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(54) **VEHICLE DIAGNOSTICS BASED ON INFORMATION COMMUNICATED BETWEEN VEHICLES**

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(58) **Field of Classification Search**

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See application file for complete search history.

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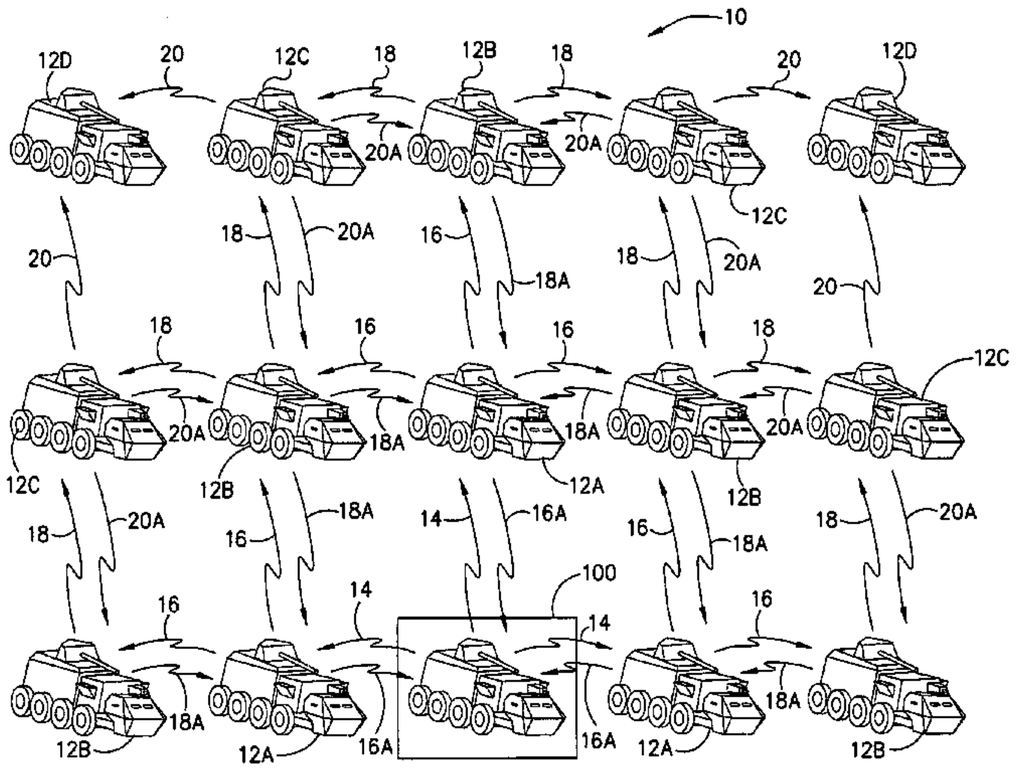
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(57) **ABSTRACT**

A system and method for controlling a convoy of vehicles. The convoy of vehicles including a leader vehicle in communication with a plurality of autonomous follower vehicles. The leader vehicle is configured to receive a first autonomous follower vehicle data and compare the first autonomous follower vehicle data to at least one of a leader vehicle data, a second autonomous follower vehicle data and/or a threshold value. The first autonomous follower vehicle data, the leader vehicle data, the second autonomous follower vehicle data and the threshold value relate to a vehicle performance characteristic.

