls **110** in order to provide operation of vehicle **102**. In this manner, the resistance to movement may hold a particular pilot control in a current position, corresponding to no change in the current pilot command for the associated pilot control. Vehicle controller **120** may include a suitably programmed computer processor configured to process system and vehicle state logic and execute piloting commands through the actuators **122** in order to operate vehicle **102**. In this manner, vehicle **102** may be operated by vehicle controller **120** through the same vehicle control means accessed by pilot **104**. Interface elements (IE) **124** and interface elements **112** may include one or more of the same interface elements for interfacing between a pilot or vehicle operator.

Vehicle controller **120** may be selectively enabled and disabled so that vehicle **102** may be operated either by pilot **104** in a manned mode or by vehicle controller **120** in an unmanned mode. Pilot **104** may enable or disable vehicle controller **120** by manipulating a pilot selector **130** that communicates pilot select information **132** to vehicle controller **120**. Pilot select information **132** may include an electrical signal and/or a mechanical movement to selectively enable or disable vehicle controller **120**. Pilot **104** may access pilot selector **130** directly or through a pilot select interface element or linkage **134** located at or near the pilot operating position in vehicle **102**. Interface elements (**112**, **124**, **134**) may include one or more of pushrods, levers, solenoids, gears, pulleys, belts, clutches, and/or command and control systems, alone or in combination, and are configured to communicate movement from either a human pilot or an actuator to one or more pilot controls **110** and/or pilot selector **130**.

Two or more pilot control actuators **122** may be paired into a dual actuator configuration, where more than one actuator and preferably two actuators may be used to manipulate a pilot control along a particular degree of freedom (DOF), such as an axis of rotation, a linear motion, and/or within a plane of motion such as described by a sweeping motion about a pivot point. Hence, pilot control actuators **122** may include rotational actuators, linear actuators, and/or a combination of rotational and linear actuators to provide the required actuation motions. Dual actuators may be used to provide an enhanced bandwidth capability.

Vehicle **102** may include a vehicle sensor unit **140** with one or more sensors configured to receive information **142** from vehicle operations unit **108** and/or other vehicle systems in order to measure some property or aspect of the vehicle performance and/or vehicle environment and provide a plurality of sensor signals as information **144** to pilot interface unit **106**, vehicle operation unit **108**, and/or vehicle controller **120**. Information **144** may be measurement signals from one or more sensors that provide a measurement of various vehicle parameters, including vehicle pitch, roll, yaw, acceleration, fuel capacity, vehicle and/or ambient temperature,

engine speed and/or temperature, and/or vehicle status. Also, various additional types of sensor signals may be added to a manned vehicle to provide an unmanned capability. Vehicle controller **120** may include one or more sensors to provide measurement of any such property or parameter not already provided by vehicle sensor unit **140**. In this manner, vehicle controller **120** may sense the relevant aircraft properties and compute a vehicle controller response that is communicated to vehicle **102** through pilot control actuators **122** to pilot controls **110**.

System **100** may include a remote vehicle commander **150** that provides vehicle command information **152** to vehicle controller **120**. Remote vehicle commander **150** may include a pilot located at a remote site defined as anywhere except for in direct contact with pilot controls **110**. Alternatively, remote vehicle commander **150** may include a computer operated system configured to provide closed loop control of vehicle **102** through pre-programmed vehicle commands, where the computer operated system is located either on vehicle **102** or located at some remote site, such as a ground station and/or other remote site from vehicle **102**. Further, vehicle controller **120** may be located in an unused space within a pilot or passenger compartment to allow continued seating of a pilot, co-pilot, other crew members, and/or passengers. At least a portion of vehicle controller **120** may be accessible from outside vehicle **102** through a lockable door or access panel to provide for removal of components or media associated with vehicle controller **120** in order to promote security and/or minimize loss of sensitive information.

Remote vehicle commander **150** may send an override command to vehicle controller **120** to selectively enable or disable vehicle controller **120** regardless of the selection made locally within vehicle **102** by a pilot **104**. This capability may compensate for a possible failure in the pilot select **130** mechanism as well as to address a pilot emergency situation. For example, in the event a rogue pilot commandeers vehicle **102** without authorization, remote vehicle commander **150** can take control of vehicle **102** to prevent the loss of a valuable asset, to regain control of vehicle **102** if pilot **104** is disabled due to injury, and/or to remotely pilot vehicle **102** regardless of the previous status of pilot select **130**. For an aircraft flying above 10,000 feet, a pressurized cabin and oxygen may be required. In the event of a sudden loss in cabin pressure, a pilot may become disoriented or unconscious if he is not able to receive oxygen from a mask or other emergency supply. If the pilot is not able to achieve the lower altitude in time, it may be necessary for vehicle controller **120** to temporarily take control of vehicle **102** until the pilot is able to regain control.

In another emergency situation, pilot **104** may be unable to respond adequately to an emerging threat. For example, vehicle **102** may be attacked with a weapon so that evasive maneuvers are required. Vehicle controller **120** may detect the necessity of evasive or aggressive maneuvers and implement these maneuvers with or without pilot knowledge or consent. In response to the threat, vehicle controller **120** may put vehicle **102** into a proper offensive attitude. Emergency response conditions may include the necessity of implementing sophisticated recovery techniques, such as an auto-rotate maneuver for a helicopter vehicle that can provide a softer landing after a loss of power.