16 Claims, 26 Drawing Sheets



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FIG. 1

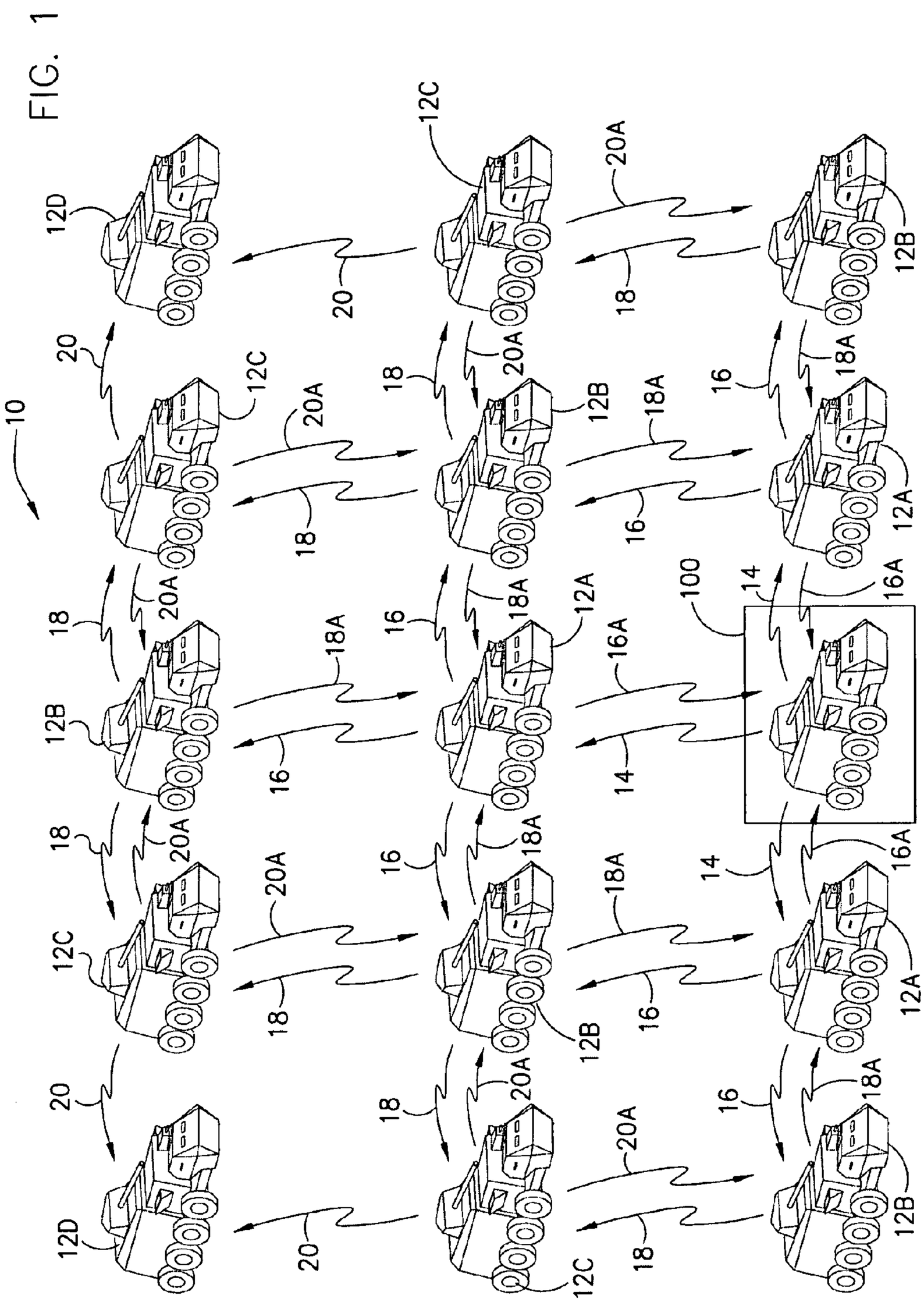


FIG. 2

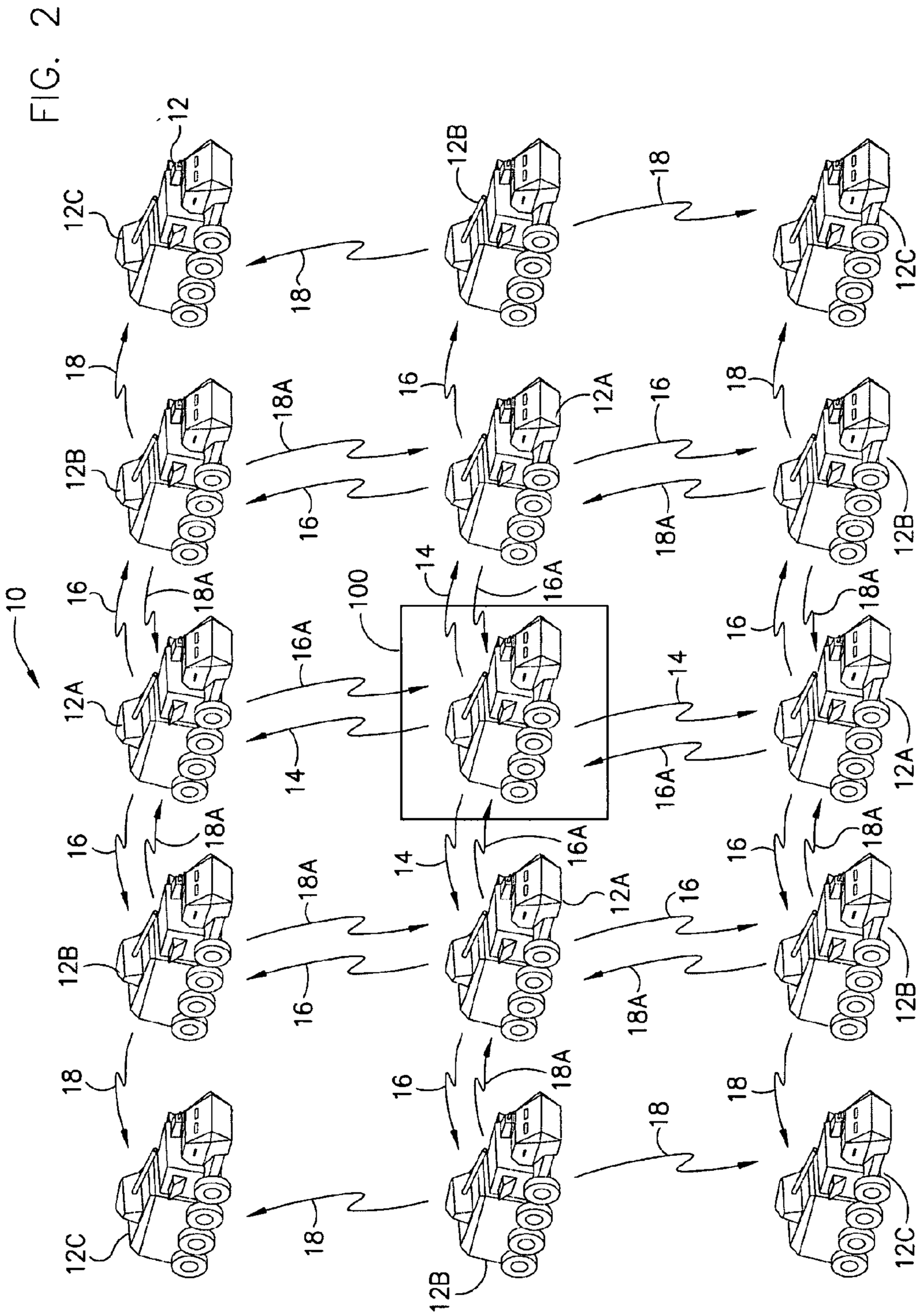


FIG. 3

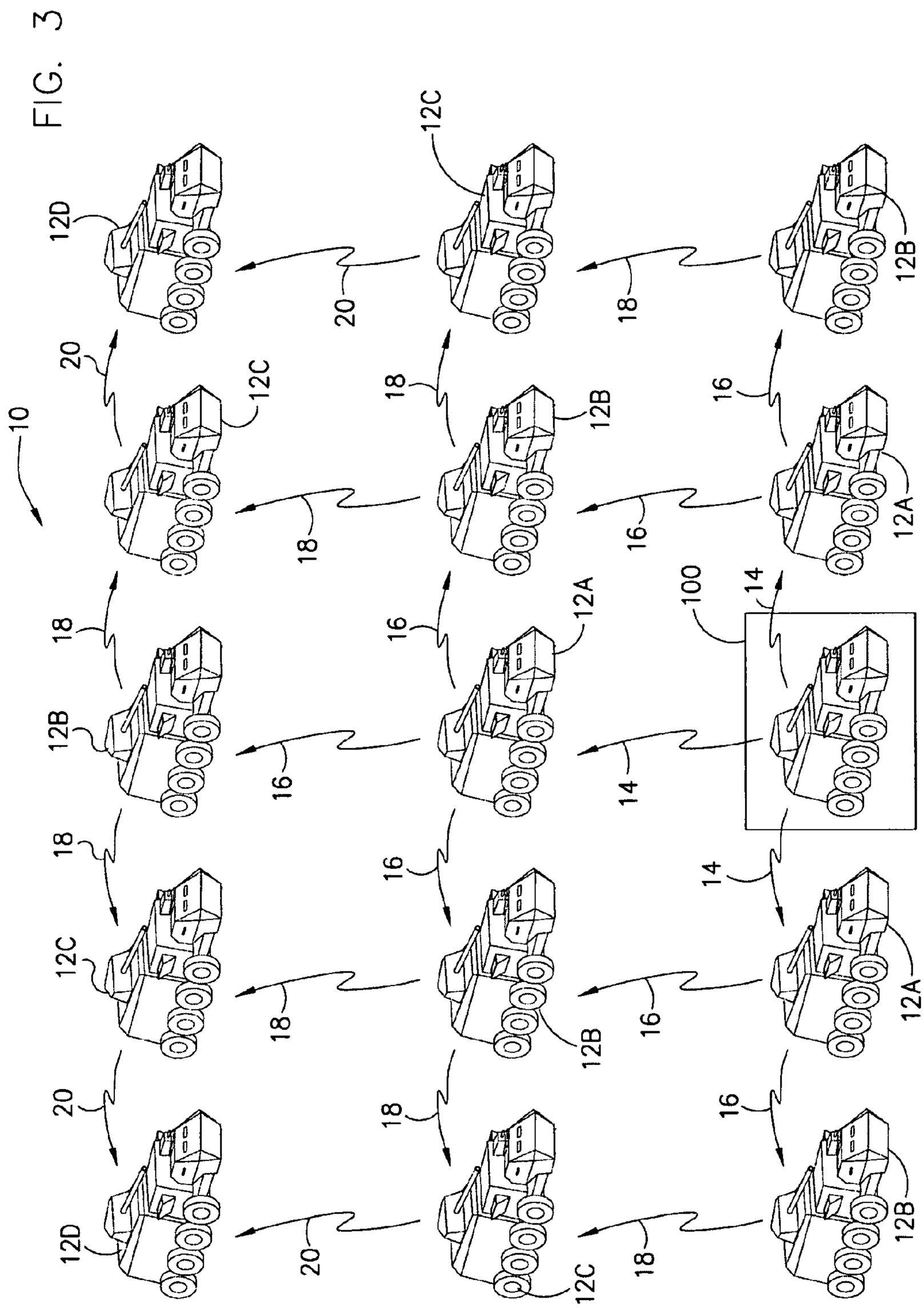


FIG. 4

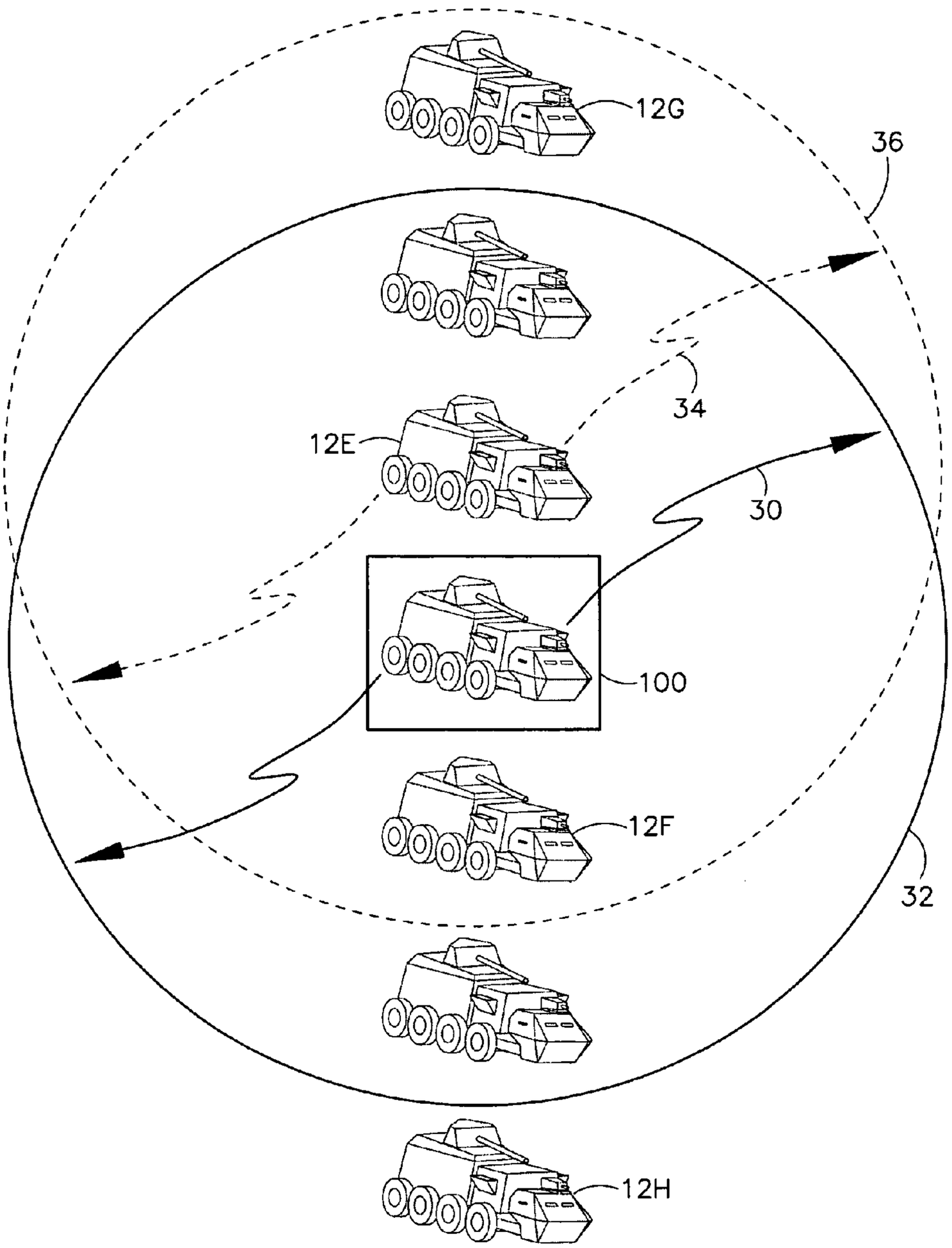


FIG. 5A

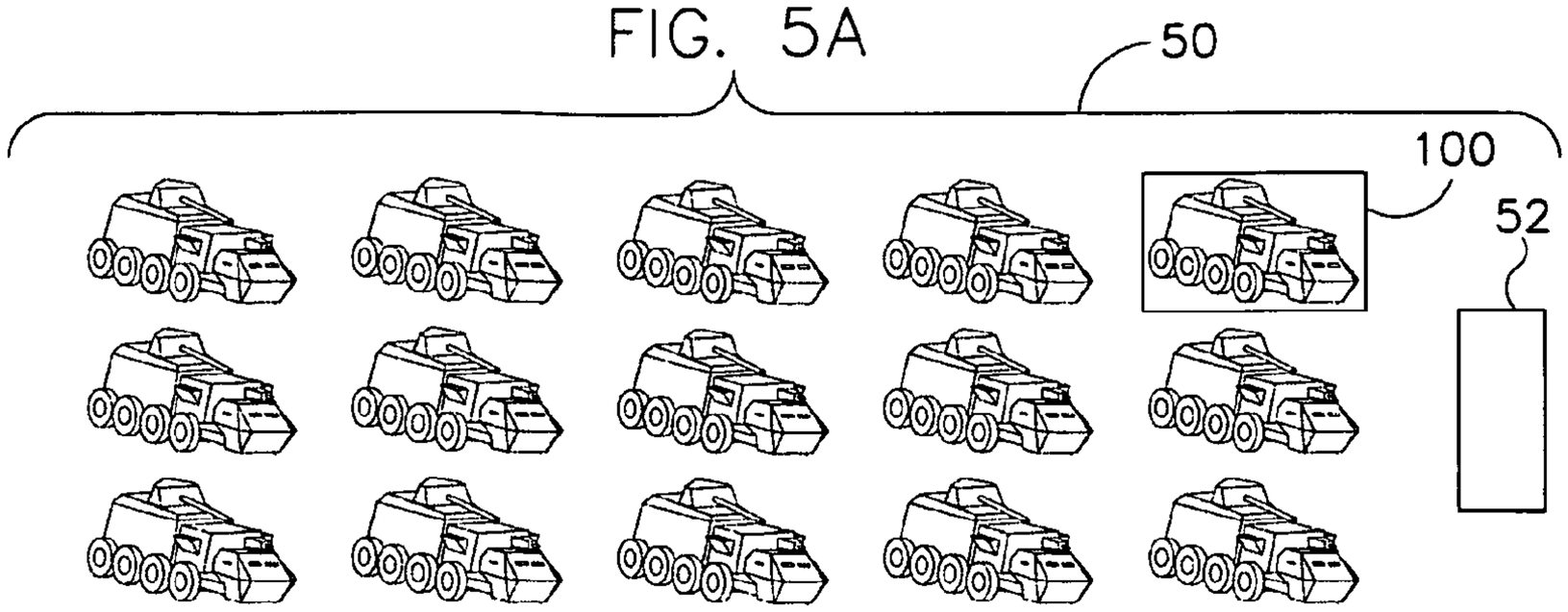


FIG. 5B

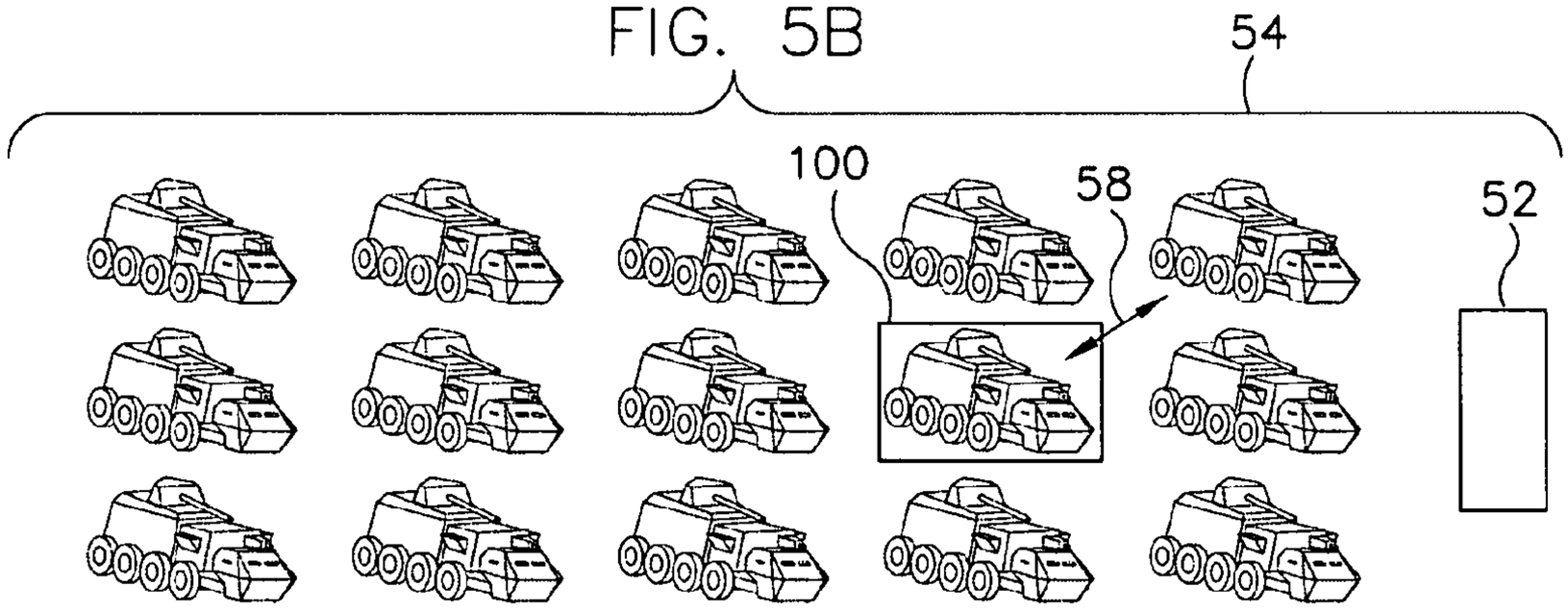


FIG. 5C

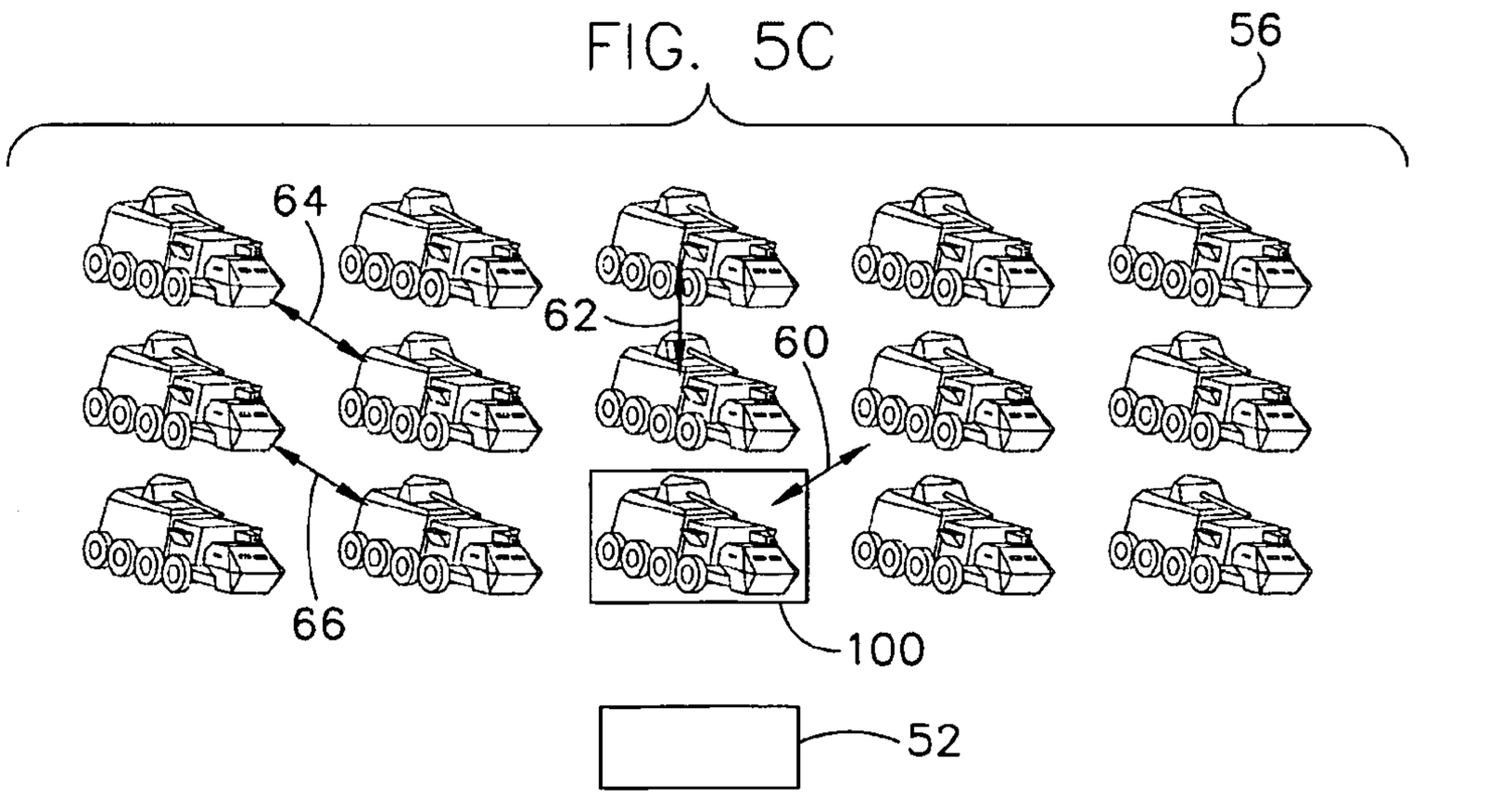


FIG. 6A

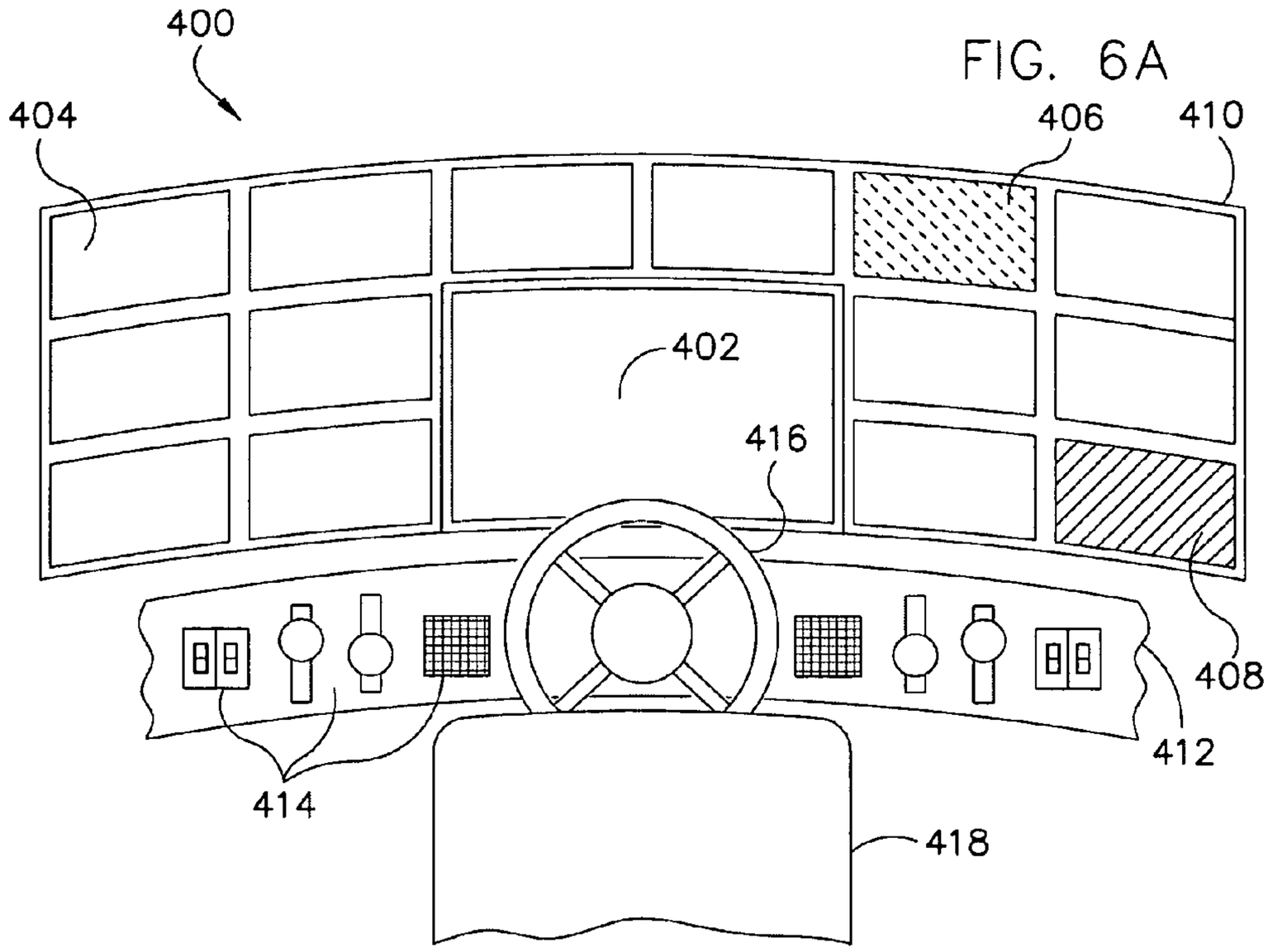
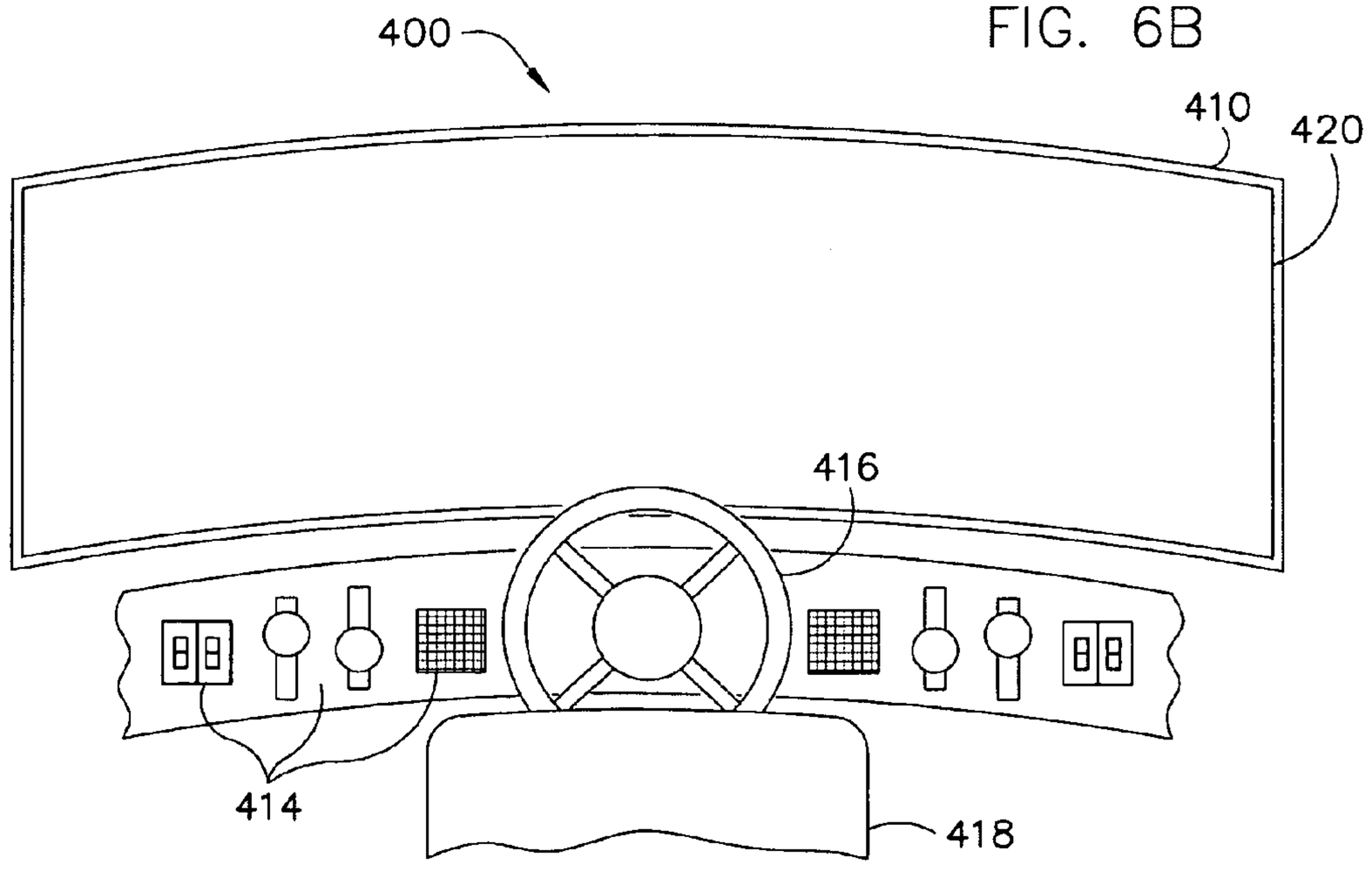