Emergency response conditions may also include recovery from a vehicle failure or the emergence of a condition that is beyond the ability of a human pilot to adequately negotiate, such as recovery from a flat spin for an airplane vehicle and/or landing on an aircraft carrier with zero visibility. In some cases, a human pilot may become physically overstressed so

that pilot performance is degraded, such as by a blackout during an extreme turning maneuver, requiring temporary assistance from vehicle controller 120. Further, emergency response conditions may include the avoidance of a collision either in the air or on the ground. Vehicle controllers in neighboring vehicles may cooperate to provide a coordinated response to an emergency condition, such as collision avoidance, especially when an uncoordinated response may lead to a potentially more hazardous condition.

Finally, remote piloting or vehicle controller piloting of a vehicle may be used during the testing of a new vehicle, such as when it may be too dangerous for a human pilot, when pilot training is needed, and/or to perform an autonomous piloting of the vehicle for some other purpose, including reconnaissance, retrieving a pilot from a remote location, and/or conducting an autonomous cargo sortie by ferrying supplies between locations. In one application, a pilot trainee may utilize the vehicle controller to demonstrate a particular technique or maneuver. In this manner, a pilot trainee may experience the maneuver in a tactile and dynamic way that may be difficult to adequately convey in a pilot simulator.

FIG. 2 is a schematic plan view of a portion of a helicopter vehicle pilot position that includes pilot controls 200 according to an embodiment of the present invention. Where vehicle 102 is a manned helicopter converted for unmanned flight without losing the ability for manned flight, a pilot 104 located at or near pilot seat 202 has access to pilot controls 200 that may include a cyclic 204 or "stick" for controlling one or more rotor heads defining the plane of rotation for each main rotor, a collective 206 for controlling the pitch of the rotor blades, a throttle 208 for controlling the speed of one or more engines, yaw pedals 210 for controlling the speed of a tail rotor configured to control rotation of vehicle 102 in a yaw direction, and/or trim controls 212 for applying corrections to one or more maneuvering controls. Although shown as a single element, trim controls 212 may include one or more trim pilot interface elements.

Other pilot controls 200 may include landing gear operation, cargo winch operation, door operation, and/or weapon system targeting and/or deployment. Hence, this list of pilot controls 200 is not to be construed as limiting. When pilot 104 manipulates pilot controls 200, vehicle 102 responds based on the dynamics of the vehicle conditions, including speed, altitude, attitude, and vehicle status. At least two associated actuators may be operatively coupled in a dual actuator configuration to provide manipulation of each associated pilot control 200. Typically, an individual actuator may be used for each degree of freedom provided by the associated pilot control. When actuation of the associated pilot control requires a linear movement, a linear actuator may be used. Conversely, when actuation of the associated pilot control requires a rotational movement, a rotational actuator may be used.

In one embodiment, pilot control actuators 216, such as electromechanical actuators (EMAs), where two associated EMAs may be combined into a dual EMA (DEMA), may be used to provide manipulation of one or more pilot controls 200. As will be more fully described below, the two EMAs in the dual EMA configuration cooperate to provide a novel capability for enhanced bandwidth operation, and one of the EMAs associated with a particular pilot control 200 may already be included with the vehicle in some embodiments. Preferably, pilot actuators 216 include electromechanical actuators, but alternatively, may include electro-hydraulic, electro-pneumatic, or some other technology configured to respond to electrical/electronic/optical signal control and provide operation of pilot controls 200.

In a helicopter embodiment, a lateral DEMA 220, comprising a roll actuator pair, may operate cyclic 204 through a linkage 222 in order to provide roll commands to the helicopter vehicle. A longitudinal DEMA 224, comprising a pitch actuator pair, may operate cyclic 204 through a linkage 226 in order to provide pitch commands to the helicopter rotor(s). DEMA 220 and DEMA 224 together or separately may operate cyclic 204. A collective DEMA 228 may operate collective 206 through a linkage 230 in order to provide rotor blade pitch commands to one or more helicopter rotors. A throttle DEMA 232 may operate throttle 208 through a linkage 234. A Directional Series DEMA 238, comprising a yaw parallel actuator pair, may operate one or more yaw pedals 210 through one or more linkages 240 in order to provide yaw commands to the helicopter tail rotor and/or related assemblies in order to command a directional orientation or movement for vehicle 102. Finally, a trim DEMA 242 may operate one or more trim controls 212 through one or more linkages 244 in order to provide a bias adjustment to one or more pilot controls and/or control surfaces.

Any associated actuator may be located anywhere along a control path for a particular pilot control. In one example, an actuator configured to operate yaw pedals 210 may be in communication with one or more of the pedals themselves through linkage 240, or the actuator may be in communication with a portion of a pedal operation system anywhere between the pedals 210 and the portion of vehicle 102 directly affected by the operation of pedals 210.

FIG. 3 is a schematic side elevation view of a helicopter cyclic pilot control 204 according to an embodiment of the present invention. DEMA 220 and DEMA 224 may interface with a cyclic extension 302 as an interface element attached to a portion of or extending from cyclic 204. Pilot selector 304, also denoted as a disengage button 304, is a particular embodiment of pilot selector 130 shown in FIG. 1, and may be located on a portion of cyclic 204, such as near a hand-grip portion, for convenient access by a pilot 104 located in a position to grasp cyclic 204.

Although shown in a position on cyclic 204, pilot selector 304 may be located anywhere that may be accessed by pilot 104. Operation of pilot selector 304 may communicate pilot select information 132 to vehicle controller 120 through a communication link 136, as shown in FIG. 1. In one application, a pilot 104 may selectively engage or disengage the operation of vehicle controller 120 by operation of pilot selector 304. Alternatively, enabling or disabling the operation of vehicle controller 120 may be accomplished under computer and/or external control. Also, status and/or other information for vehicle controller 120 may be communicated along link 136 to display 107, as shown in FIG. 1, for communication to pilot 104 and/or other passengers.

FIG. 4 is a perspective view of a portion of a helicopter vehicle pilot position including pilot controls 400 according to an embodiment of the present invention. Where vehicle 402 is a helicopter, pilot controls 400 may include a cyclic 404 or "stick" for controlling one or more rotor heads defining the plane of rotation for each main rotor, a collective 406 for controlling the pitch of the rotor blades, a throttle 408 for controlling the speed of one or more engines, and/or yaw pedals 410 for controlling the speed of a tail rotor configured to control rotation of helicopter vehicle 402 in a yaw direction. Other pilot controls 400 may include trim operation, landing gear operation, cargo winch operation, door operation, and/or weapon system targeting and/or deployment. Hence, this list of pilot controls 400 should not be construed as limiting.

When pilot **104** manipulates one or more pilot controls **400**, helicopter vehicle **402** responds based on the dynamics of the vehicle conditions, including speed, altitude, attitude, and vehicle status. At least one associated actuator may provide manipulation of each associated pilot control **400**. In one embodiment, pilot control actuators **416**, such as electromechanical actuators (EMAs) where two associated EMAs may be combined into a dual EMA (DEMA), may be used to provide manipulation of pilot controls **400**. Alternatively, the pilot control actuators **416** may be electro-pneumatic, or some other technology configured to respond to electrical/electronic control and provide operation of pilot controls **400**.

In a helicopter embodiment, a lateral DEMA **420**, comprising a roll actuator pair, may operate cyclic **404** through a linkage **422** in order to provide roll commands to the helicopter vehicle. A longitudinal DEMA **424**, comprising a pitch actuator pair, may operate cyclic **404** through a linkage **426** in order to provide pitch commands to the helicopter rotor(s). DEMA **420** and DEMA **424** together or separately may operate cyclic **404**. A collective DEMA **428** may operate collective **406** through a linkage **430** in order to provide rotor blade pitch commands to one or more helicopter rotors. A first directional DEMA **438**, comprising a yaw parallel actuator pair, may operate one or more yaw pedals **410** through one or more linkages **440** in order to provide yaw commands to the helicopter tail rotor and/or related assemblies in order to command a directional orientation or movement for helicopter vehicle **402**.

A second directional DEMA **442**, comprising a yaw series actuator pair, may be coupled with first directional DEMA **438** to provide yaw control for helicopter vehicle **402** through linkages **446**, **448**, **450**, and **452**. Any actuator may be located anywhere along a control path for a particular pilot control. Since first directional DEMA **438** and second directional DEMA **442** comprise a directional series control, the two directional EMAs **438** and **442** may be referred to collectively as a directional series dual EMA. Pilot selector **460** is a particular embodiment of pilot selector **304** as shown in FIG. **3**, and may be used to selectively enable or disable vehicle controller **120**.

FIG. **5** is a schematic plan view of a portion of an airplane vehicle pilot position, including pilot controls **500**, according to an embodiment of the present invention. Where vehicle **102** is a manned airplane converted for unmanned flight without losing the ability for manned flight, a pilot located at or near pilot seat **502** has access to pilot controls **500** that may include a yoke **504**, rudder pedals **506**, a throttle control **508**, and/or trim controls **510**. Yoke **504** provides roll and pitch control, rudder pedals **506** provide yaw control, throttle control **508** provides engine speed control, and trim **510** provides for corrections to one or more maneuvering controls. Other pilot controls **500** (not shown) may include landing gear operation, cargo winch operation, door operation, and/or weapon system deployment. Hence, this list of pilot controls **500** is not limiting. When pilot **104** manipulates one or more pilot controls **500**, vehicle **102** responds based on the dynamics of the vehicle conditions including speed, altitude, attitude, and vehicle status.

In one embodiment, pilot control actuators **516**, such as electromechanical actuators (EMAs), or some other technology configured to respond to electrical/electronic control, where two associated EMAs may be combined into a dual EMA (DEMA), may be used to provide manipulation of pilot controls **500**. A lateral DEMA **520**, comprising a roll actuator pair, may operate yoke **504** through a linkage **522** in order to provide roll commands to the airplane's flight control surfaces, including ailerons. A longitudinal DEMA **524**, com-

prising a pitch actuator pair, may operate yoke **504** through a linkage **526** in order to provide pitch commands to the airplane flight control surface(s), including an elevator or tail horizontal stabilizer. A throttle DEMA **528** may operate throttle **508** through a linkage **530**. A Directional Series DEMA **532**, comprising a yaw parallel actuator pair, may operate one or more yaw pedals **506** through one or more linkages **534** in order to provide yaw commands to the airplane rudder. Finally, a trim DEMA **536** may operate one or more trim controls **510** through one or more linkages **538** in order to provide adjustments to various maneuvering controls and/or control surfaces. Each dual actuator includes at least two pilot control actuators operatively coupled to the pilot control and configured to manipulate the pilot control, where the dual actuators provide an enhanced bandwidth capability. A pilot selector **540**, such as a disengage button **540**, may be located on a portion of yoke **504**, such as near a hand-grip portion, for convenient access by a pilot **104** in a position to grasp yoke **504**. Although shown in a position on yoke **504**, pilot selector **540** may be located anywhere that may be accessed by pilot **104**.

Operation of pilot selector **540** may communicate pilot select information **132** to vehicle controller **120**, as shown in reference to FIG. **1**. In one application, a pilot **104** may selectively engage or disengage the operation of vehicle controller **120** by operation of pilot selector **540**. Alternatively, enabling or disabling the operation of vehicle controller **120** may be accomplished under computer and/or external control. In this manner, vehicle controller **120** is configured to operate the dual actuators where vehicle controller **120** is capable of being selectively enabled during manned flight to operate the pilot control actuators to provide unmanned operation of the aircraft and disabled during manned flight to provide manned operation of the aircraft. Although FIG. **5** shows pilot controls related to a helicopter vehicle, any type of powered or un-powered aircraft may be used including an airplane, a glider, a blimp, a sub-orbital vehicle, and a spacecraft, where various vehicle-specific pilot controls and associated DEMAs may be used.