FIG. 6B



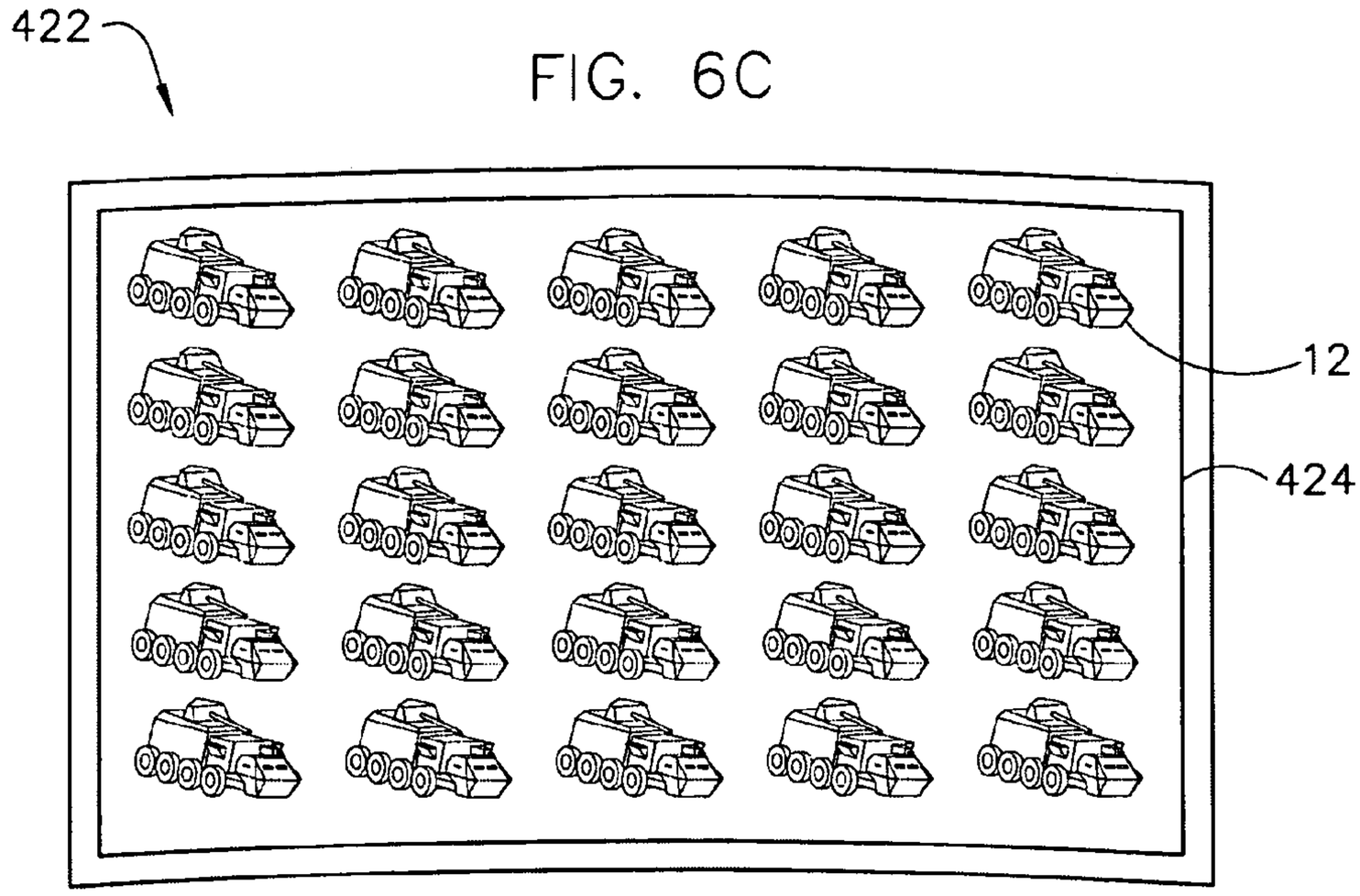


FIG. 6C

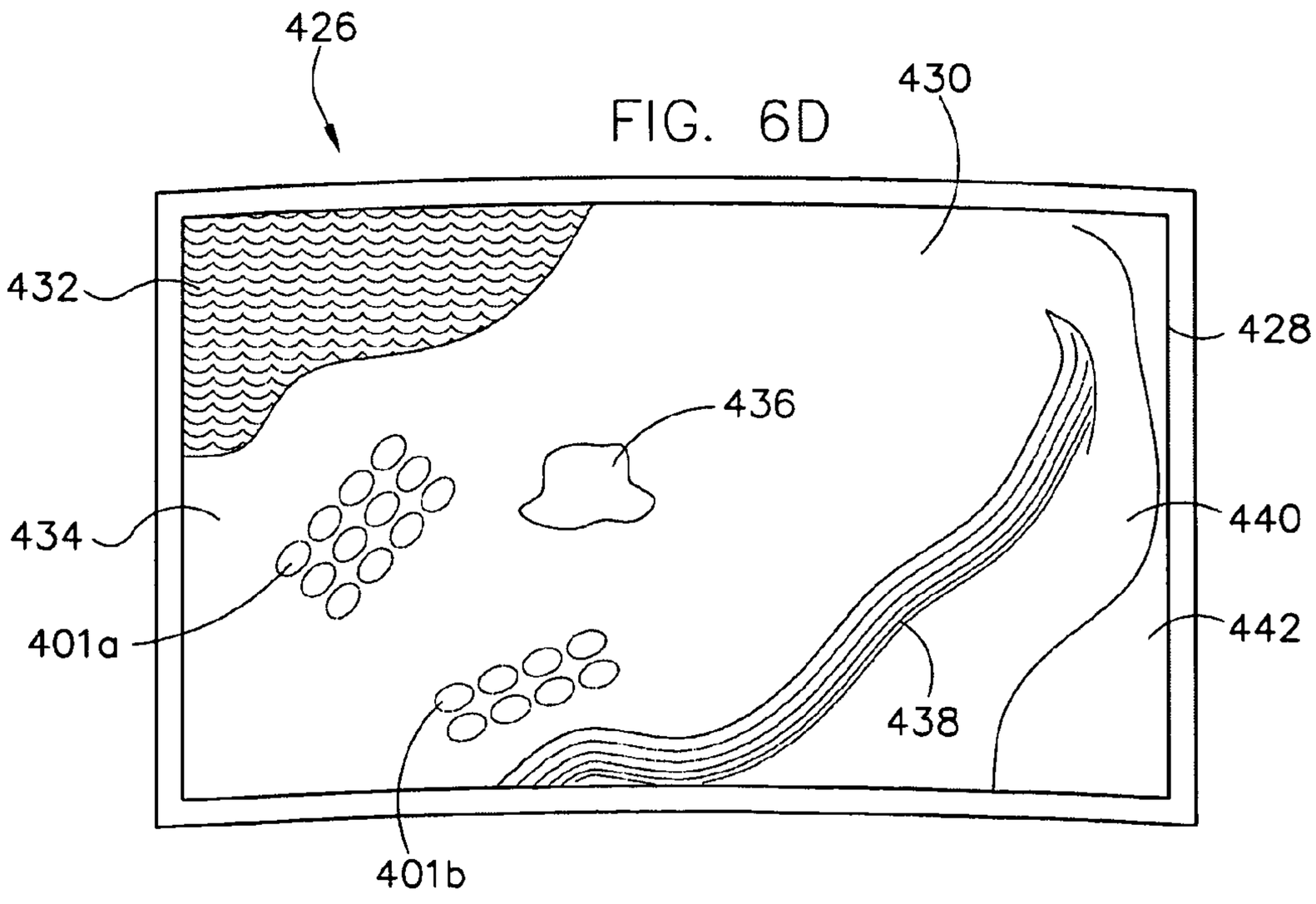


FIG. 6D

FIG. 6E

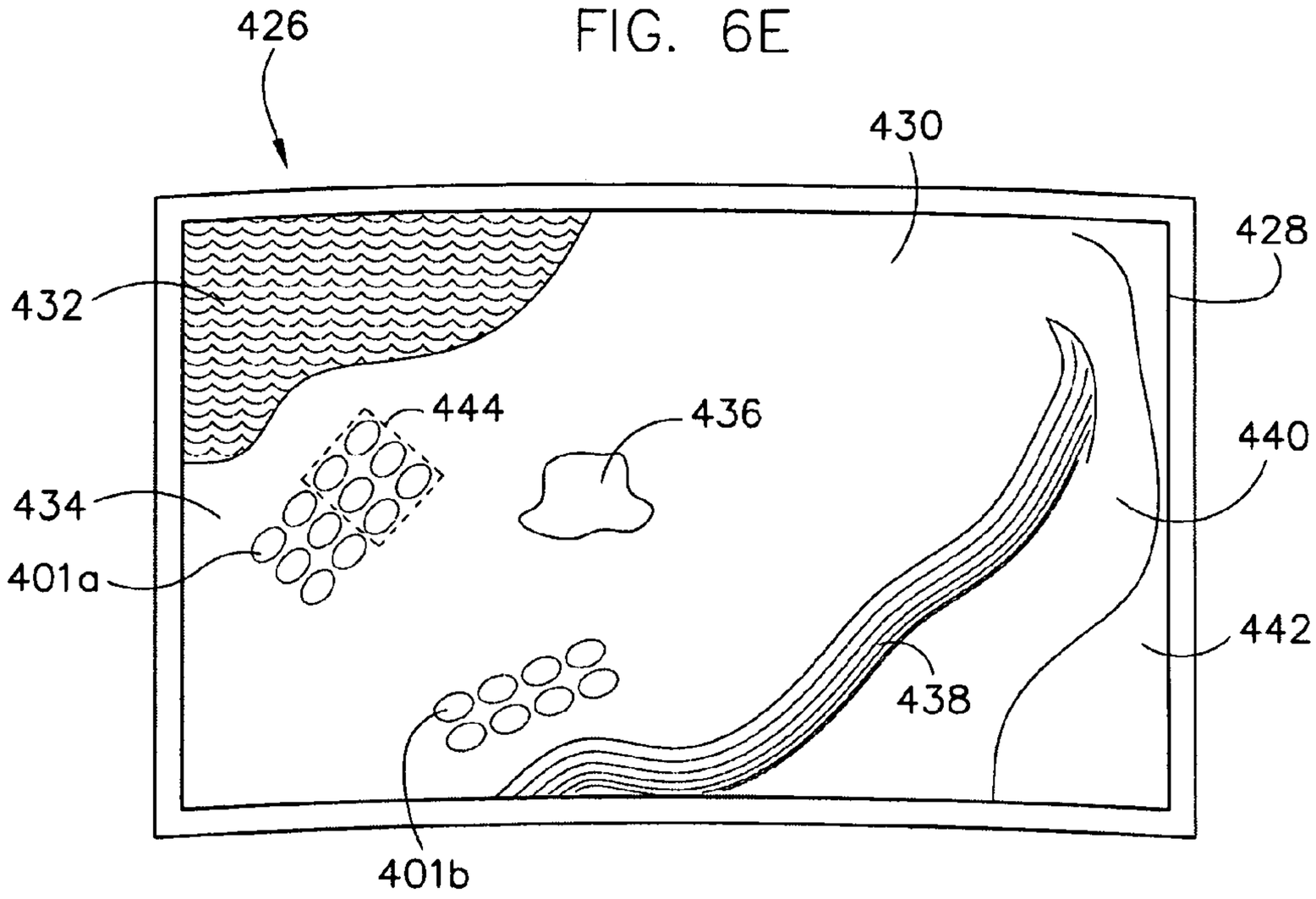

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401b

FIG. 6F

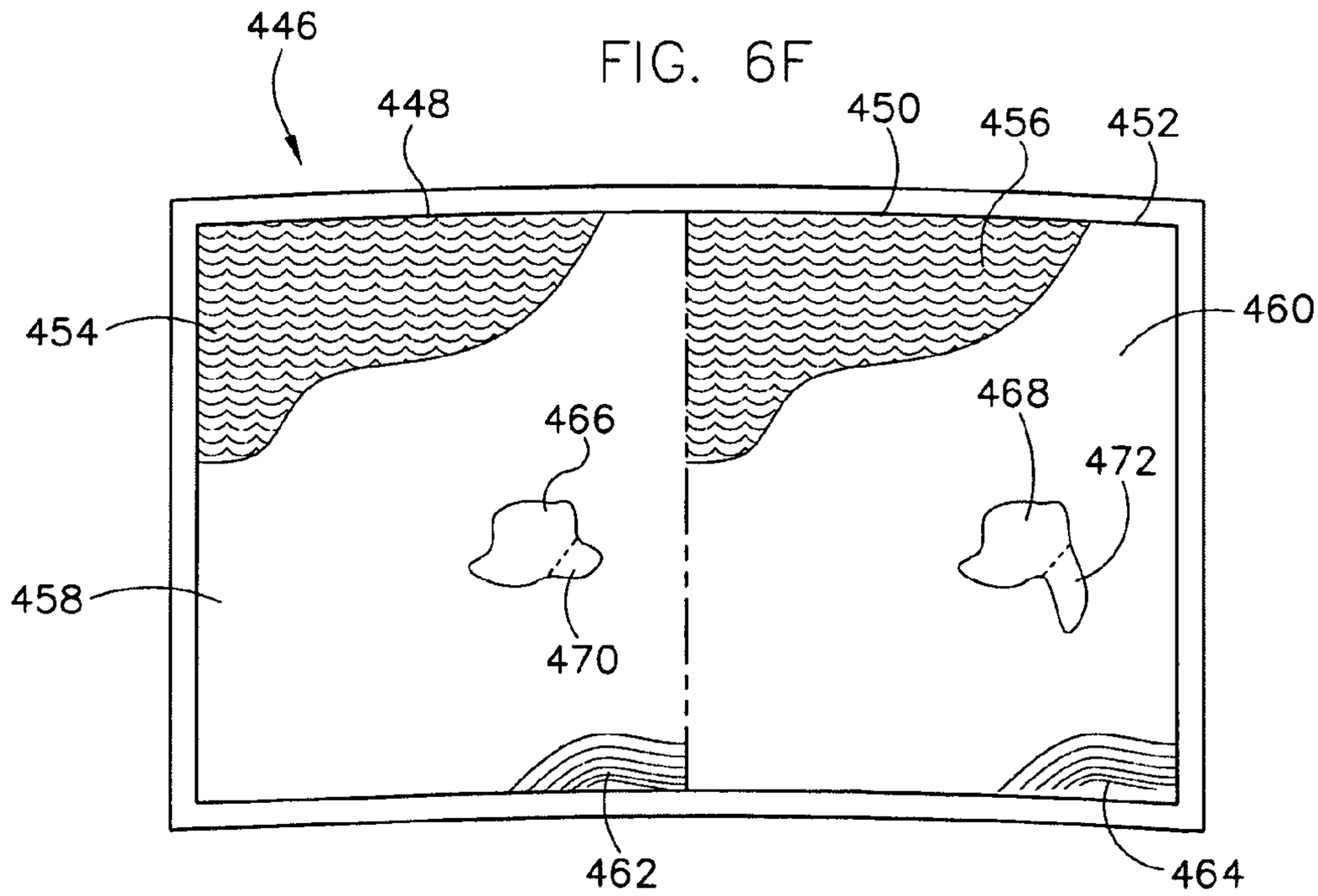

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FIG. 7A

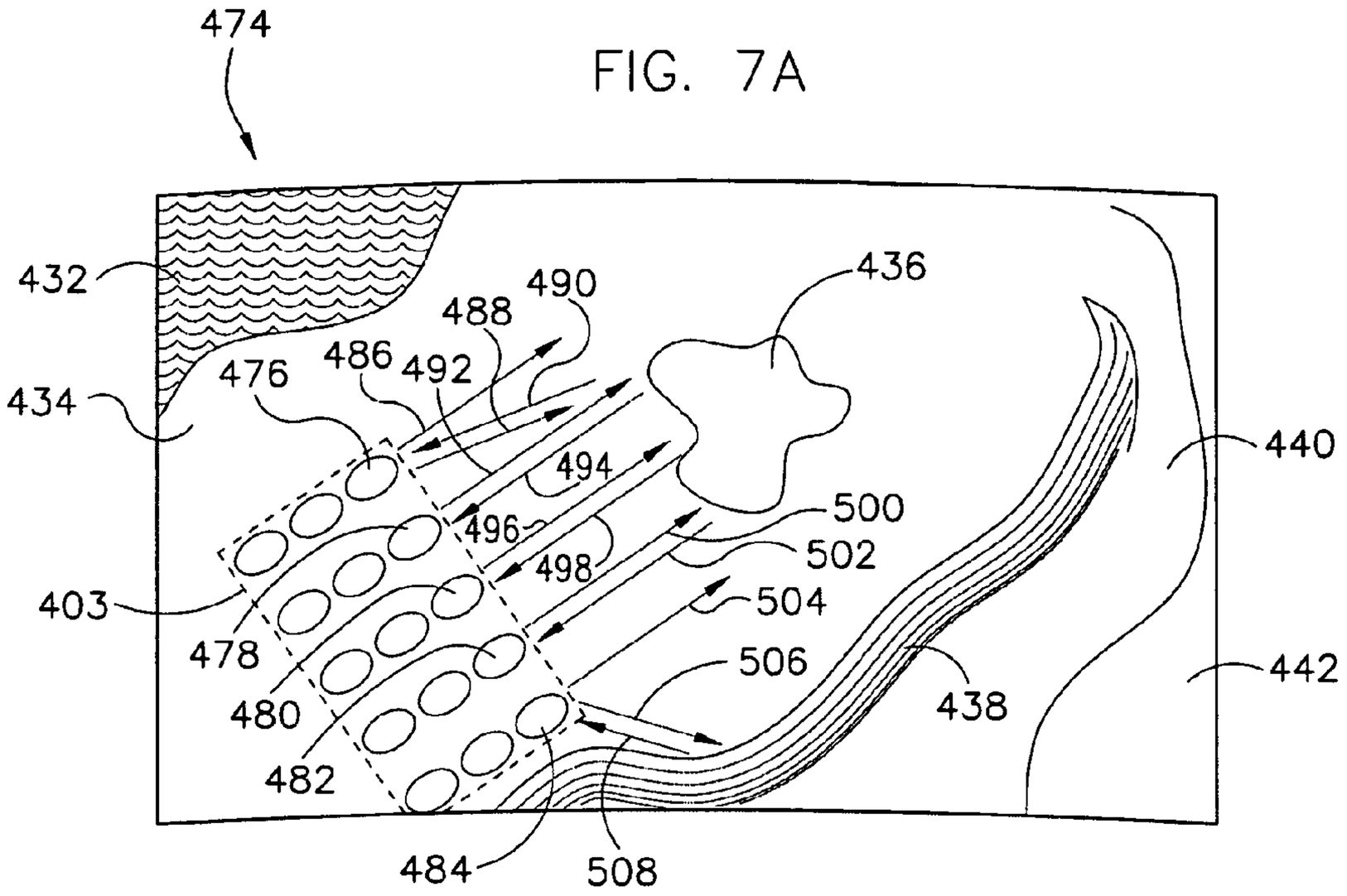

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FIG. 7B

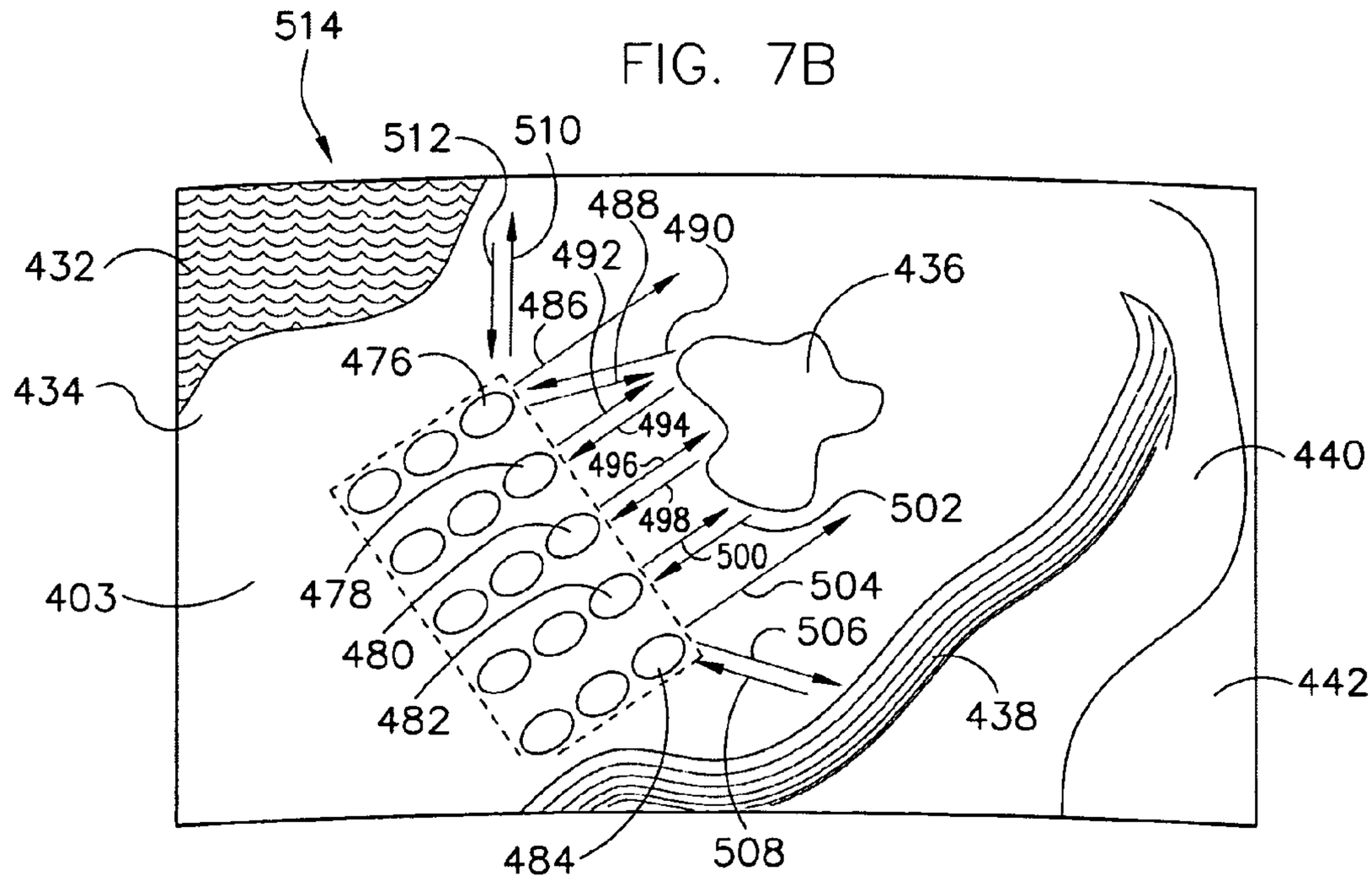

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FIG. 7C

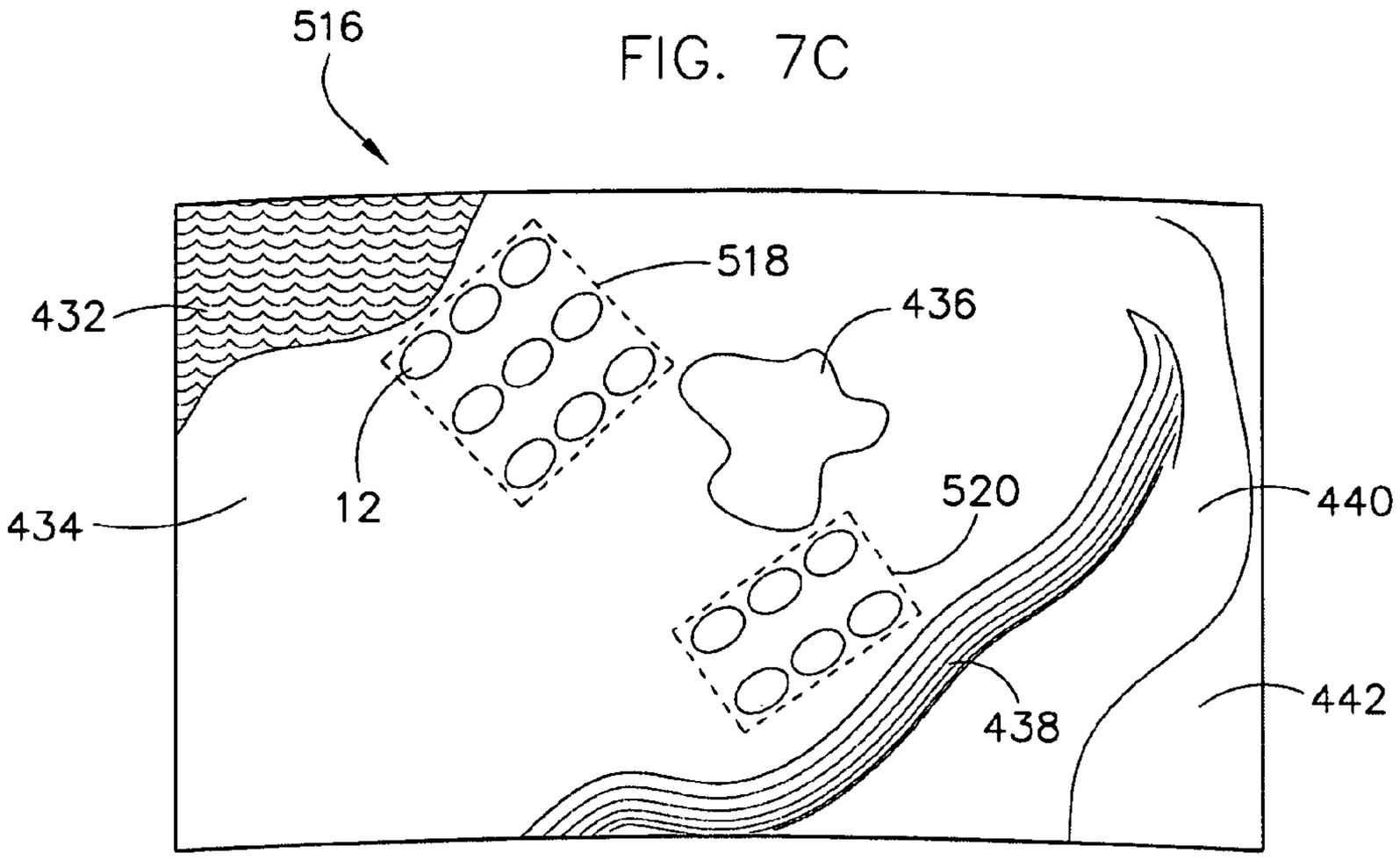