FIG. **6** is a plan view of a portion of an automobile vehicle pilot position including pilot controls **600** according to an embodiment of the present invention. Where vehicle **102** is a manned automobile or truck converted for unmanned operation without losing manned operational capability, a pilot **104** located at or near pilot seat **602** has access to pilot controls **600** that may include a steering wheel **604** for controlling the orientation of two or more steerable wheels, a brake **606** for slowing or stopping vehicle **102**, and/or an accelerator **608** for controlling the acceleration of vehicle **102**. Other pilot controls **600** (not shown) may include handbrake operation, winch operation, and door operation, so this list of pilot controls **600** is not limiting. When pilot **104** manipulates one or more pilot controls **600**, vehicle **102** responds based on the dynamics of the vehicle conditions, including speed, orientation, and vehicle status.

In one embodiment, pilot control actuators **616**, such as electromechanical actuators (EMAs), or some other technology configured to respond to electrical/electronic control, where two associated EMAs may be combined into a dual EMA (DEMA), may be used to provide manipulation of pilot controls **600**. A steering DEMA **620**, comprising a steering actuator pair, may operate steering wheel **604** through a linkage **622** in order to provide steering commands to the steerable automobile wheels. A brake DEMA **624**, comprising a brake actuator pair, may operate brake **606** through a linkage **626** in order to provide braking commands to vehicle **102**. An accelerator DEMA **628**, comprising an accelerator actuator

pair, may operate accelerator **608** through a linkage **630** in order to provide acceleration commands to vehicle **102**. Any associated actuator may be located anywhere along the control path for a particular pilot control **600**. A pilot selector **632**, such as a disengage button **632**, may be located on a portion of steering wheel **604**, such as near a hand-grip portion, for convenient access by a pilot **104** in a position to grasp steering wheel **604**. Operation of pilot selector **632** may communicate pilot select information **132** to vehicle controller **120**, as shown in reference to FIG. 1. In one application, a pilot **104** may selectively engage or disengage the operation of vehicle controller **120** by operation of pilot selector **632**. Alternatively, enabling or disabling the operation of vehicle controller **120** may be accomplished under computer and/or external control.

FIG. 7 a functional block diagram of a flight system **700** according to an embodiment of the present invention. Flight vehicle **702** is a particular embodiment of vehicle **102** shown in FIG. 1, and may include a flight vehicle controller **704** that is a particular embodiment of vehicle controller **120** shown in FIG. 2. Flight vehicle controller **704** may include a flight control computer **706**, one or more pilot control actuators **708**, a secure communication unit **710**, an intra-vehicular communication unit **712**, an external communication unit **714**, and/or a sensor unit **716**. Flight control computer **706** may be located either on-board or off-board vehicle **702** and may be located within flight vehicle **702** separate from flight vehicle controller **704**. Pilot control actuators **708** are a particular embodiment of pilot control actuators **122** as shown in FIG. 1 and may include electromechanical actuators (EMAs) or some other technology adapted to respond to electrical/electronic control.

Flight control computer **706** or mission controller **706** may include a processor **720** and/or a processor memory **722** that may include a mission program **724** and/or one or more encryption keys **726** for encrypting and decrypting messages in cooperation with secure communication unit **710**. In order to prevent unauthorized access to flight controller **704**, some or all communications into and out of flight vehicle controller **704** may be encrypted or authenticated using various cryptographic algorithms. Secure communication unit **710** may include a cryptographic processor, a communication firewall, a memory for storing and retrieving cryptographic keys, and/or dedicated cryptographic hardware for use in performing cryptographic functions, including the implementation of cryptographic algorithms, such as the Data Encryption Standard (DES), the Advanced Encryption Standard (AES), the Secure Hash Algorithm (SHA-1), and the Message Digest (MD-5) Algorithm. Alternatively, secure communication unit **710** may be selectively enabled so that only certain commands and information are cryptographically protected. In yet another alternative, secure communication unit **710** may be disabled or omitted altogether so that no information flow is cryptographically protected. In one embodiment, sensor unit **716** includes at least one sensor that provides a measurement signal of a property of the aircraft during flight, where the measurement signal is not used by flight control computer **706**, but is instead used by flight vehicle controller **704** to affect operation of one or more dual actuators.

Processor **720** may be a general-purpose computer processor suitably programmed to fetch, decode, and execute computer instructions, including mission program **724**. Processor memory **722** may be any medium for storing and retrieving information, including a Random Access Memory (RAM), a Read Only Memory (ROM), a magnetic disc, an optical disc, a content addressable memory, and/or a register file. Processor memory **722** may be removable from flight vehicle con-

troller **702** in order to provide safekeeping of information, to provide convenient transfer to another vehicle controller, and/or reconfiguration of a replacement vehicle controller. Mission program **724** may include an implementation of an algorithm designed to operate flight vehicle **702** according to a predetermined plan including pre-programmed instructions and options for handling various contingencies. Encryption keys **726** may be used to encrypt and decrypt information sent to or received from external communication unit **714** and/or intra vehicle communication unit **712** through secure communication unit **710**.

Pilot controls **730** may be either a particular embodiment of pilot controls **200** as shown in FIG. 2, or a particular embodiment of pilot controls **500** as shown in FIG. 5. Alternatively, pilot controls **730** may correspond to a standard set of pilot controls corresponding to any flight vehicle, including a helicopter, airplane, glider, blimp, airship, and/or spacecraft. Pilot controls **730** are coupled with corresponding pilot control actuators **708** through a linkage **732** to provide manipulation of pilot controls **730** in order to operate flight vehicle **702**. Pilot selector **740** is a particular embodiment of pilot selector **130** shown in FIG. 1 and provides pilot select information **742** through a communication link **744** to flight vehicle controller **704**. In one embodiment, pilot selector **740** includes a status light indicating whether a pilot **104** or flight vehicle controller **704** is in command of flight vehicle **704**. In another embodiment, pilot selector **740** includes an electromechanical switch that can be toggled into either an enabled position or a disabled position by flight vehicle controller **704** in order to provide tactile feedback to a pilot regarding the status of pilot selector **740**.

Intra vehicle communication unit **712** may communicate with a portable computer **750** located either onboard flight vehicle **702** or located remotely from flight vehicle **702**. Portable computer **750** may be a ruggedized laptop computer suitable for use in a harsh environment and configured to communicate with flight vehicle controller **704** to upload and/or download information including mission program **724** and/or status information across communication link **752**. Both communication links (**744**, **752**) may access flight vehicle controller through intra-vehicular communication unit **712**, where links (**744**, **752**) may include wired, wireless, and/or optical communication paths.

External communication unit **714** may send status information to and receive command information from a remote vehicle commander **760** across communication link **762** that may include any wireless communication technology, including Radio Frequency (RF), microwave, and optical communications. The vehicle status information can include the operational status (e.g., health) and/or history of various flight vehicle systems. External communication unit **714** may include one or more antennas, receivers, and/or optical detectors that may be use instead of or in addition to any external communication equipment already available on flight vehicle **702**. Either intra vehicle communications unit **712** or external communications unit **714** are configured to send command messages to and receive status messages from flight vehicle controller **704**.

Sensor unit **716** may include one or more sensors, such as a Global Positioning Satellite (GPS) receiver configured to provide location information, dynamic sensors for detecting acceleration and/or rotation, altimeter for detecting altitude, cabin sensors for air-pressure, oxygen level, and/or temperature, environmental sensors for detecting conditions either inside or outside the aircraft, and/or reconnaissance. In one embodiment, sensor unit **716** may include a GPS receiver such as manufactured by NovAtel of Calgary, Alberta,

Canada. Other sensors may be included and listed sensors may be omitted in some embodiments, so this list should not be considered as limiting.

FIG. 8 is a functional block diagram of an exemplary embodiment of a helicopter vehicle **802** in accordance with the present invention. Helicopter vehicle **802** is a particular embodiment of vehicle **702** in FIG. 7, and may include a flight vehicle controller **804**, a pilot interface unit **806**, a vehicle operation unit **808**, a vehicle sensor unit **828**, a weapons control unit **840**, a visualization and documentation unit **842**, a communications unit **844**, and/or a portable computer **750**.

Flight vehicle controller **804** is a particular embodiment of vehicle controller **120** of FIG. 1, and may include pilot control actuators **850** that are a particular embodiment of pilot control actuators **708** shown in FIG. 6. Pilot control actuators **850** may include a lateral DEMA **852**, a longitudinal DEMA **854**, a collective DEMA **856**, a throttle DEMA **858**, a directional series DEMA **860**, and/or a trim DEMA **862**. Lateral DEMA **852**, comprising a roll actuator pair, may be configured to provide roll control of helicopter vehicle **802** through roll controlling elements of pilot controls **870**. Similarly, longitudinal DEMA **854**, Collective DEMA **856**, throttle DEMA **858**, directional series DEMA, and trim DEMA provide control of associated helicopter pilot controls **870**.

Pilot interface unit **806** is a particular embodiment of pilot interface unit **106** shown in FIG. 1, and may include pilot controls **870** and/or pilot selector **872**. Pilot selector **872** is a particular embodiment of pilot selector **130** shown in FIG. 1. Vehicle operation unit **808** is a particular embodiment of vehicle operation unit **108** in FIG. 1 and may include an airspeed sensor, a pressure altimeter, a radar altimeter, a Global Positioning System (GPS), as well as sensors to measure engine speed, torque, transmission operation, and rotor speed. Although specific sensors are described, this should not be considered as limiting.

Weapons control unit **840** may provide targeting and launch control over one or more weapon systems associated with helicopter vehicle **802** including air-to-air missiles, Gatling cannon, chaff dispensers, and/or tactical countermeasures. Visualization and documentation unit **842** may include one or more cameras, a voice recorder, and/or a data recorder to provide visualization and documentation of a helicopter mission including weapons targeting and deployment information, vehicle navigation, and/or vehicle and/or vehicle controller sensor readings. Communications unit **844** may include radios, lights, a vehicle transponder, a microwave modem, and/or an airborne link, such as the tactical common data link (TCDL). Portable computer **750** may provide mission data for use by a pilot and/or flight crew where the mission data may include a mission program for use in flight vehicle controller **804**. Alternatively, portable computer **750** may provide survey and/or environmental information for a pilot and/or passengers.

Modification of an existing helicopter platform provides an unmanned helicopter with the same performance as its manned counterpart, where pilot control actuators are tied into the pilot controls of the existing helicopter controls in a parallel fashion so that the pilot control actuators may be quickly engaged or disengaged. A flight control computer in flight vehicle controller **804** may provide commands to the actuators using aircraft state data to determine the appropriate commands to fly the defined mission profiles. The quick disconnect feature of the actuators provide an effective safety feature to the manned aircraft and does not increase the control loads in the baseline aircraft control system. One exem-

plary embodiment of the quick disconnect capability may include a belt-drive in combination with an electric or electromechanical clutch.