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FIG. 8A

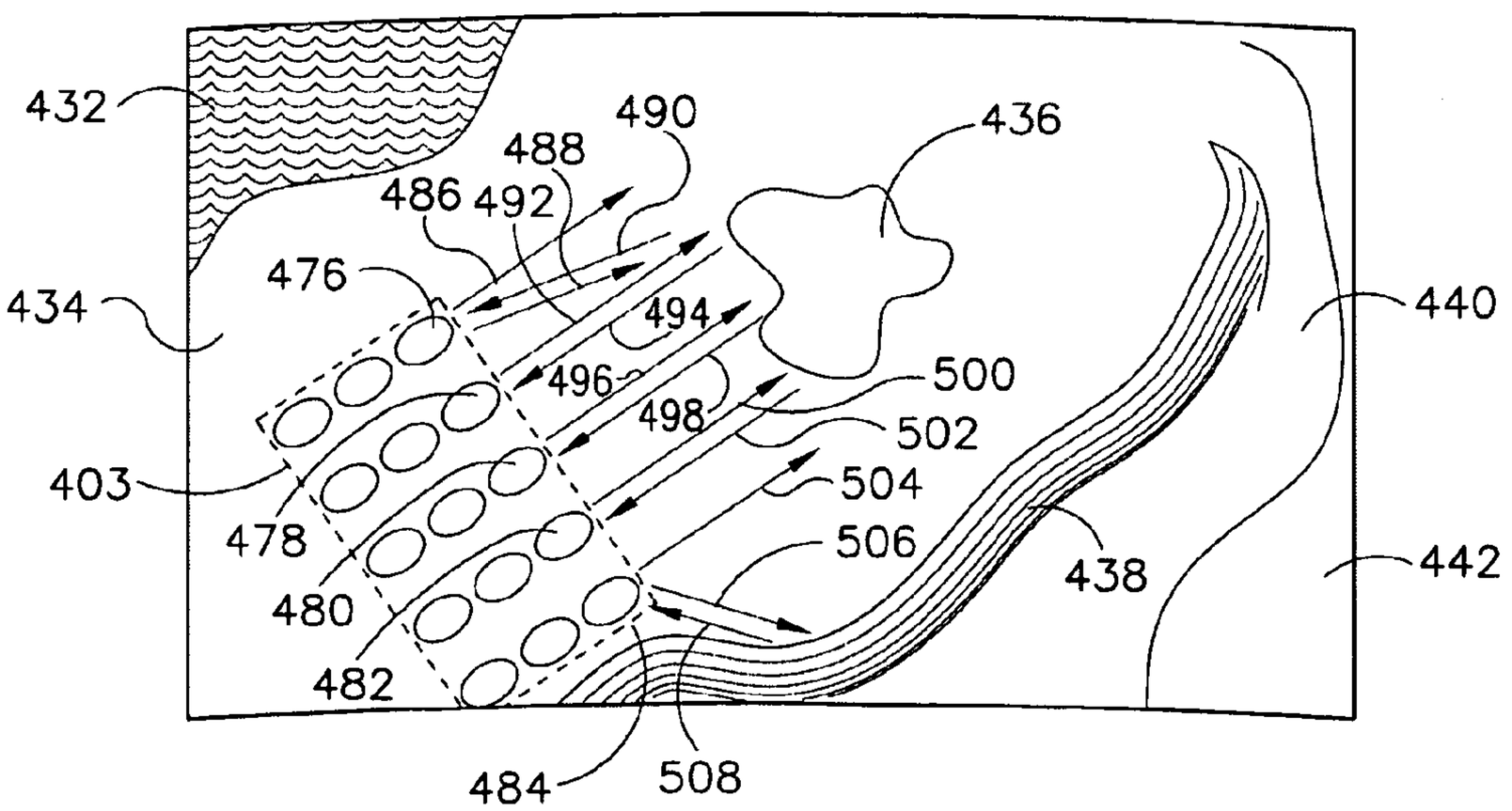

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FIG. 8B

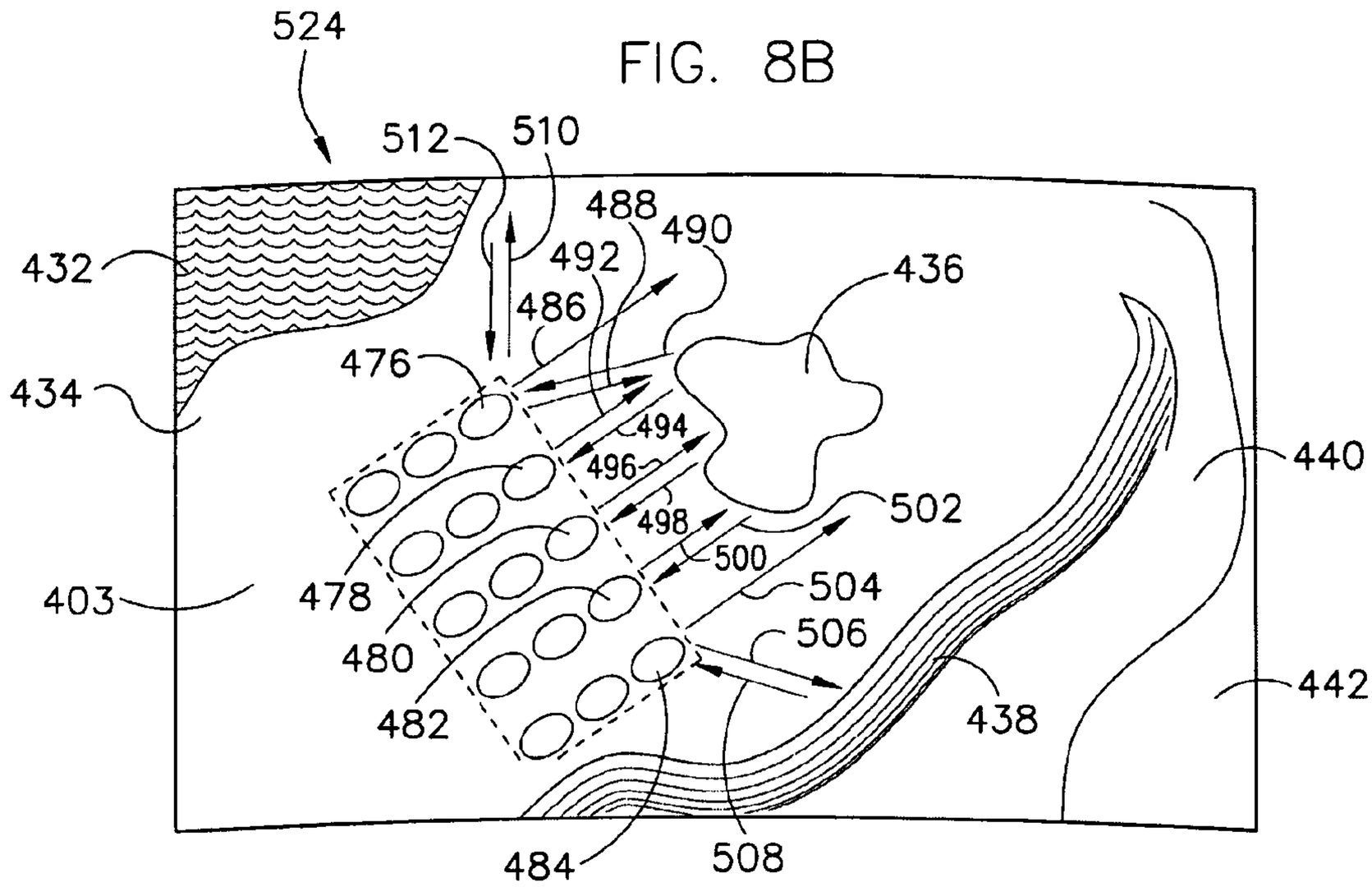

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FIG. 8C

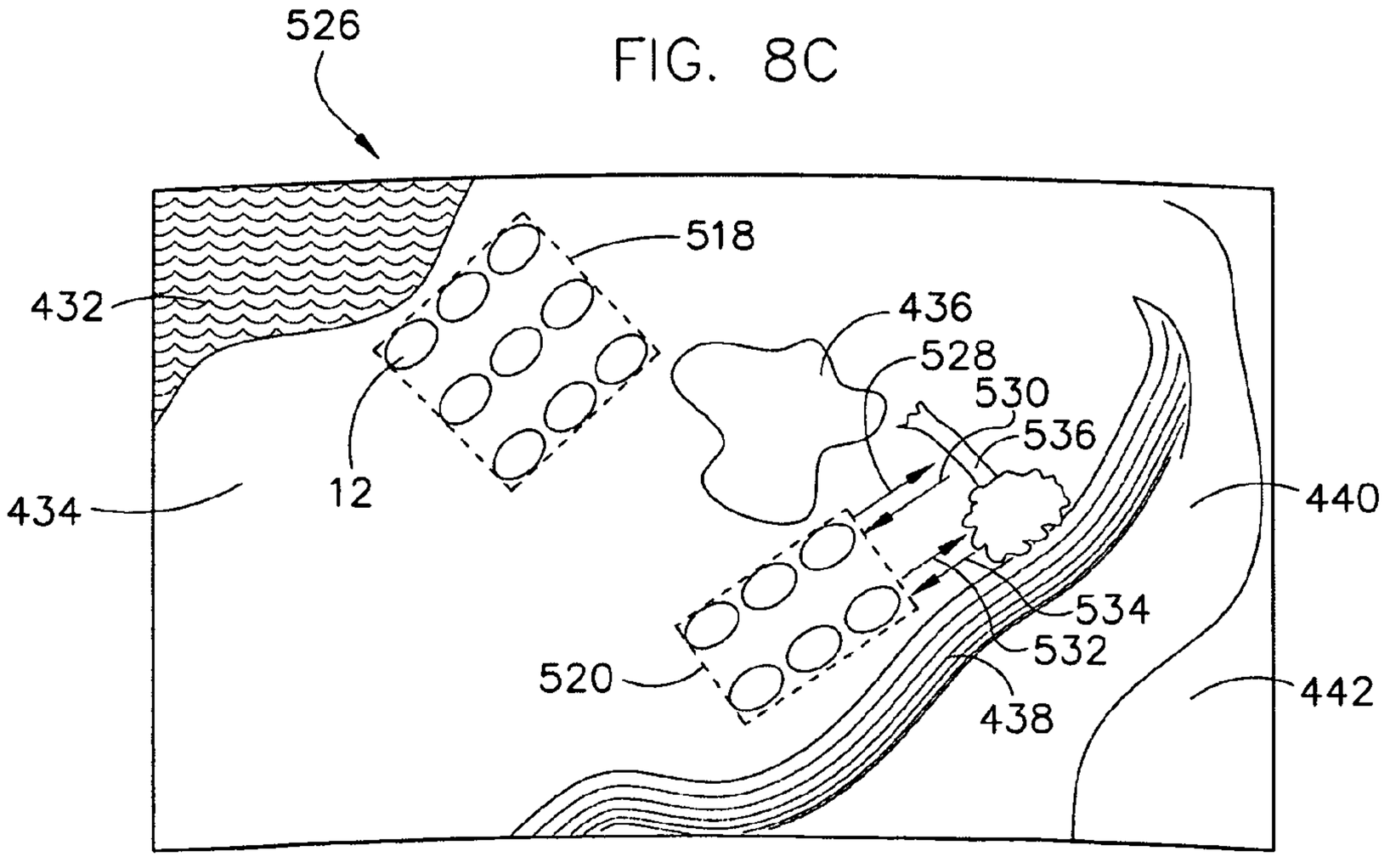

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FIG. 8D

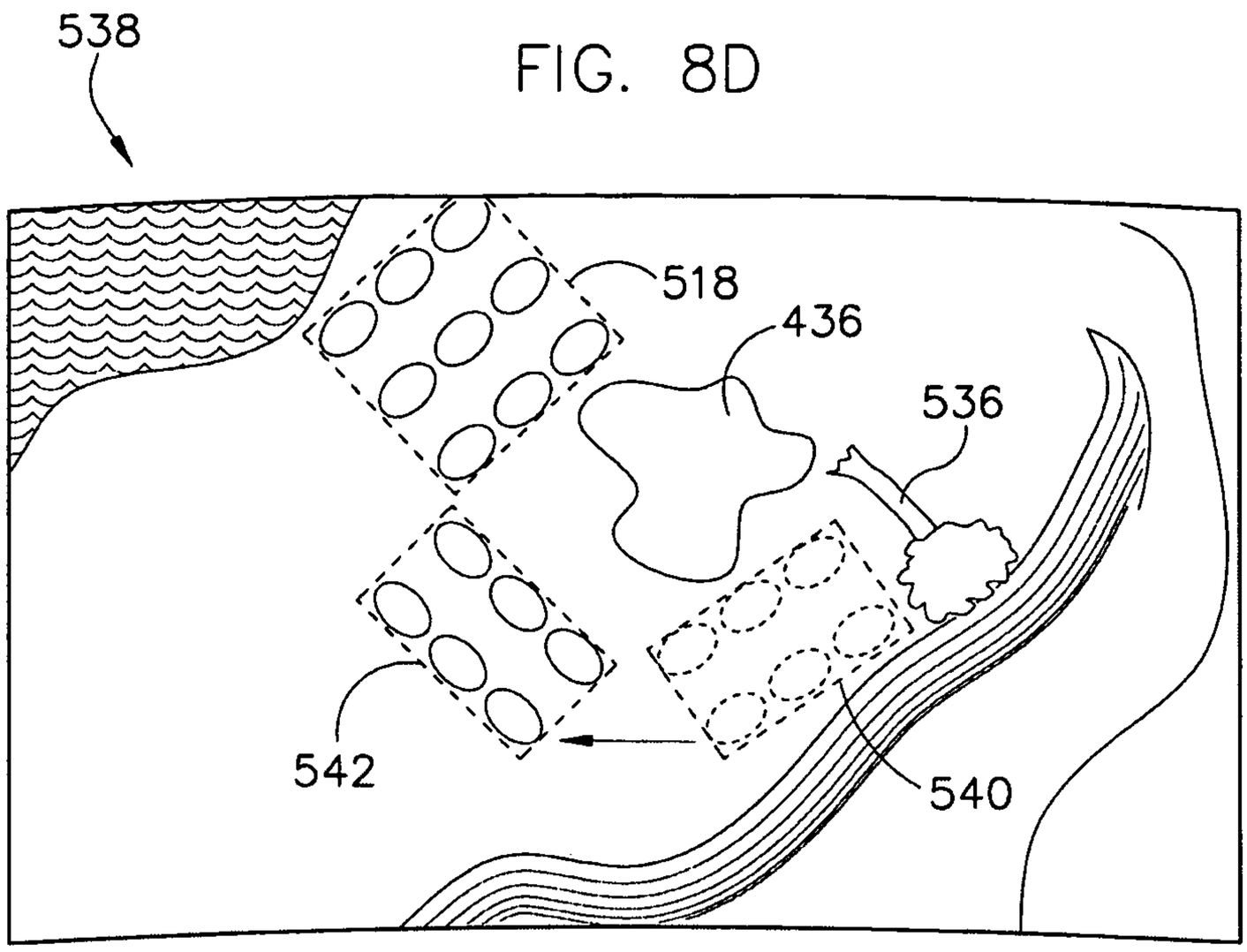


FIG. 9A

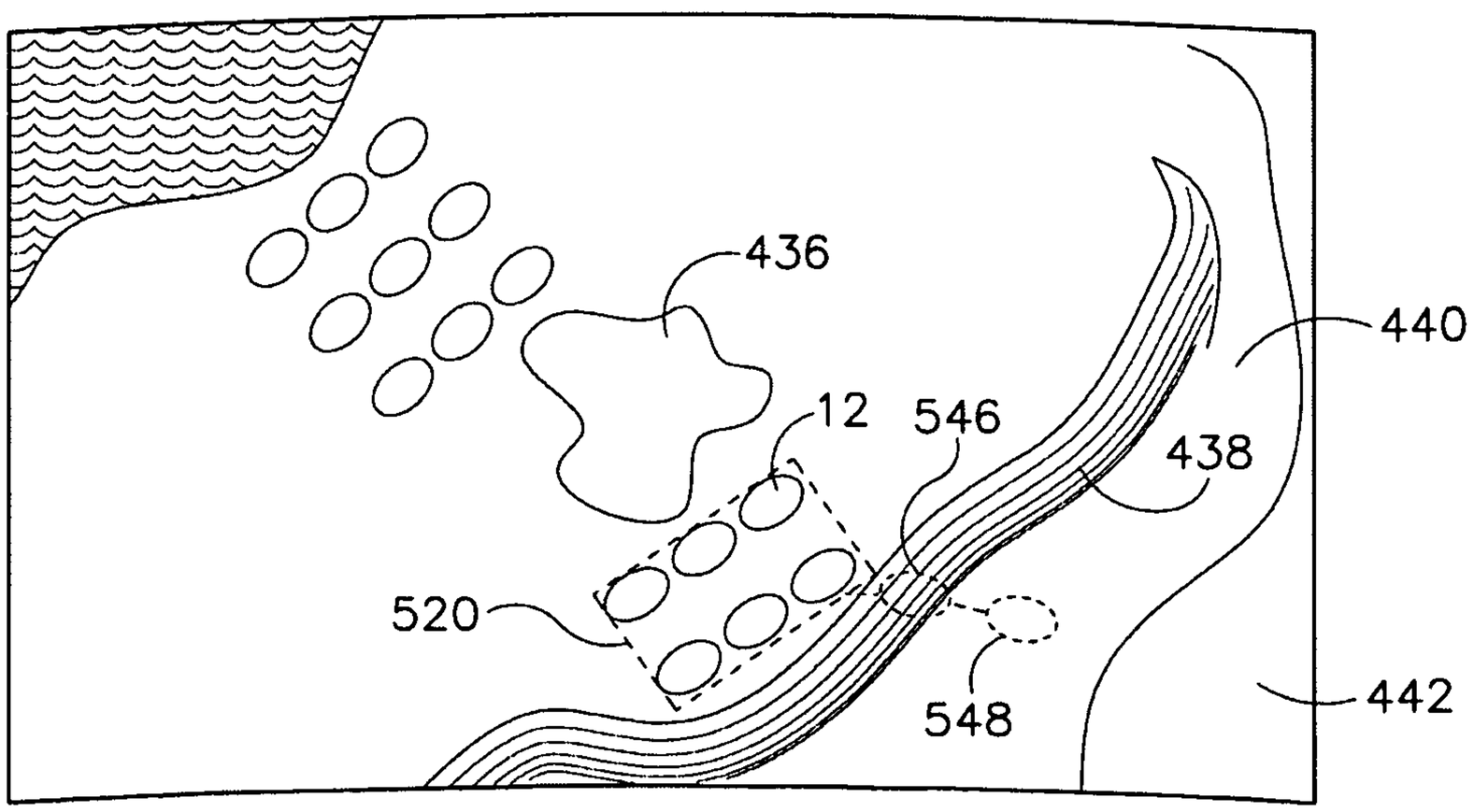


FIG. 9B

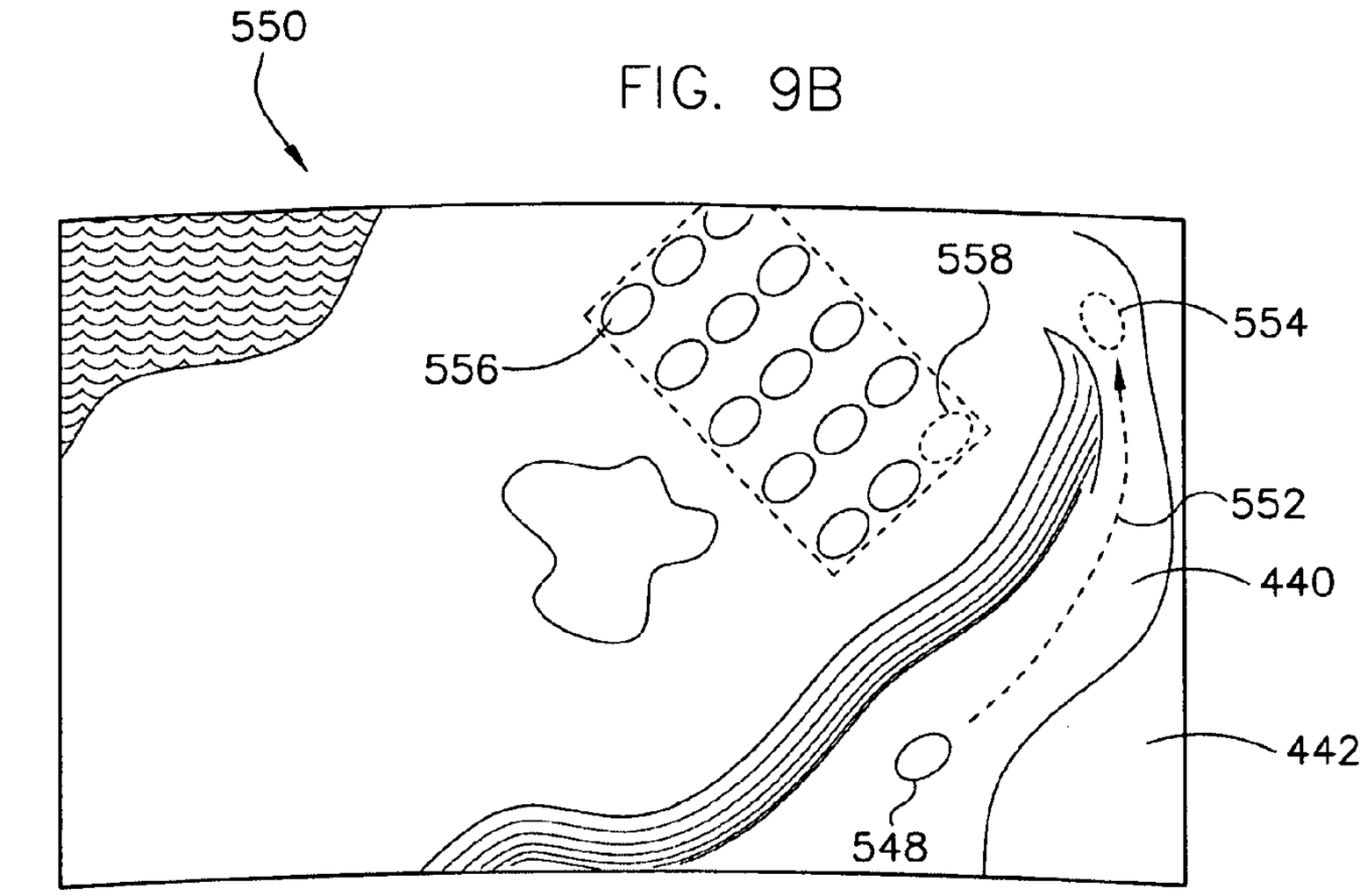


FIG. 10A

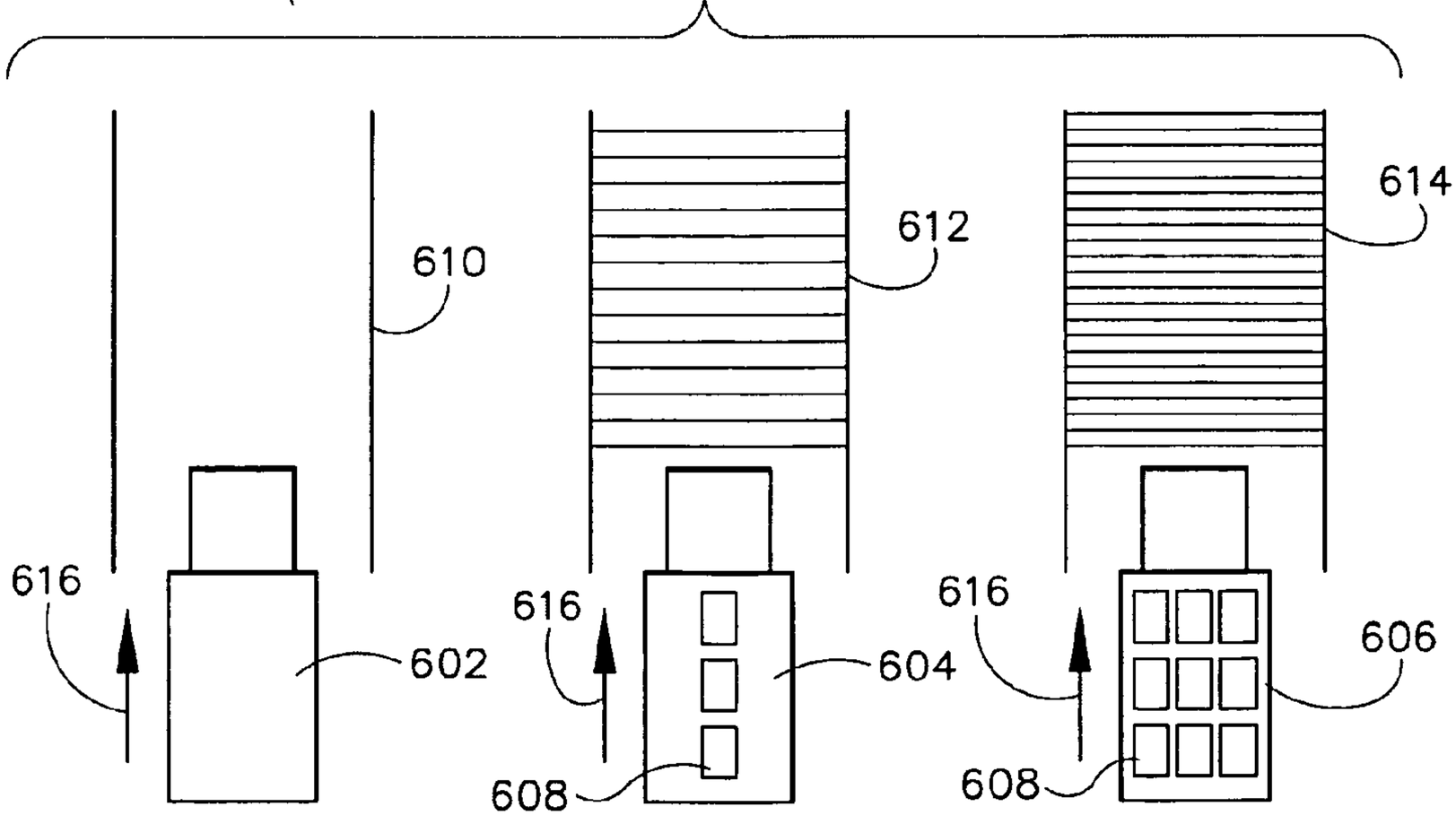