FIG. 9 is a flow diagram of an example embodiment of a multi-mode unmanned and manned vehicle piloting method **900** in accordance with the present invention. Method **900** includes a method of piloting a vehicle including the operations of modifying a vehicle having at least one pilot control to include a vehicle controller and at least one pilot control actuator in operation **902**, where the at least one pilot control actuator is operatively coupled with the at least one pilot control. A plurality of pilot controls and pilot control actuators may be used.

Method **900** continues with detecting whether the vehicle controller is enabled in operation **904**. Detection in this case may be accomplished by vehicle controller **120**, where the status of pilot selector **130** is examined as discussed above in reference to FIG. 1. If vehicle controller **120** is enabled, then flow **900** continues with piloting the modified vehicle with the vehicle controller to provide unmanned operation of the modified vehicle in operation **906**. Conversely, if the vehicle controller is not enabled, then flow **900** continues with piloting the modified vehicle with a human pilot to provide manned operation of the modified vehicle in operation **908**.

During manned and/or unmanned operation of the modified vehicle, the status of pilot selector **130** may again be assessed, where method **900** returns to operation **904** after a predetermined delay, such as a control system sampling period. In this manner, operation of pilot selector **130** to enable and/or disable vehicle controller **120** may be detected and a smooth transition effected between manned and unmanned operation as well as between unmanned and manned operation. The pilot select transition time between the time at which the vehicle controller is enabled to provide unmanned operation of the modified vehicle and time at which the vehicle controller is disabled to provide manned operation of the modified vehicle is less than about one second after a selection change is registered. This rapid pilot select transition time may also be considered a "quick disconnect" feature that enables a human pilot to rapidly take command of a modified vehicle previously under the command of the vehicle controller.

FIG. 10 shows an exemplary dual electromechanical actuator (DEMA) **1002** operatively coupled to an interface element (IE) **1004** according to an embodiment of the present invention. DEMA **1002** is a particular embodiment of DEMA **220** in FIG. 2, and may include a higher-bandwidth (HB) electromechanical actuator (HB-EMA) **1006** and a lower-bandwidth LB-EMA **1008**. A higher-bandwidth EMA may have a faster response time to electronic control and/or a quicker movement through a particular range of motion and/or rotation. Conversely, a lower-bandwidth EMA may have a slower response time and/or a slower movement through a particular range of motion and/or rotation. In some exemplary embodiments, a gear ratio of a transmission device may determine the torque and/or response speed as a measure of bandwidth. HB-EMA **1006** and LB-EMA **1008** may be operatively coupled to interface element (IE) **1004** in a parallel connection so that both HB-EMA **1006** and LB-EMA **1008** may independently control the same type of motion of IE **1004**. Other DEMAs may be used, so this description should not be considered as limiting.

HB-EMA **1006** may be coupled through a first linkage **1010** operatively coupled to a first clutch **1012** that selectively couples movement on a first linkage **1010** to a first portion of IE **1004**. First clutch **1012** may be engaged to couple movement between first linkage **1010** and the first portion of IE

1004 and disengaged to isolate movement of first linkage 1010 and IE 1004. Similarly, LB-EMA 1008 may be coupled through a second linkage 1014 operatively coupled to a second clutch 1016 that selectively couples movement on a second linkage 1014 to a second portion of IE 1004. Second clutch 1016 may be engaged to couple movement between second linkage 1014 and the second portion of IE 1004 and disengaged to isolate movement of second linkage 1014 and IE 1004. First clutch 1012 and second clutch 1016 may be electrically operated to selectively and independently couple movement on the first and second linkages (1010, 1012) to IE 1004. Together, linkage 1010 and linkage 1014 may comprise a parallel linkage 1018 that is a particular embodiment of linkage 222 shown in FIG. 3. Further, LB-EMA 1008 may provide movement through an entire range of motion, while HB-EMA 1006 may provide movement through only a portion of the entire range of motion. In this manner, LB-EMA 1008 may have full authority and HB-EMA may have only partial authority. Due to the faster response time of HB-EMA 1006, the authority of movement is restricted to limit potential control instability. Further, the dual actuator configuration provides for redundancy in the case of a component or system failure.

The larger scope of LB-EMA 1008 defines a full authority of pilot control movement covering the entire range of allowable motion for the particular pilot control. The smaller scope of HB-EMA 1006 defines a partial authority for pilot control movement having a first center of travel when HB-EMA 1006 is engaged with the pilot control. LB-EMA 1008 may be included as a part of an existing aircraft trim system or supplied separately for a pilot control without an associated trim element. In this and other embodiments, an existing vehicle having entirely manual pilot controls may be modified for unmanned operation while maintaining the ability to pilot the vehicle in a manned vehicle mode.

In this exemplary embodiment, DEMA 1002 is a particular embodiment of lateral DEMA 220, while IE 1004 is a particular embodiment of cyclic extension 302, both shown in FIG. 3. In this embodiment, IE 1004 is connected to a pilot control 1030 that is a particular embodiment of cyclic 204 shown in FIG. 3. For descriptive purposes, pilot control 1030 has an axis 1032 extending through a portion of pilot control 1030 that defines motion through a range of lateral and/or rotational movement. In one example, movement of pilot control through a plane of motion defined as a back-and-forth movement through a larger range 1040 that includes a smaller range 1042, where larger range 1040 defines movement from a first limit 1050 to a second limit 1052, while smaller range 1042 defines movement from a third limit 1054 and a fourth limit 1056. In this manner, movement through the larger range 1040 has a first range of motion 1060 and movement through the smaller range 1042 has a second range of motion 1062. Although smaller range 1042 is shown as entirely included within larger range 1040, this should not be considered as limiting, since larger range 1040 and smaller range 1042 may completely overlap, partially overlap, or be non-overlapping. Further, smaller range 1042 may not be centered within larger range 1040, and may instead be defined anywhere in the range of motion defined for IE 1004.