FIG. 10B

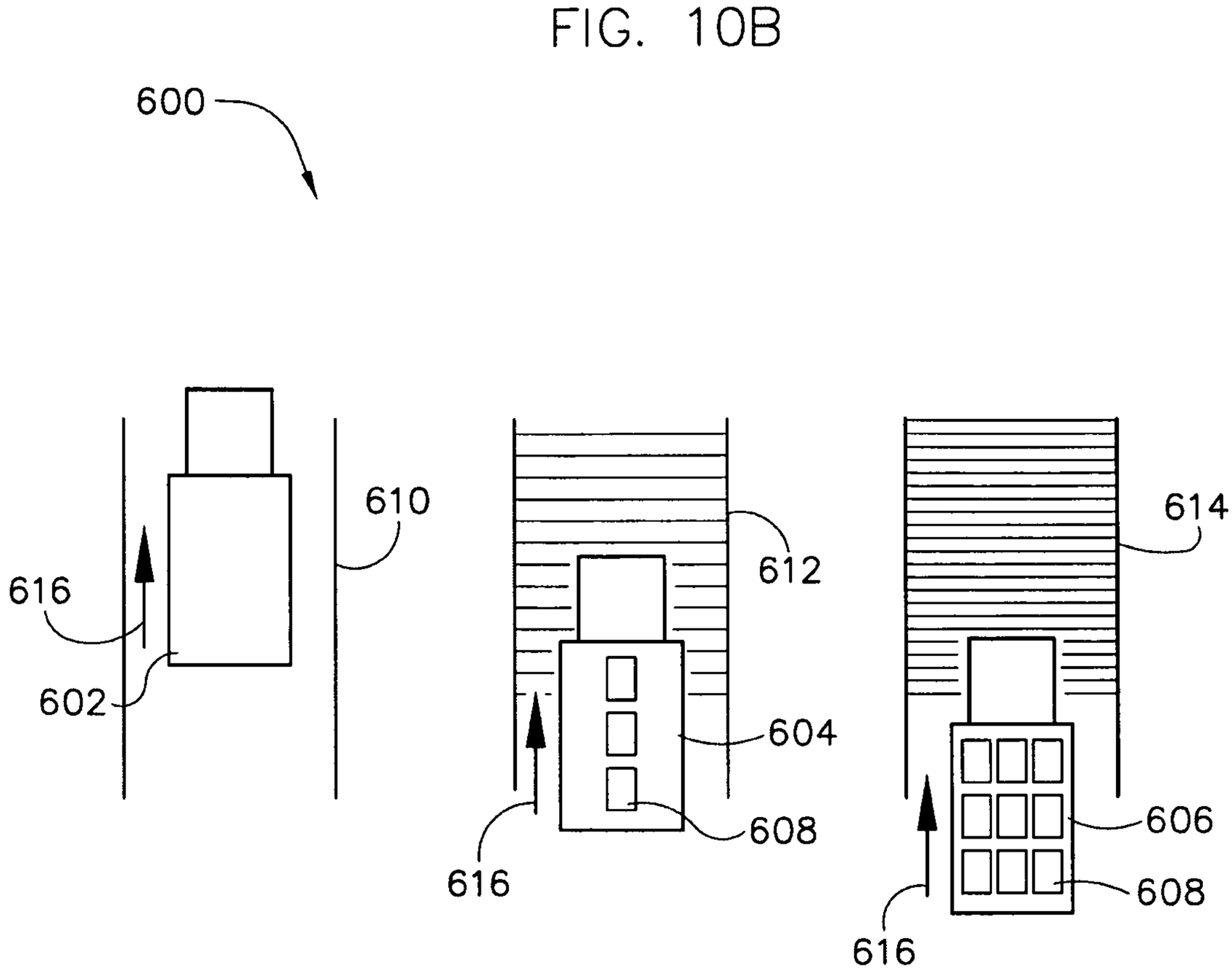


FIG. 10C

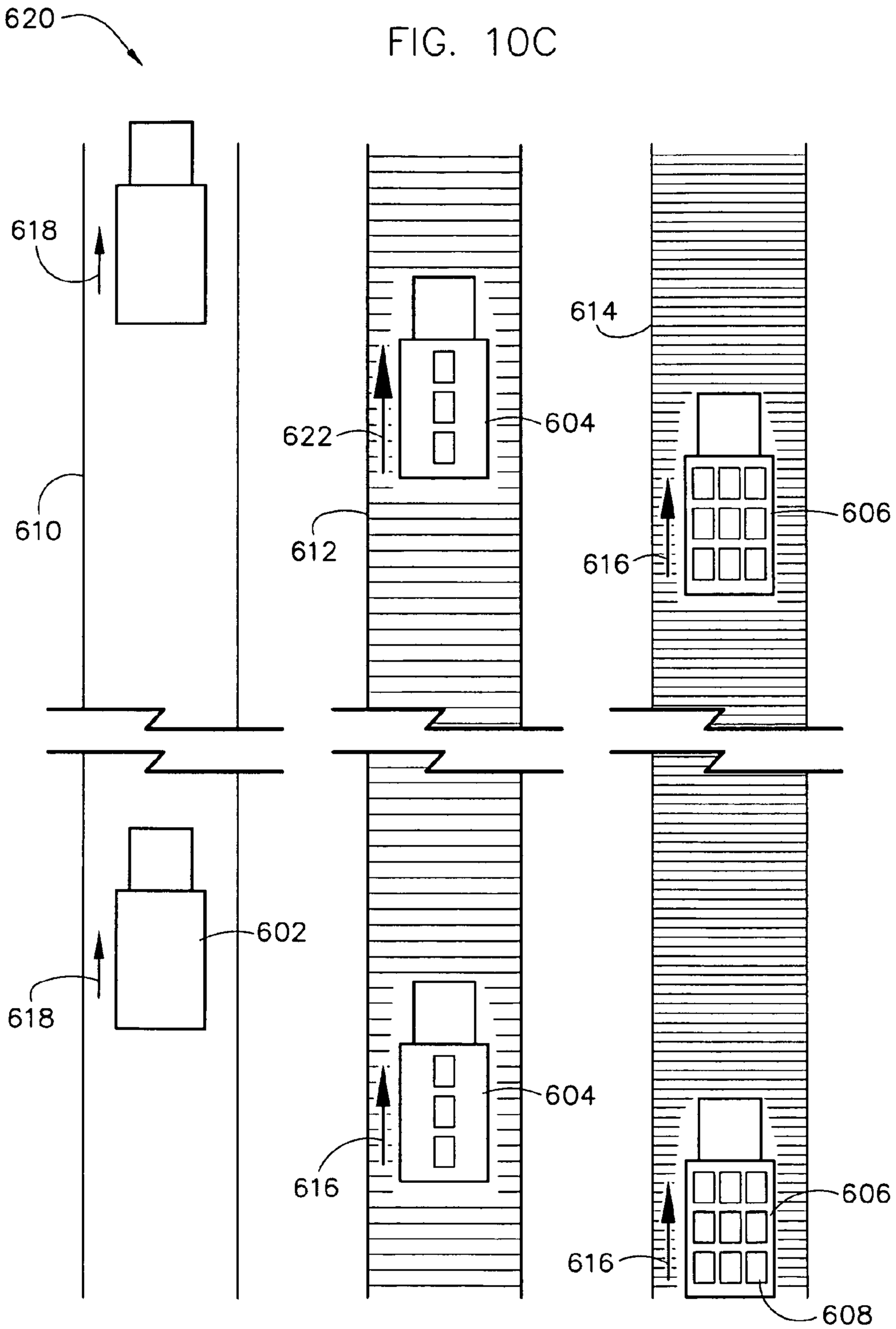


FIG. 10D

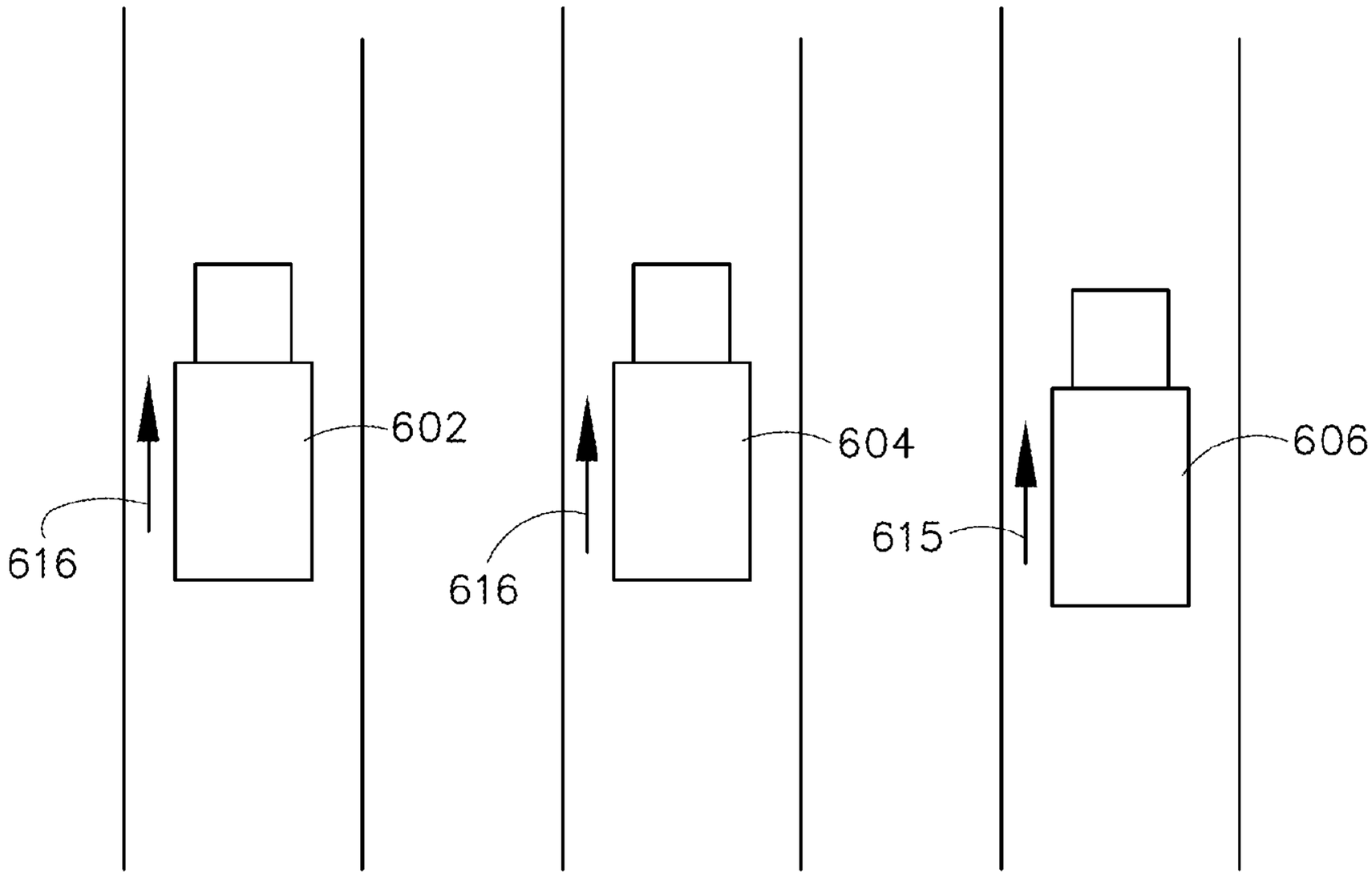


FIG. 11

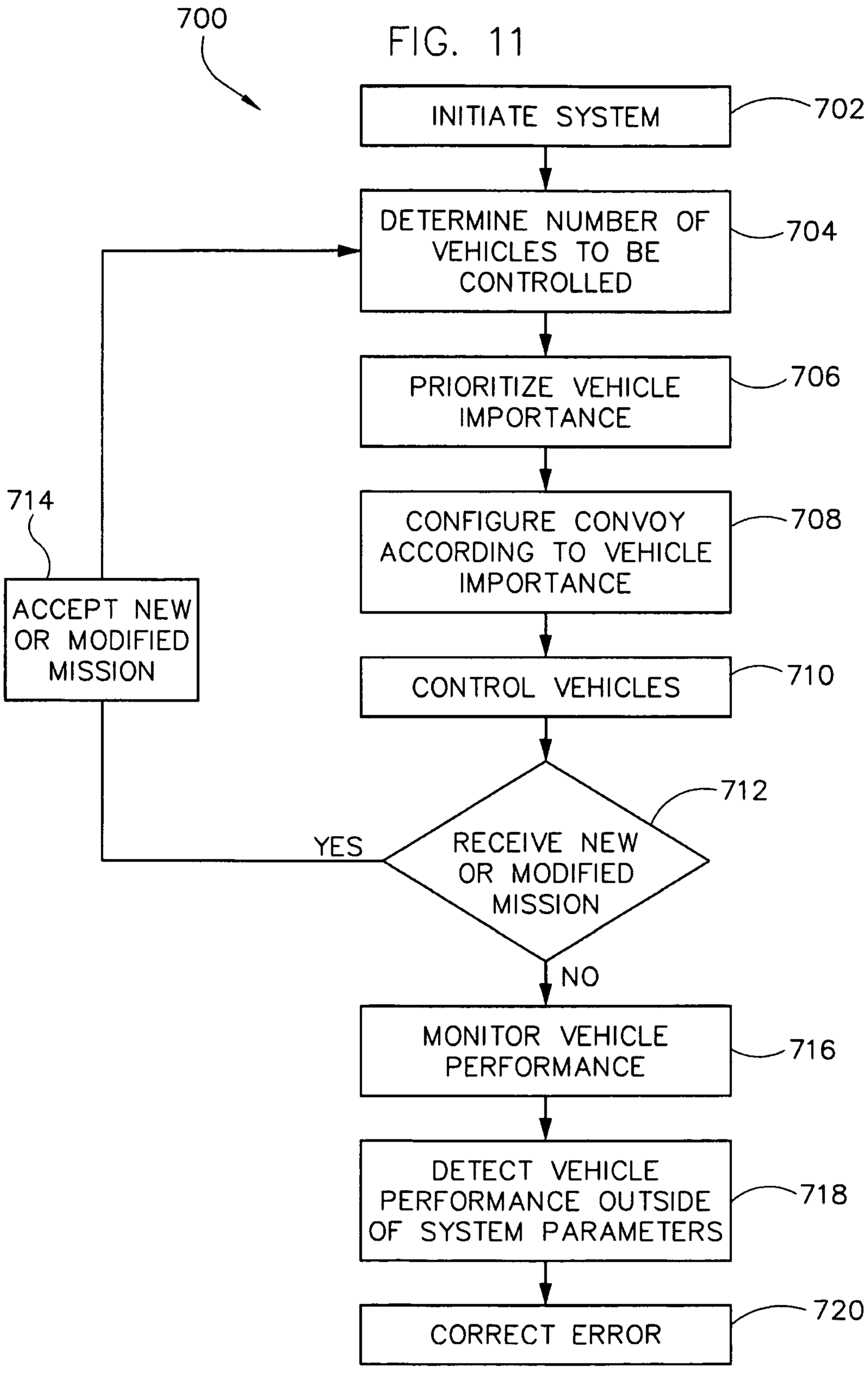

700
INITIATE SYSTEM
702
DETERMINE NUMBER OF VEHICLES TO BE CONTROLLED
704
PRIORITIZE VEHICLE IMPORTANCE
706
CONFIGURE CONVOY ACCORDING TO VEHICLE IMPORTANCE
708
CONTROL VEHICLES
710
RECEIVE NEW OR MODIFIED MISSION
712
YES
NO
714
ACCEPT NEW OR MODIFIED MISSION
MONITOR VEHICLE PERFORMANCE
716
DETECT VEHICLE PERFORMANCE OUTSIDE OF SYSTEM PARAMETERS
718
CORRECT ERROR
720

FIG. 12

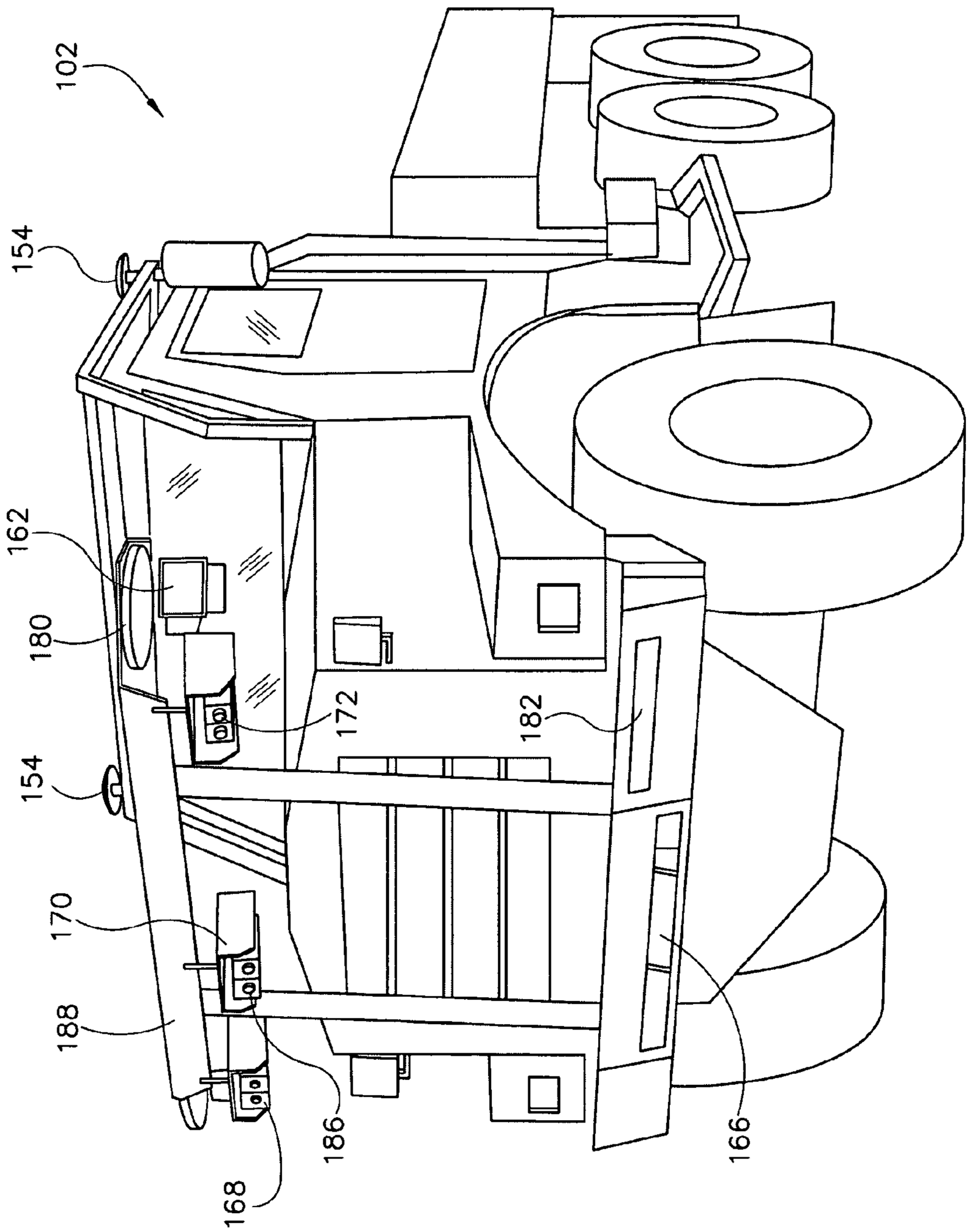


FIG. 13

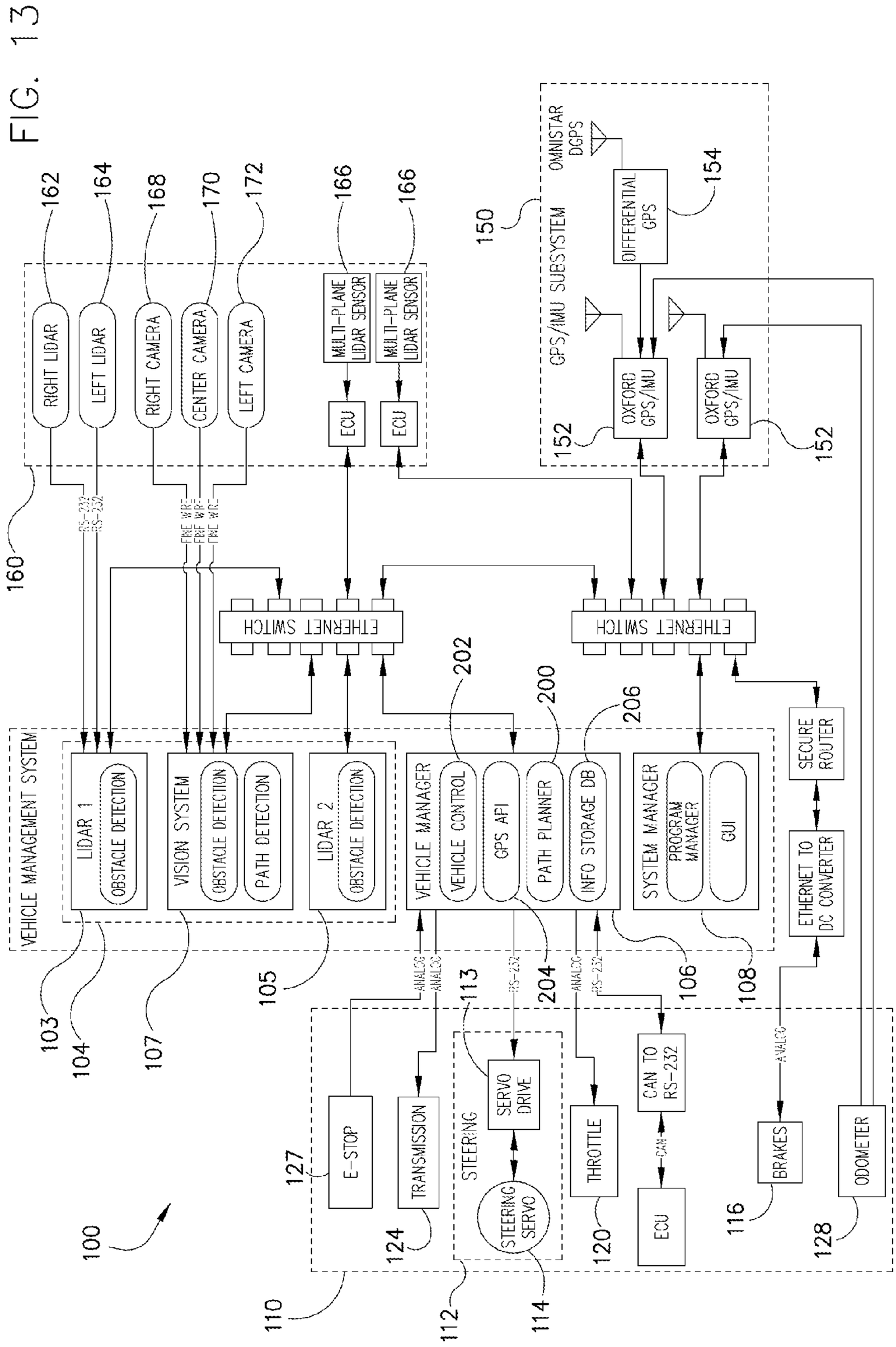

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RIGHT LIDAR
LEFT LIDAR
RIGHT CAMERA
CENTER CAMERA
LEFT CAMERA
MULTI-PLANE LIDAR SENSOR
MULTI-PLANE LIDAR SENSOR
ECU
ECU
OMNISTAR DGPS
DIFFERENTIAL GPS
GPS/IMU SUBSYSTEM
OXFORD GPS/IMU
OXFORD GPS/IMU
RS-232
RS-232
FIRE WIRE
FIRE WIRE
FIRE WIRE
ETHERNET SWITCH
ETHERNET SWITCH
202
200
206
VEHICLE MANAGEMENT SYSTEM
LIDAR 1
OBSTACLE DETECTION
VISION SYSTEM
OBSTACLE DETECTION
PATH DETECTION
LIDAR 2
OBSTACLE DETECTION
VEHICLE MANAGER
VEHICLE CONTROL
GPS API
PATH PLANNER
INFO STORAGE DB
SYSTEM MANAGER
PROGRAM MANAGER
GUI
SECURE ROUTER
ETHERNET TO DC CONVERTER
103
104
107
105
113
204
106
108
ANALOG
ANALOG
RS-232
ANALOG
RS-232
127
124
112
114
120
116
128
E-STOP
TRANSMISSION
STEERING
SERVO DRIVE
STEERING SERVO
THROTTLE
CAN TO RS-232
CAN
ECU
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ANALOG
ODOMETER
110