First clutch 1012 may be engaged with IE 1004 while second clutch 1014 is disengaged from IE 1004, or vice versa. In this manner, when second clutch 1016 is engaged, LB-EMA 1008 may hold the position of pilot control 1030, while first clutch 1012 is disengaged, allowing HB-EMA 1006 to be positioned into a favorable new position prior to re-engagement of first clutch 1012. Similarly, when first clutch 1012 is engaged, HB-EMA 1006 may hold the position of pilot con-

trol 1030, while second clutch 1016 is disengaged, allowing LB-EMA 1008 to be positioned into a favorable new position prior to re-engagement of second clutch 1016. In this manner, the EMAs (1006, 1008) may be repositioned relative to each other in order to avoid exceeding an actuator travel limit while operating an associated pilot control. The actuator travel limit may include an end-point of movement or a region of movement having a property such as higher/lower torque, and/or response time/speed.

FIG. 11 is an unmanned operation flow diagram 1100 corresponding to piloting the modified vehicle using the vehicle controller according to an embodiment of the present invention. Flow 1100 may include the operations of determining the current vehicle state and desired vehicle state in operation 1102, comparing the current vehicle state to the desired vehicle state to determine a vehicle state difference in operation 1104, and determining whether to modify the vehicle state in operation 1106. If the differences between the current vehicle state to the desired vehicle state are small (e.g., below a predetermined threshold), then the determination in operation 1106 will be "N" and control will move to operation 1102.

Alternatively, if the differences between the current vehicle state and the desired vehicle state are above a predetermined threshold, then the determination in operation 1106 will be "Y" and control will move to operation 1108. Flow 1100 continues with calculating the change in one or more pilot control positions corresponding to the vehicle state difference in operation 1108, where the change in the pilot control position is required to produce the desired vehicle state change. Once the change in each pilot control position is calculated, flow 1100 continues with calculating the required actuator position change corresponding to the pilot control position change in operation 1110. Once the new actuator position is determined, flow 1100 continues with commanding the new actuator position in operation 1112, and control moves to operation 1102.

FIG. 12 shows an actuator positioning flow diagram 1200, according to an embodiment of the present invention. Positioning flow 1200 corresponds to a particular embodiment of operation 1110 described in reference to FIG. 11. Flow 1200 begins in operation 1202 where positioning flow 1200 is invoked to command one or more new pilot control positions, and control moves to operation 1204 which determines whether or not each pilot control commanded to change corresponds to a high control load that requires adjustment. If a particular commanded pilot control is a high control load that requires adjustment, the determination in operation 1204 is "Y" and control moves to operation 1206, where the control load is adjusted using a low bandwidth actuator coupled to the vehicle pilot control. In one embodiment, the low bandwidth actuator may be included as a part of an existing vehicle trim system. If no adjustment is required in operation 1204, the determination is "N" and control moves to operation 1208, where a determination is made regarding whether the commanded position for a particular actuator will exceed the actuator travel limits. If the actuator travel limits will not be exceeded by moving to the newly commanded pilot control position, the determination in operation 1208 is "N" and control moves to operation 1210, where the actuator position is changed as commanded. Once each of the selected pilot control actuators is changed to the commanded position, flow 1200 concludes in operation 1212 with a stop.

In operation 1208, if the actuator travel limits will be exceeded by moving to the newly commanded pilot control position, the determination in operation 1208 is "Y," and control moves to operation 1214. Further, if the expected

operational motion at the new actuator position may exceed the actuator travel limits, then adjustment may also be required in order to avoid limiting or rough operation of the associated pilot control. Flow 1200 continues by disengaging the limit exceeding actuator from the associated operator control in operation 1214, moving the actuator position to a center of travel for the particular actuator in operation 1216, and re-engaging the particular actuator to the pilot control in operation 1218, and control moves to operation 1210. In this manner, an actuator configured to operate a particular pilot control is realigned to the center of travel to provide flexibility of actuator movement without exceeding actuator movement limits. In one embodiment, an electromechanical clutch device may be used to selectively engage and disengage a mechanical coupling between a portion of the particular actuator and the particular pilot control.

FIG. 13 shows an exemplary dual electromechanical actuator (DEMA) 1302 operatively coupled to an interface element (IE) 1304, according to an embodiment of the present invention. DEMA 1302 is a particular embodiment of DEMA 208 in FIG. 2, and may include a higher-bandwidth (HB) electromechanical actuator (HB-EMA) 1306 and a lower-bandwidth LB-EMA 1308. HB-EMA 1306 and LB-EMA 1308 may be operatively coupled to interface element (IE) 1304 in a series connection so that both HB-EMA 1306 and LB-EMA 1308 may cooperatively control the same type of motion of IE 1304. Other DEMAs may be used, so this description should not be considered as limiting. HB-EMA 1306 may be coupled through a first linkage 1310 operatively coupled to a first clutch 1312 that selectively couples movement on a first linkage 1310 to a first portion of IE 1304. Similarly, LB-EMA 1308 may be coupled through a second linkage 1314 operatively coupled to a second clutch 1316 that selectively couples movement on a second linkage 1314 to a second portion of IE 1304. First linkage 1310 and second linkage 1314 may each be a drive belt for coupling the rotational movement of a portion of first clutch 1312, and second clutch 1316 may be electrically operated to selectively and cooperatively couple movement on the first and second linkages (1310, 1312) to IE 1304. Together, linkage 1310 and linkage 1314 may comprise a linkage 1318 that is a particular embodiment of linkage 234 shown in FIG. 2.