FIG. 14

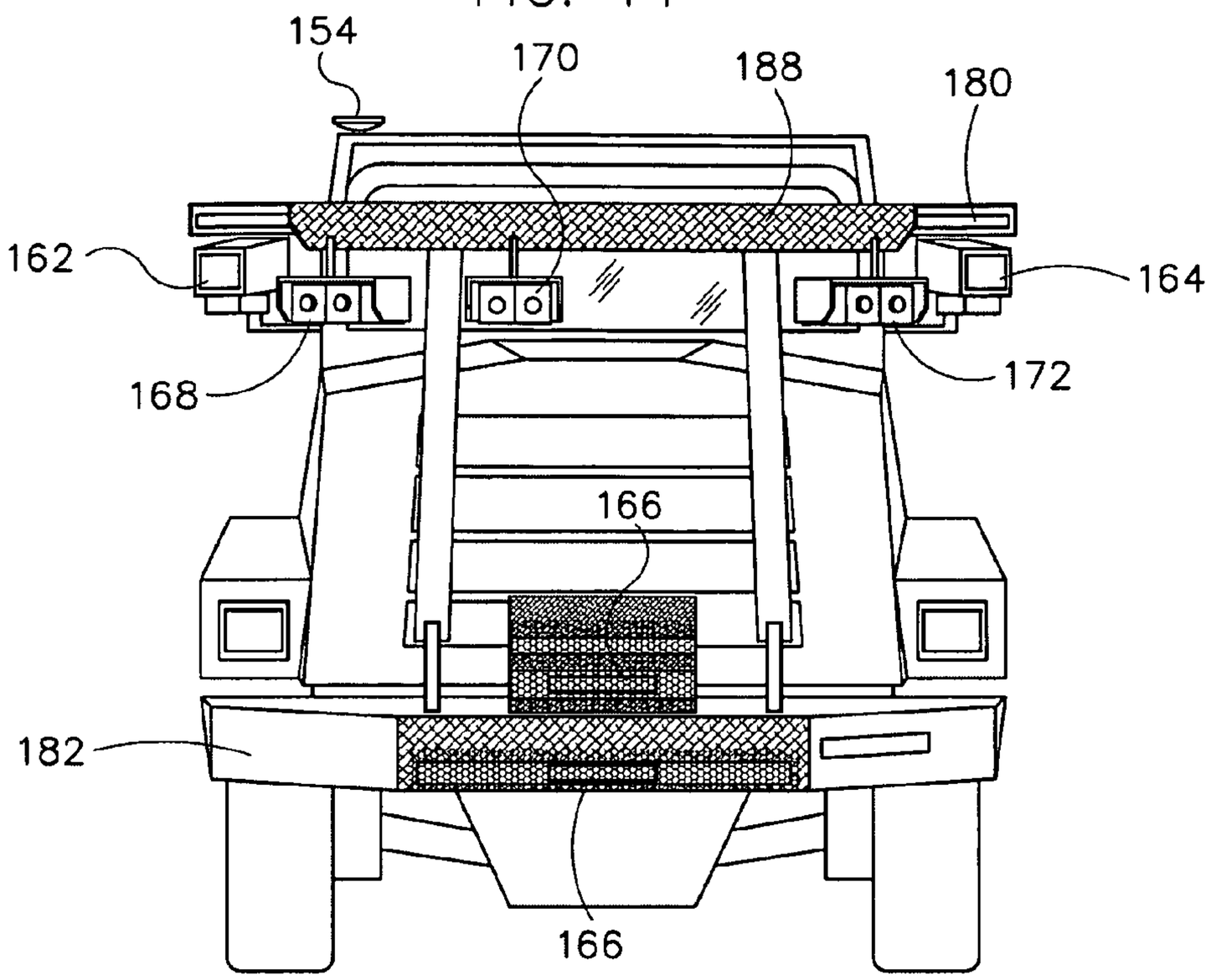

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FIG. 15

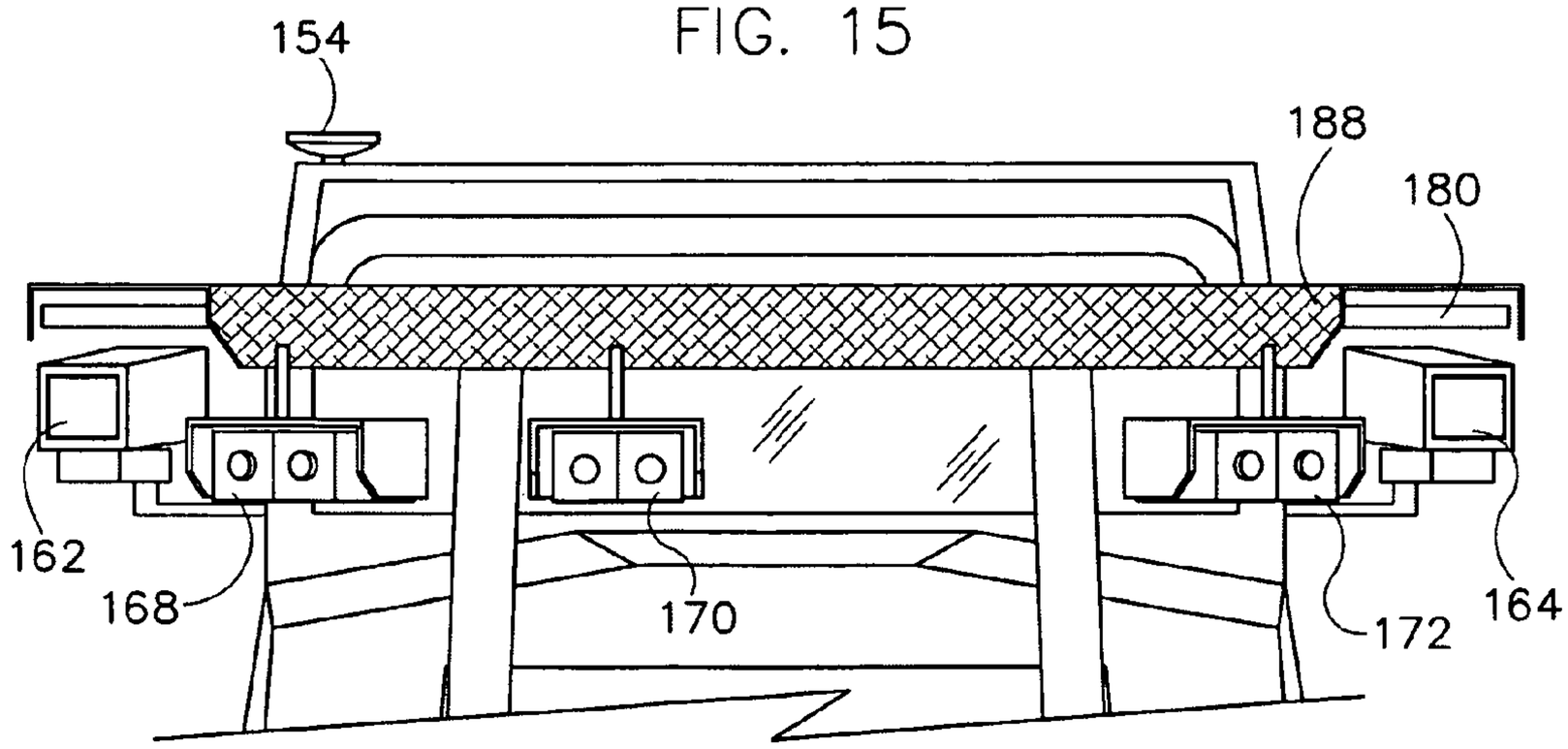

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FIG. 16

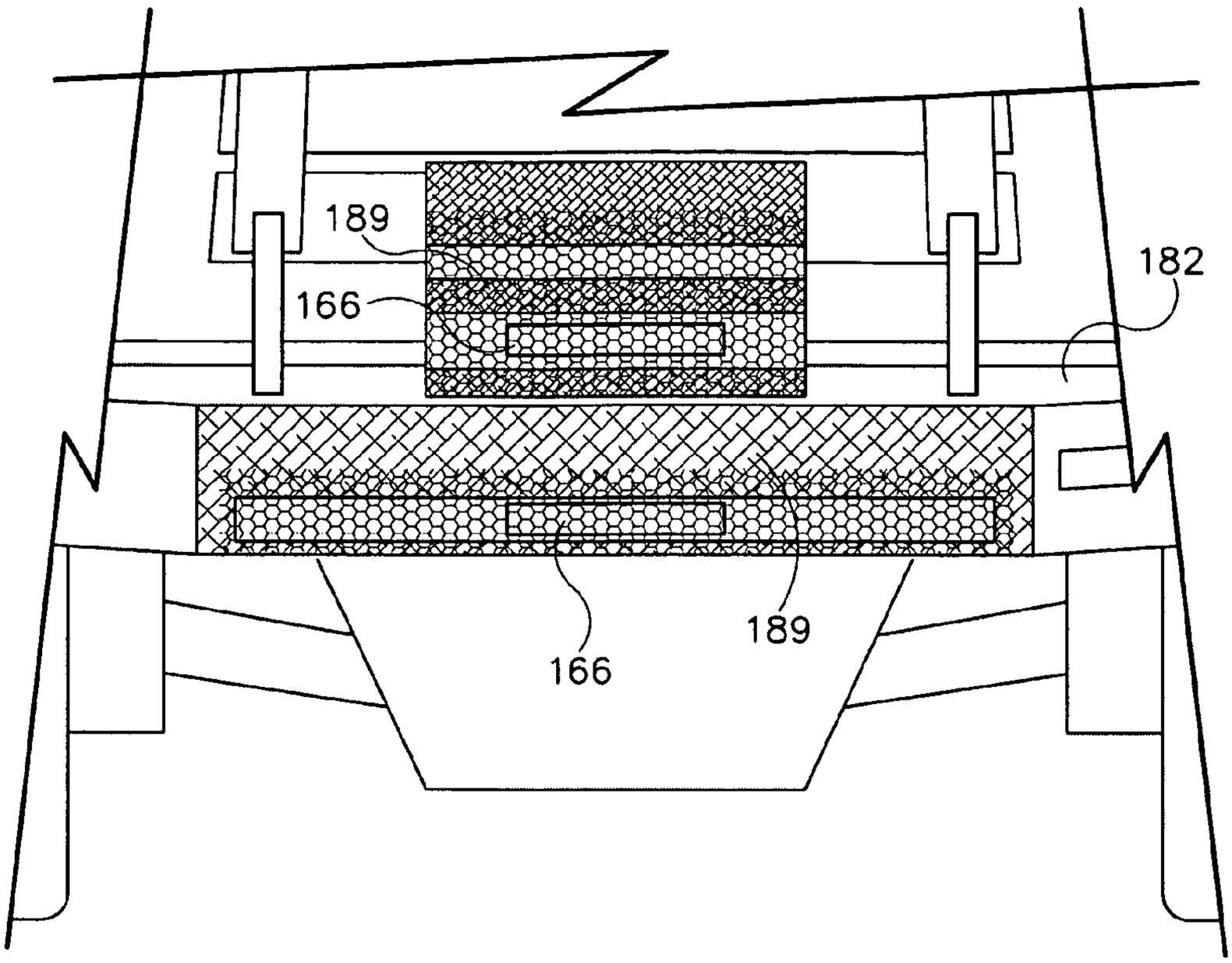


FIG. 17

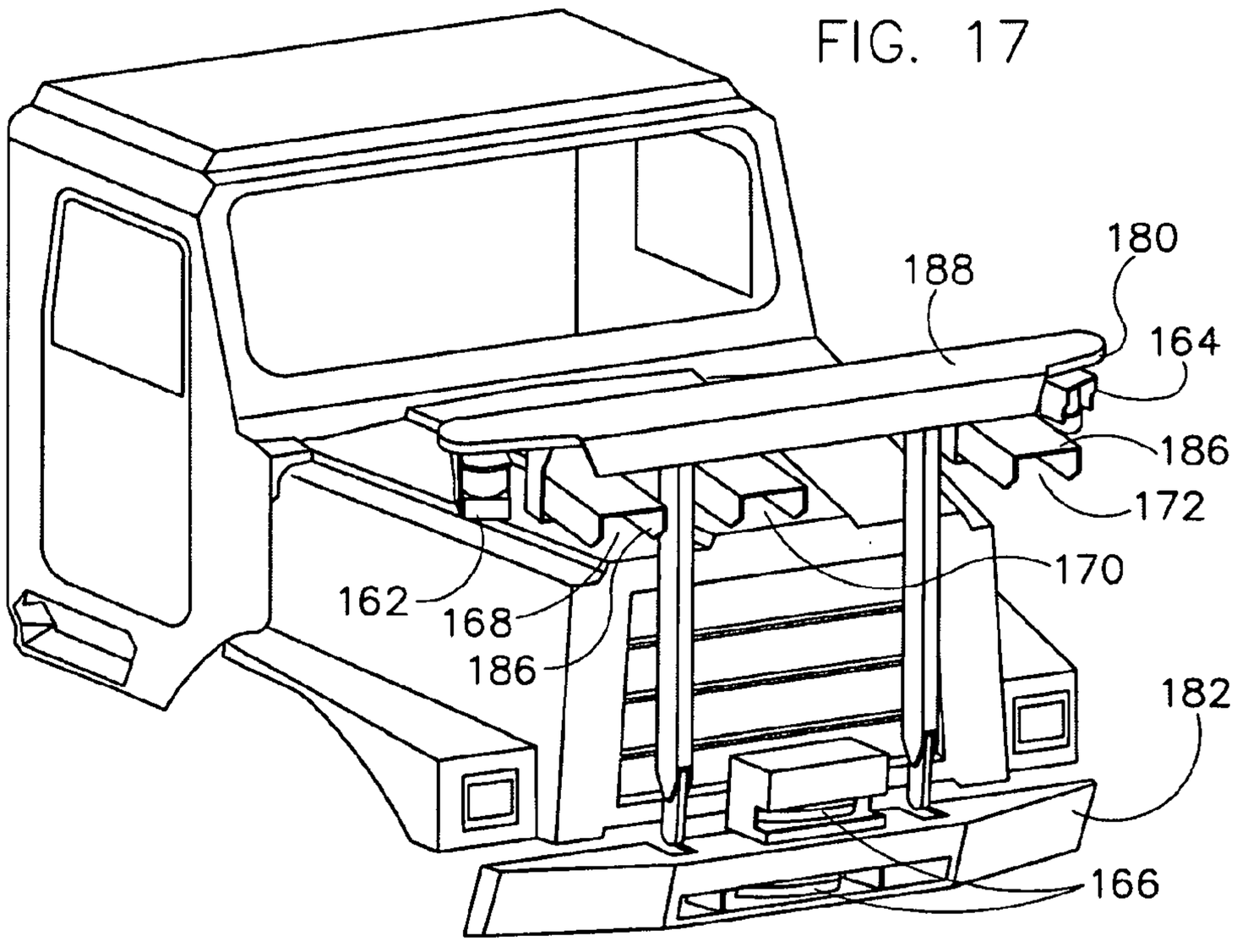


FIG. 18

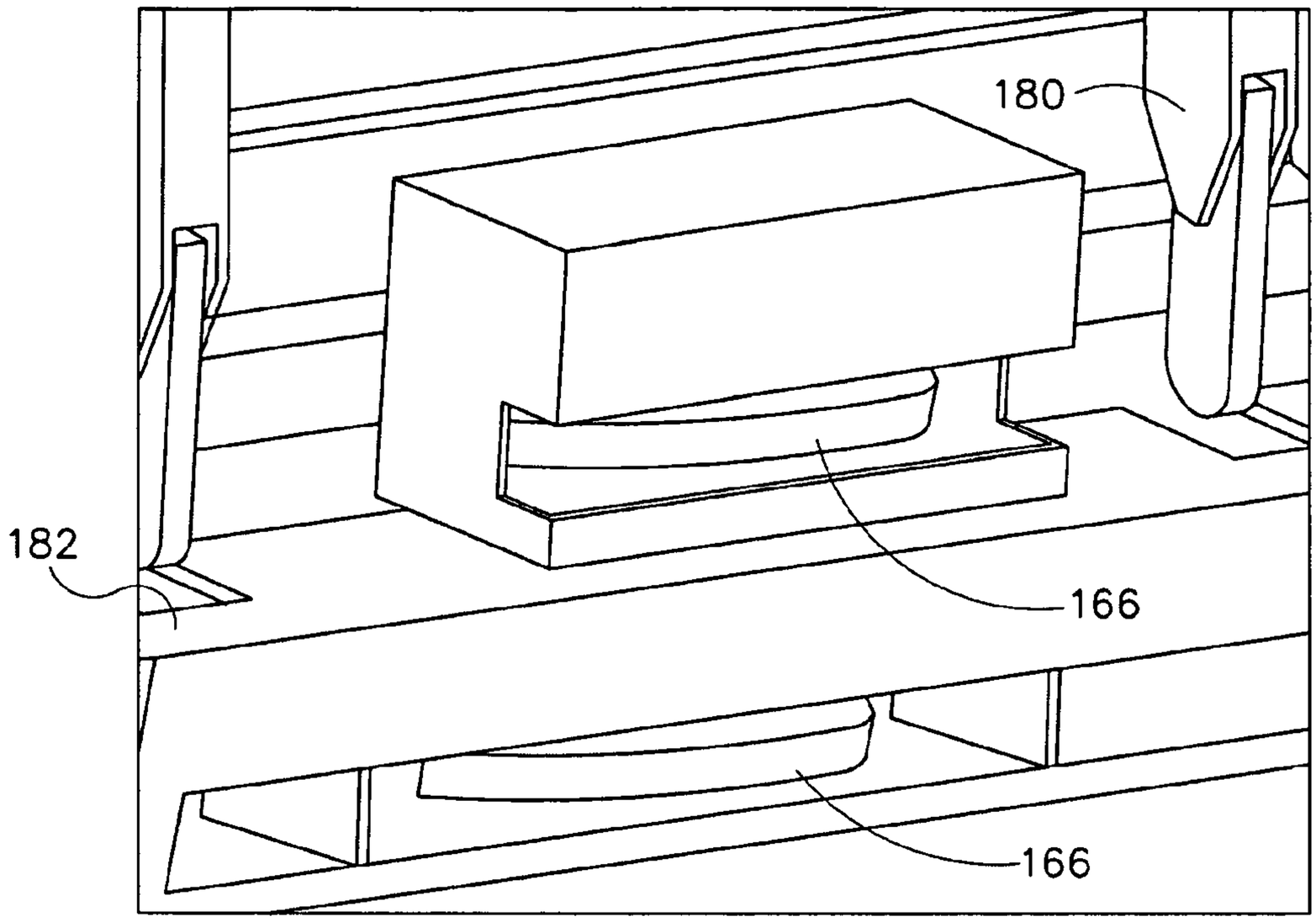


FIG. 19

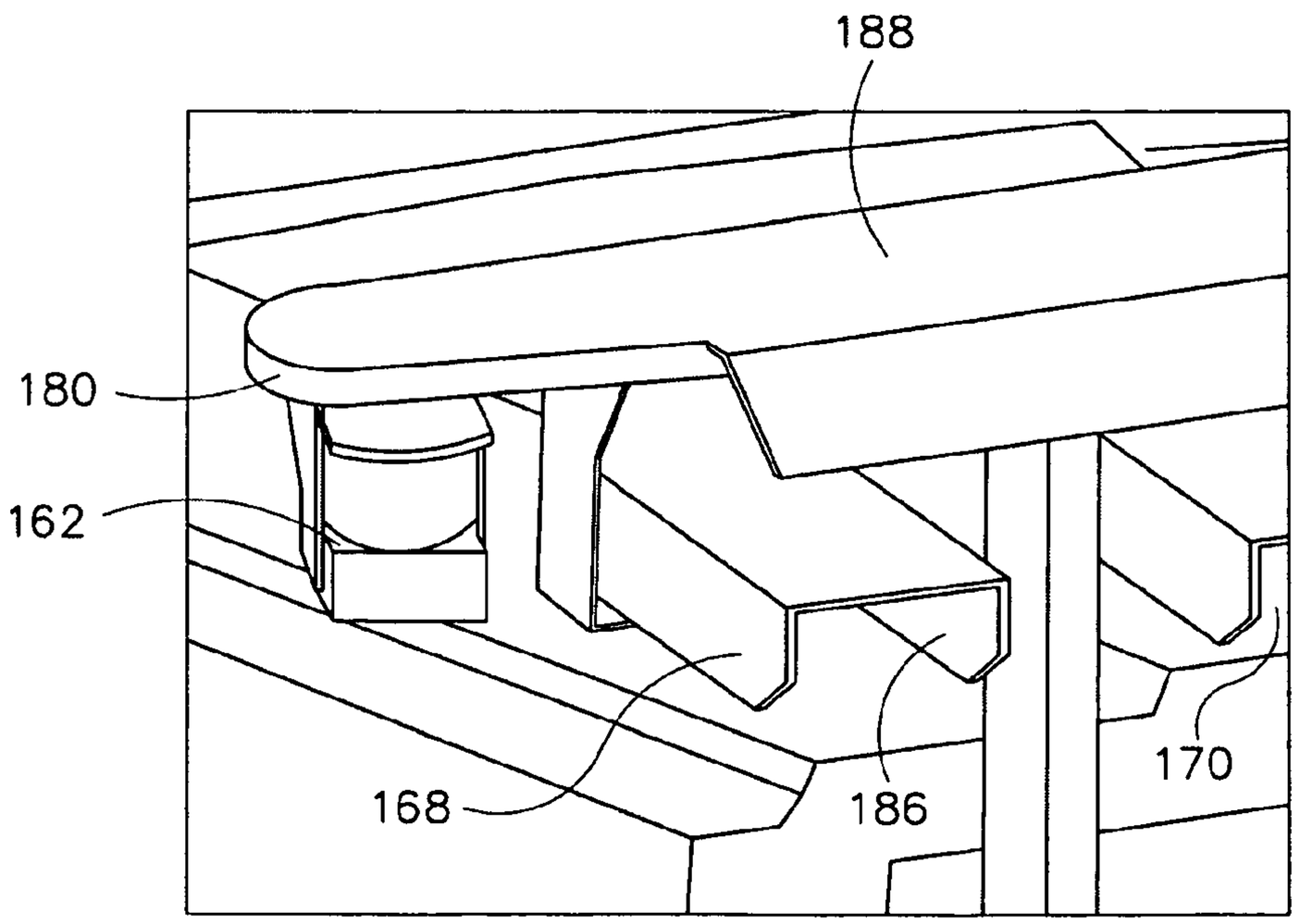


FIG. 20

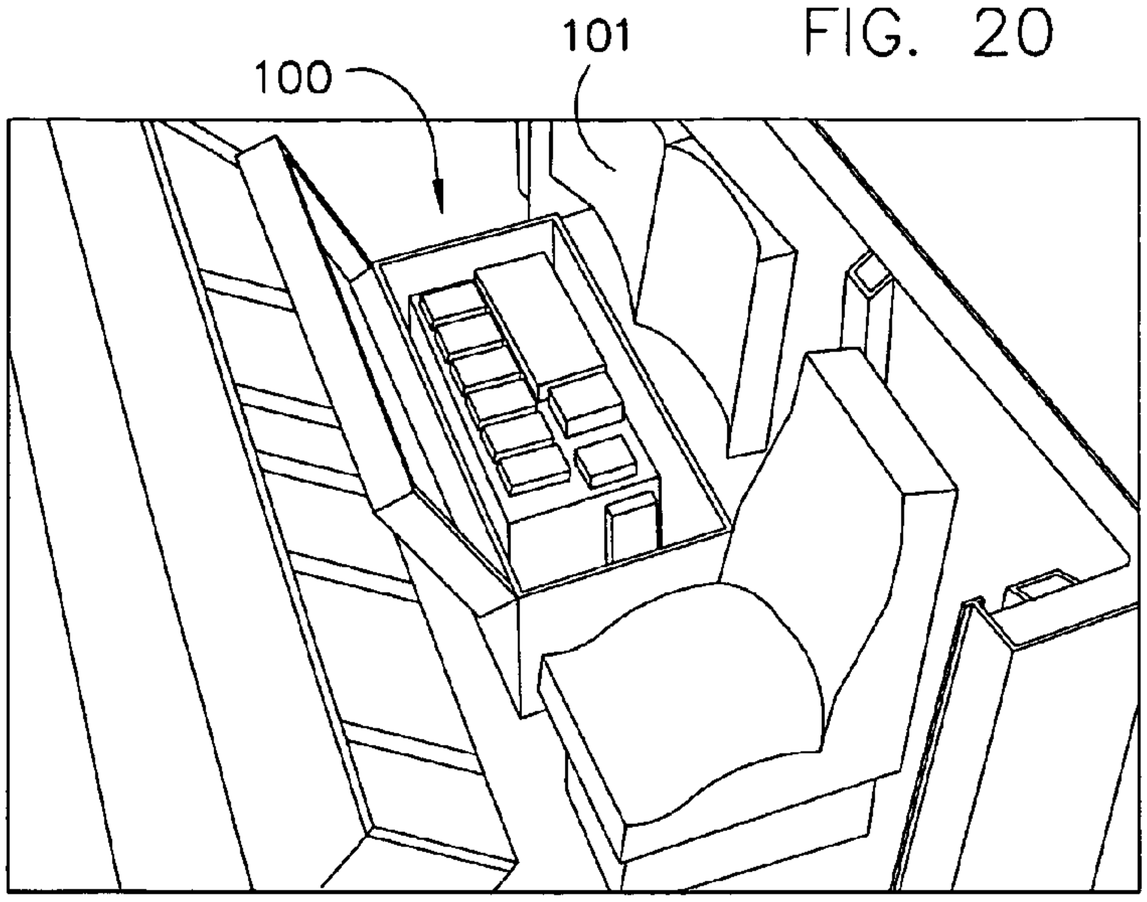


FIG. 21

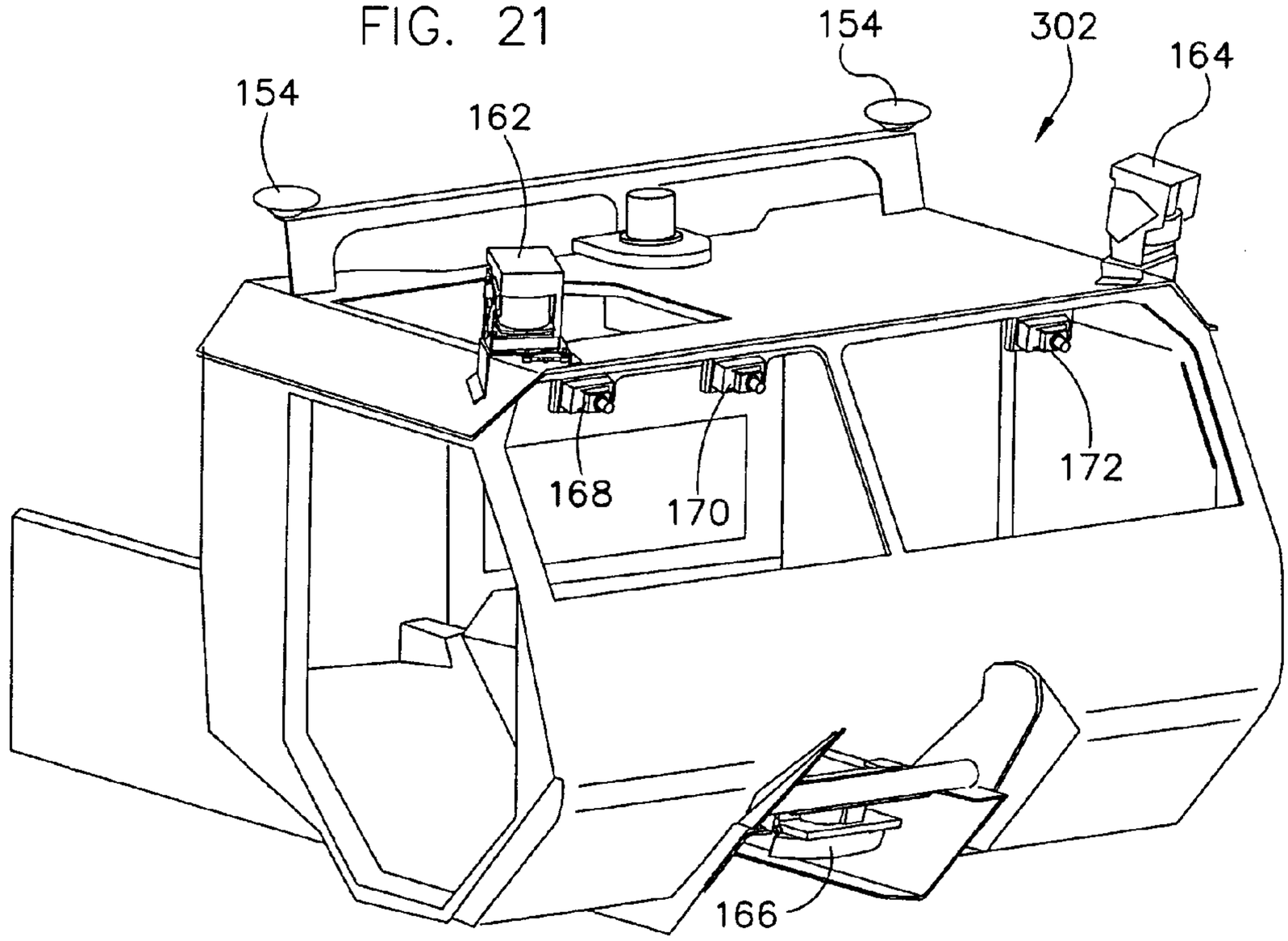


FIG. 22

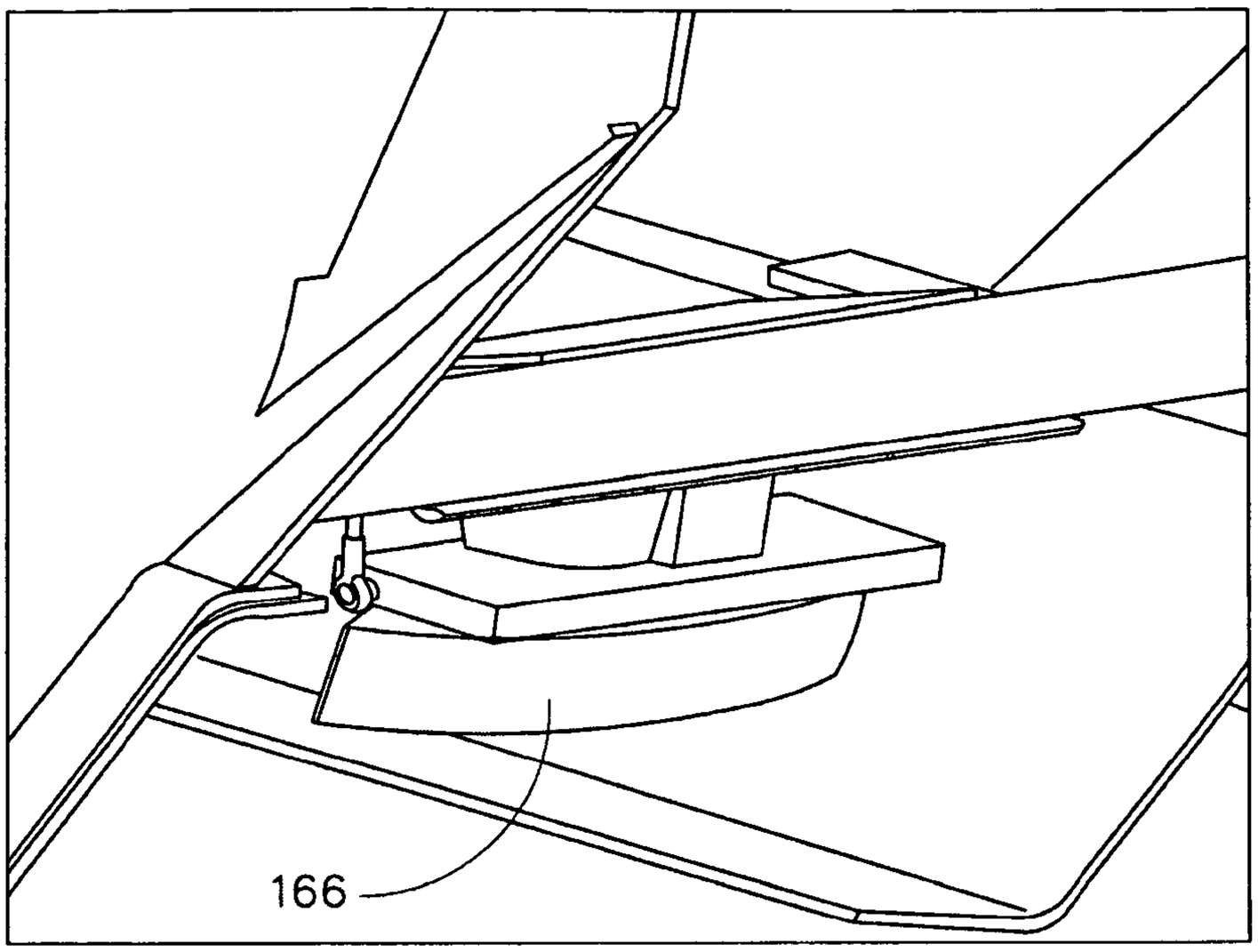


FIG. 23

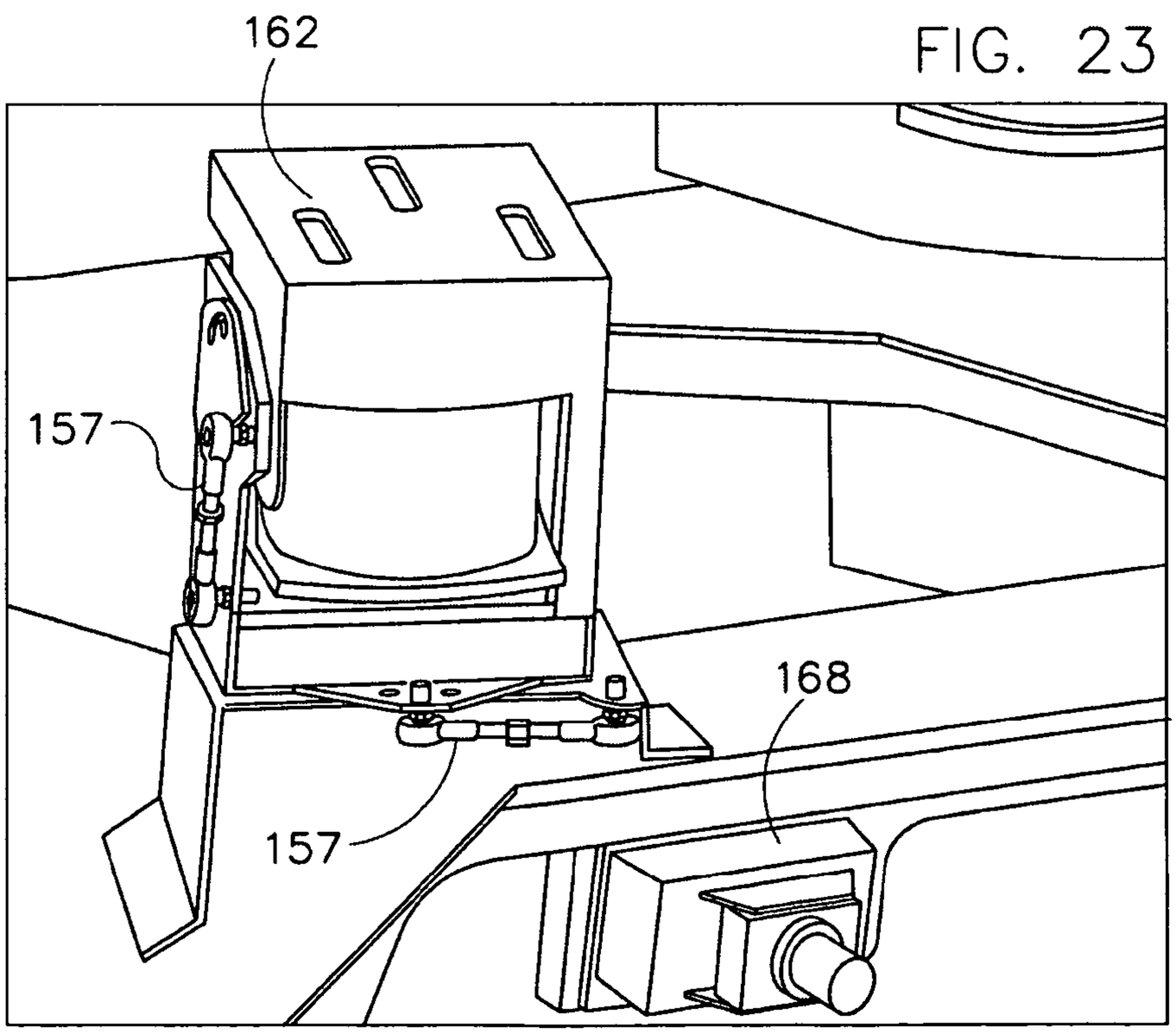
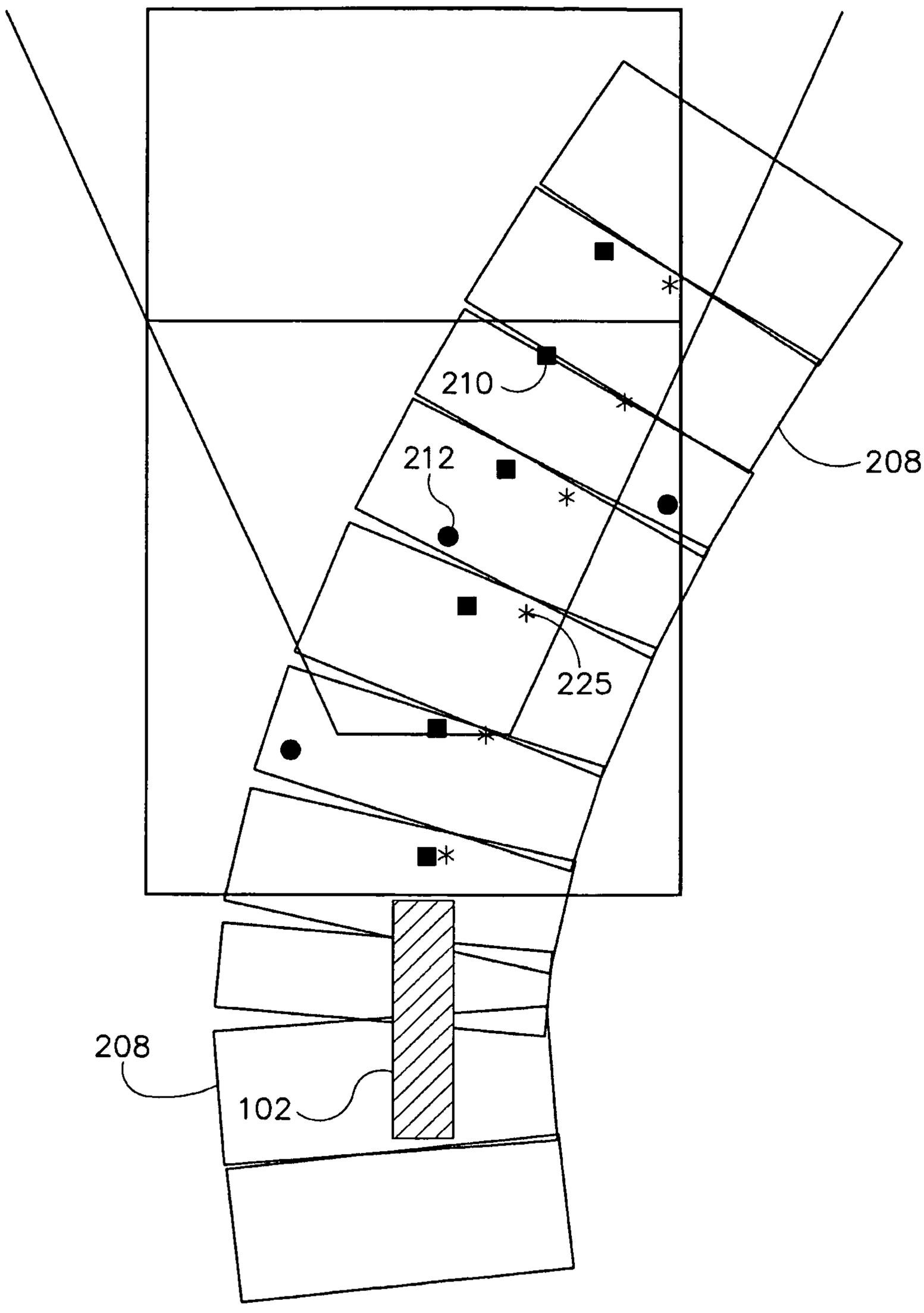