FIG. 14 is a schematic an end view of first clutch 1312, second clutch 1316, and interface element 1314, according to an embodiment of the present invention. First clutch 1312 is configured to impart back and forth rotational movement about a long axis of IE 1304 in a smaller range of motion 1402 between a first limit 1404 and a second limit 1406. Similarly, second clutch 1316 is configured to impart back and forth rotational movement about the long axis of IE 1304 in a larger range of motion 1420 between a first limit 1422 and a second limit 1424. Since smaller range of motion 1402 is smaller than larger range of motion 1420, first clutch 1312 may be disengaged from IE 1304, move to a new position at or near an expected center of travel 1430, and then re-engaged with IE 1304, as described in reference to FIG. 12. In this manner, while second clutch 1316 maintains the position of IE 1304, the range of motion 1402 may be centered about center of travel 1430, allowing first EMA 1306 to provide a full-range of expected motion at a higher bandwidth. Similarly, first clutch 1312 may be engaged while second clutch 1316 is disengaged in order to provide positive control of IE 1304 at all times. In this manner, either clutch may be alternately engaged or disengaged to re-adjust a center point of operation. Although smaller range 1402 is shown as entirely included within larger range 1420, this should not be considered as limiting since larger range 1420 and smaller range

1402 may completely overlap, partially overlap, or be non-overlapping. Further, smaller range 1402 may not be centered within larger range 1420, and may instead be defined anywhere in the range of motion defined for IE 1304.

In one application, second EMA 1308 is not moving and second clutch 1316 is engaged to maintain IE 1304 in a stationary position while first clutch 1312 is re-adjusted. Alternatively, first EMA 1306 is not moving and first clutch is engaged to maintain IE 1304 in a stationary position while second clutch 1316 is re-adjusted. In this manner, either EMA/clutch pair may independently control the operation of IE 1304 to provide for re-adjustment of the other EMA/clutch pair and to compensate for system failures where either EMA/clutch pair or the related control hardware and/or software may not be functioning properly. In another application, second EMA 1308 is moving according to the commands of a vehicle control loop. In this case, first EMA 1306 is moved in harmony with the movement of second EMA 1308 to provide a smooth clutching and de-clutching action whether IE 1304 is stationary or moving at the time of readjustment. Although rotational motion is described in reference to rotational motion limits, EMAs (1306, 1308) may be used to provide linear movement in reference to linear motion limits. Hence, the type of EMA and/or movements described above should not be considered as limiting.

One or more embodiments of the present invention provide various benefits, including lower unmanned vehicle development and deployment costs, while providing enhanced multi-mode unmanned and manned vehicle capabilities. Embodiments described above illustrate but do not limit the invention. It should also be understood that numerous modifications and variations are possible in accordance with the principles of the present invention. Accordingly, the scope of the invention is defined only by the following claims.

What is claimed is:

1. A method of piloting an aircraft, the method comprising: providing an unmodified aircraft having at least one pilot control configured for operation by a pilot for manned operation; retrofitting the aircraft so as to include a vehicle controller and at least two pilot control actuators arranged in a dual actuator configuration, wherein the vehicle controller is capable of being selectably enabled or disabled during flight of the aircraft to operate the at least two pilot control actuators, and the at least two pilot control actuators are each capable of being selectably coupled to or from the at least one pilot control during flight of the aircraft by an associated, independently controllable clutch and operative to provide an enhanced bandwidth capability; flying the retrofitted aircraft; detecting without pilot input whether the vehicle controller is enabled; and when the vehicle controller is enabled: sensing at least one aircraft property; computing a vehicle controller response based on the sensed property; and piloting the modified aircraft using the vehicle controller by operating the at least two pilot control actuators according to the vehicle controller response.
2. The method of claim 1, further comprising piloting the retrofitted aircraft using a human pilot when the vehicle controller is not enabled.
3. The method of claim 2, wherein a pilot select transition time between when the vehicle controller is enabled to provide unmanned operation of the retrofitted vehicle and when

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the vehicle controller is disabled to provide manned operation of the retrofitted vehicle is less than about one second.

4. The method of claim 2, further comprising:

sensing a condition of the pilot;
 detecting an impaired condition of the pilot;
 enabling the vehicle controller; and
 piloting the retrofitted aircraft using the vehicle controller.

5. The method of claim 4, wherein the piloting of the retrofitted aircraft using the vehicle controller comprises piloting the aircraft using an onboard computer.

6. The method of claim 4, wherein the piloting of the retrofitted aircraft using the vehicle controller comprises piloting the aircraft from a remote location.

7. The method of claim 2, further comprising:

sensing aircraft ambient conditions;
 detecting a threat to the aircraft;
 enabling the vehicle controller; and
 piloting the retrofitted aircraft using the vehicle controller so as to avoid the threat.

8. The method of claim 1, wherein the computing of a vehicle controller response based on the sensed property further comprises:

comparing a current vehicle state to a desired vehicle state to determine a vehicle state difference;

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calculating a change in one or more positions of the at least one pilot control based on the vehicle state difference;
 calculating a change in one or more positions of the at least two actuators corresponding to the calculated change in the one or more positions of the at least one pilot control,
 and

commanding the calculated change in the one or more positions of the at least two actuators.

9. The method of claim 8, wherein the piloting of the retrofitted aircraft using the vehicle controller by operating the at least two pilot control actuators when the commanded change in the position of at least one of the at least two actuators will exceed an actuator travel limit further comprises:

decoupling the at least one actuator from the at least one pilot control;
 positioning the at least one actuator to a center of travel;
 and
 re-coupling the at least one actuator to the at least one pilot control.

10. The method of claim 1, wherein one of the at least two pilot control actuators is included in the unmodified aircraft.

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