FIG. 24



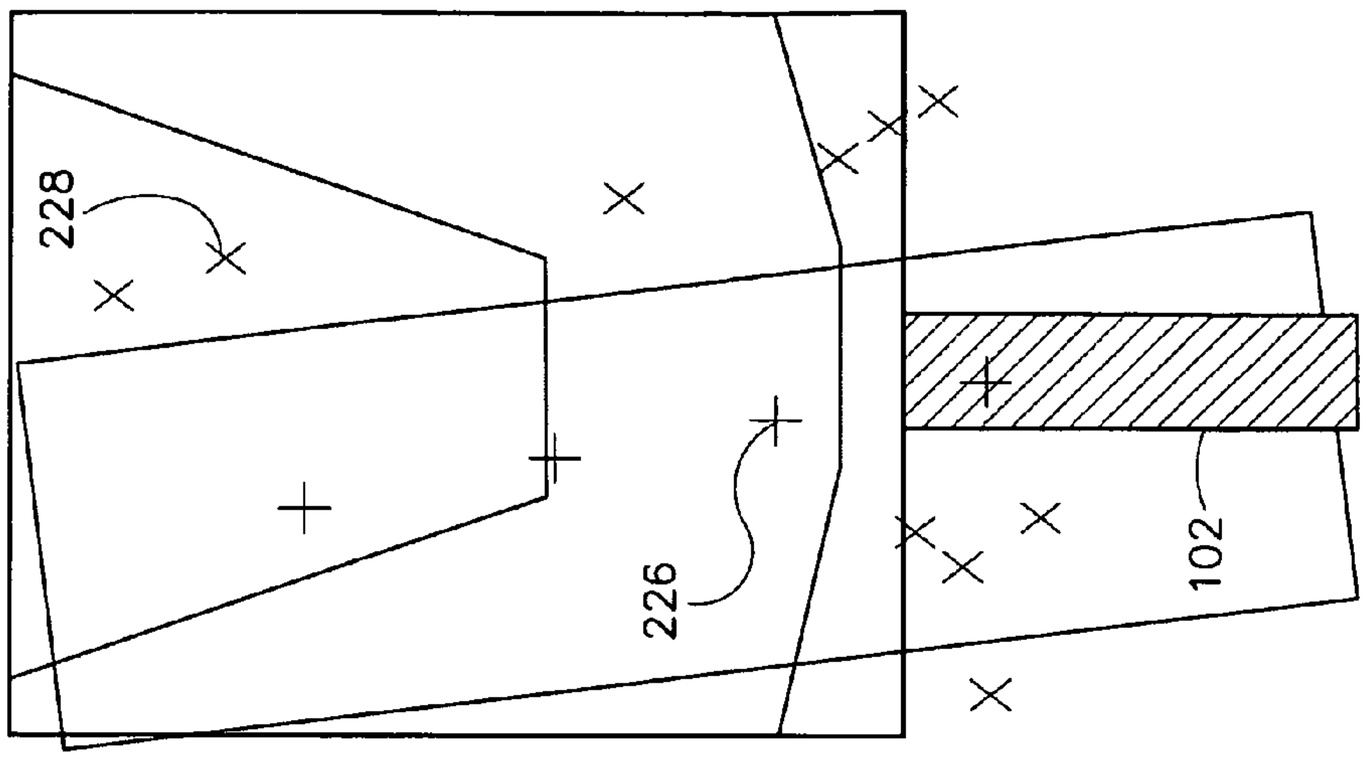


FIG. 26

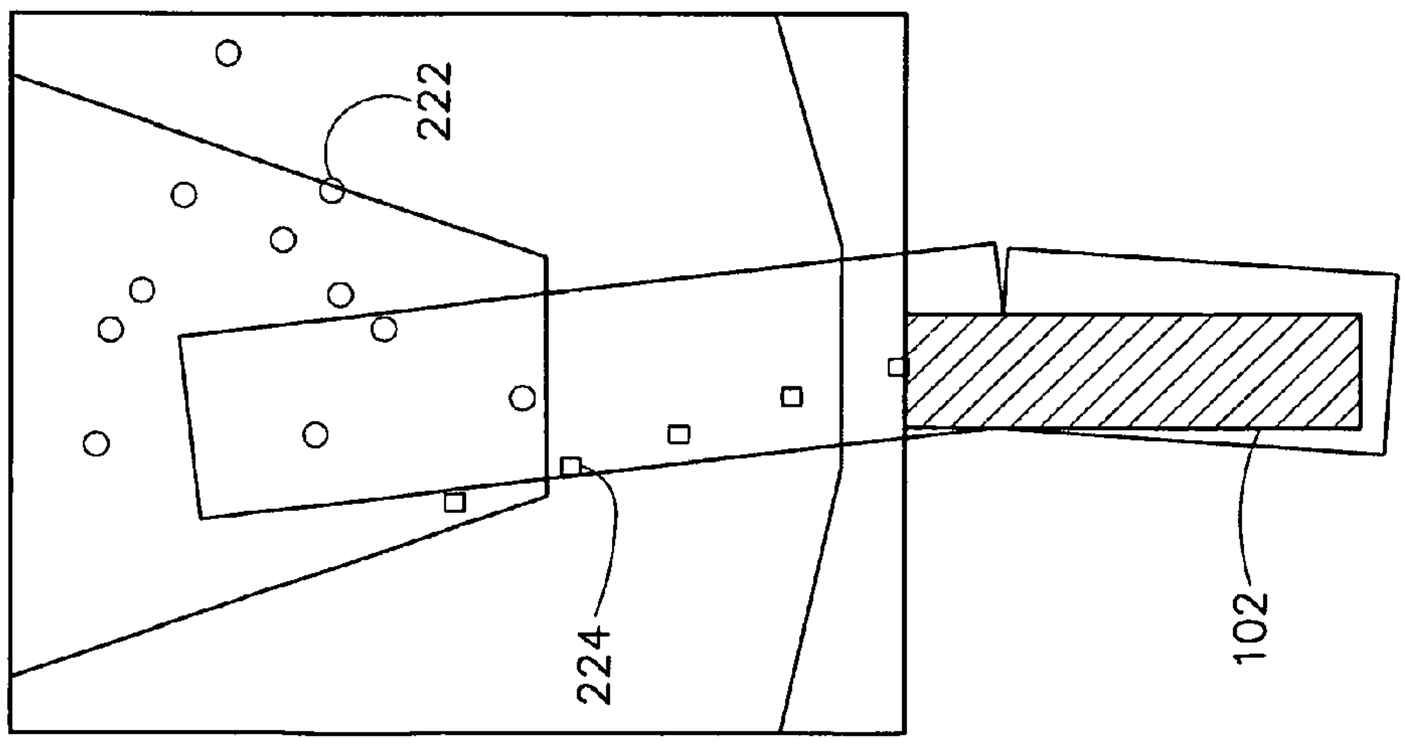


FIG. 25

VEHICLE DIAGNOSTICS BASED ON INFORMATION COMMUNICATED BETWEEN VEHICLES

CROSS-REFERENCE TO RELATED PATENT APPLICATIONS

This application is a continuation-in-part of U.S. Ser. No. 11/562,824, filed Nov. 22, 2006, entitled "Vision System For An Autonomous Vehicle," pending, which claims priority to U.S. Prov. No. 60/805,197, filed Jun. 19, 2006, entitled "Vision System For An Autonomous Vehicle," all of which are hereby expressly incorporated by reference.

BACKGROUND

The present disclosure relates generally to the field of the fleet vehicles. More specifically, the present disclosure relates to military vehicles (e.g., tanks, trucks, ambulances, ships, airplanes, trains), cargo transportation vehicles (e.g., trucks, trains, ships, airplanes), personnel transportation vehicles (e.g., buses, ships, airplanes, trains), emergency response vehicles (e.g. fire engines, ambulances, police cars), or any other type of service vehicle (hereinafter "vehicle").

Vehicles have become increasingly complex, difficult to maintain and require increased operator sophistication/training to be properly deployed. The movement of vehicles has become increasingly intertwined to enhance the effectiveness of vehicle movement.

A convoy is a modification of a caravan, which allows vehicles to travel together for a mutual support. The vehicle movement may also be coordinated to position multiple vehicles in an attack position to achieve an overall goal. For example, a plurality of tanks may take up position surrounding a target (e.g., city) to provide protection, to eliminate a hostile force, provide reinforcement or any combination thereof. In another example, a plurality of fire engines may take up position surrounding a target (e.g., burning building) to extinguish a fire.

The convoy and/or coordinated maneuvering functionality is limited by the amount of trained human resource available. The convoy and/or coordinated maneuvering functionality is further limited by the imprecision introduced by requiring multiple human operators to coordinate complex tactical actions.

A system that could minimize the need for trained human resource would increase human to machine efficiency, precision and tactical consistency.

What is needed is a system and/or method that satisfies one or more of these needs or provides other advantageous features. Other features and advantages will be made apparent from the present specification. The teachings disclosed extend to those embodiments that fall within the scope of the claims, regardless of whether they accomplish one or more of the aforementioned needs.

SUMMARY

One embodiment of the disclosure relates to a convoy of vehicles including a leader vehicle in communication with a plurality of autonomous follower vehicles. The leader vehicle being configured to receive a first autonomous follower vehicle data and compare the first autonomous follower vehicle data to at least one of a leader vehicle data, a second autonomous follower vehicle data and/or a threshold value. The first autonomous follower vehicle data, the leader vehicle data, the second autonomous follower vehicle data and the threshold value relate to a vehicle performance characteristic.

Another embodiment of the disclosure relates to a convoy of vehicles including a leader vehicle in communication with a plurality of autonomous follower vehicles and configured to receive at least one autonomous follower vehicle data, the leader vehicle configured to transmit at least one command signal to the plurality of autonomous follower vehicles. The plurality of autonomous follower vehicles implements the at least one command signal.

Yet another embodiment of the disclosure relates to a method for controlling a leader-follower convoy including transmitting a first command from a leader vehicle to a first follower vehicle and receiving the first command at the first follower vehicle. The method further includes transmitting a second command from the first follower vehicle to a second follower vehicle and transmitting a first confirmation signal from the first follower vehicle to the leader vehicle. The further includes wherein the second command is a retransmission of the first command.

BRIEF DESCRIPTION OF THE DRAWINGS

The disclosure will become more fully understood from the following detailed description, taken in conjunction with the accompanying drawings. The exemplary embodiments will hereafter be described with reference to the accompanying drawings, wherein like numerals depict like elements.

FIG. **1** is an illustration of a lead vehicle in communication with follower vehicles in a leader-follower convoy, according to an exemplary embodiment;

FIG. **2** is another illustration of a lead vehicle in communication with follower vehicles in a leader-follower convoy, according to an exemplary embodiment;

FIG. **3** is another illustration of a lead vehicle in communication with follower vehicles in a leader-follower convoy, according to an exemplary embodiment;

FIG. **4** is an illustration of a lead vehicle in communication with follower vehicles based on the difference distance between the lead vehicle and the follower vehicles, according to an exemplary embodiment;

FIGS. **5**A-**5**C are illustrations of the lead vehicle changing positions based on the detection of a hazard, according to exemplary embodiments;

FIG. **6**A is an illustration of a vehicle control center utilizing a master screen and a plurality of secondary screens, according to an exemplary embodiment;

FIG. **6**B is an illustration of a vehicle control center utilizing one master screen, according to an exemplary embodiment;

FIG. **6**C is an illustration of a vehicle control center master screen where all of the vehicles are displayed on the master screen, according to an exemplary embodiment;

FIG. **6**D is an illustration of a vehicle control center master screen where the display image is a composite image based on data received from multiple vehicles in the convoy, according to an exemplary embodiment;

FIG. **6**E is an illustration of a vehicle control center master screen where the operator can select a subset of the convoy and initiate a mission for this selected subset, according to an exemplary embodiment;

FIG. **6**F is an illustration of a vehicle control center master screen where the display image includes a composite image based on data received from multiple convoy vehicles and an image generated by a terrain database, according to an exemplary embodiment;

FIGS. **7**A-**7**C are illustrations of the convoy utilizing an object detection system to avoid an obstacle, according to an exemplary embodiment;

FIGS. **8**A-**8**D are illustrations of a subset of the convoy reaching an obstacle and initiating maneuvers to circumvent the obstacle, according to an exemplary embodiment;

FIGS. **9**A-**9**B are illustrations of a convoy vehicle becoming separated from the main convoy and traversing the landscape to rejoin the convoy, according to an exemplary embodiment;

FIGS. **10**A-**10**C are illustrations of convoy vehicles with different load factors and traveling on different inclines maintain convoy formation, according to an exemplary embodiment;

FIG. **10**D is an illustration of a vehicle diagnostic comparison, according to an exemplary embodiment;

FIG. **11** is a flow diagram of the convoy operation procedures, according to an exemplary embodiment;

FIG. **12** is a perspective view of a vehicle that is autonomous and/or semi-autonomous, according to an exemplary embodiment;

FIG. **13** is a block diagram schematically illustrating a vehicle control system, according to an exemplary embodiment;

FIG. **14** is a front view of an autonomous and/or semi-autonomous vehicle, according to an exemplary embodiment;

FIG. **15** is a front view of the vehicle in FIG. **14** which shows some of the sensors coupled to the roll cage and/or on or near the cab of the vehicle, according to an exemplary embodiment;

FIG. **16** is a front view of the vehicle in FIG. **14** which shows some additional sensors positioned near the bumper of the vehicle, according to an exemplary embodiment;

FIG. **17** is a perspective view of an autonomous and/or semi-autonomous vehicle showing sensors positioned near the roll cage and the bumper, according to an exemplary embodiment;

FIG. **18** is a perspective view of the vehicle in FIG. **17** showing two LIDAR sensors coupled to the bumper of the vehicle, according to an exemplary embodiment;

FIG. **19** is a perspective view of the vehicle in FIG. **17** showing a LIDAR sensor and a camera coupled to the roll cage of the vehicle, according to an exemplary embodiment;

FIG. **20** is a perspective view of the interior of an autonomous and/or semi-autonomous vehicle showing at least a portion of the hardware for the vehicle control system positioned under the passenger seat, according to an exemplary embodiment;

FIG. **21** is another perspective view of an autonomous and/or semi-autonomous vehicle, according to an exemplary embodiment;

FIG. **22** is a perspective view of the vehicle in FIG. **21** showing sensors positioned near the lower front section of the vehicle, according to an exemplary embodiment;

FIG. **23** is a perspective view of the vehicle in FIG. **21** showing sensors coupled to the cab of the vehicle, according to an exemplary embodiment; and

FIGS. **24-26** are illustrations of the path planning, obstacle detection, and obstacle avoidance capabilities of another embodiment of an autonomous and/or semi-autonomous vehicle.

DETAILED DESCRIPTION OF THE EXEMPLARY EMBODIMENTS

Although the description below contains many specificities, these specificities are utilized to illustrate some of the exemplary embodiments of this disclosure and should not be construed as limiting the scope of the disclosure. The scope of this disclosure should be determined by the claims, their legal equivalents and the fact that it fully encompasses other embodiments which may become apparent to those skilled in the art. A method or device does not have to address each and every problem to be encompassed by the present disclosure. All structural, chemical and functional equivalents to the elements of the below-described disclosure that are known to those of ordinary skill in the art are expressly incorporated herein by reference and are intended to be encompassed by the present claims. A reference to an element in the singular is not intended to mean one and only one, unless explicitly so stated, but rather it should be construed to mean at least one. No claim element herein is to be construed under the provisions of 35 U.S.C. §112, sixth paragraph, unless the element is expressly recited using the phrase "means for." Furthermore, no element, component or method step in the present disclosure is intended to be dedicated to the public, regardless of whether the element, component or method step is explicitly recited in the claims.

It should be appreciated that the vehicles, control systems, features, advantages, and any other subject matter described in: (1) U.S. Pat. No. 6,922,615, entitled "Turret Envelope Control System and Method for a Fire Fighting Vehicle," issued on Jul. 26, 2005, (2) U.S. Pat. No. 6,885,920, entitled "Control System and Method for Electric Vehicle," issued on Apr. 26, 2005, (3) U.S. Pat. No. 6,882,917, entitled "Steering Control System and Method," issued on Apr. 19, 2005, (4) U.S. Pat. No. 6,421,593, entitled "Military Vehicle having Cooperative Control Network with Distributed I/O Interfacing," issued on Jul. 16, 2002, and (5) U.S. Prov. Pat. App. No. 60/723,363, entitled "Vehicle Control System and Method," filed on Oct. 4, 2005, may be used and/or incorporated with the subject matter described herein. All possible configurations of the subject matter described in these documents and the subject matter described herein is contemplated and hereby expressly disclosed. For example, any of the vehicles or any portion of any of the vehicles (e.g., vehicle control systems, components for vehicle control systems, etc.) in these documents with their various configurations, control systems, features, and components may be combined with all or any part of the subject matter described herein. In particular, this disclosure could be utilized with the turret envelope control strategy of U.S. Pat. No. 6,922,615, the control system of U.S. Pat. No. 6,885,920, the steering control system of U.S. Pat. No. 6,882,917, the cooperative control network with distributed input/output interfacing of U.S. Pat. No. 6,421,593, and/or the control system of U.S. Prov. Pat. App. No. 60/723,363. The documents (1)-(5) listed in this paragraph are hereby incorporated by reference herein in their entireties as if the entire contents of these documents were reproduced herein.

Referring to FIG. **1**, an illustration of a lead vehicle in communication with follower vehicles in a leader-follower convoy is shown, according to an exemplary embodiment. In exemplary embodiments, a convoy **10** can be made up of a two convoy vehicles **12**, multiple convoy vehicles **12**, and/or a plurality of convoy vehicles **12**. In an exemplary embodiment, convoy **10** can include a leader vehicle **100**, which initiates commands to convoy vehicles **12**. In an exemplary embodiment, leader vehicle **100** can be in the front of convoy **10**, the back of convoy **10**, the right side of convoy **10**, the left side of convoy **10**, the middle of convoy **10** and/or any other position inside or outside of convoy **10**. In a exemplary embodiment, there can be more than one leader vehicle **100**. In an exemplary embodiment, convoy **10** can be controlled by

commands initiated by a single leader vehicle **100**, a few leader vehicles **100** or a plurality of leader vehicles **100**. In an exemplary embodiment, multiple leader vehicles **100** can initiate commands utilizing a composite analysis, a composite image, composite sensor data and/or a composite data. In an exemplary embodiment, any of the composite analysis, composite image, composite sensor data and/or composite data is based off of data received from multiple leader vehicles **100** and/or convoy vehicles **12**.

Convoy vehicles **12** follow the commands of leader vehicle **100** without regard to any other program, according to an exemplary embodiment. In another exemplary embodiment, convoy vehicles **12** compare the commands of leader vehicle **100** to predetermined values. The predetermined values can be mission specific values entered before the mission started and/or values entered during the manufacturing process. In an exemplary embodiment, the predetermined values can be vehicle performance characteristics or tolerances (e.g., cargo load capacity, speed, turning radius, rpms, temperature maximum and/or minimum values, etc.). In another exemplary embodiment, the predetermined values can be mission tolerances, such as, duration, mission phase timelines, acceptable loses, temperature ranges, visibility, distance, etc.). In an exemplary embodiment, if leader vehicle **100** commands are within the predetermined value, then convoy vehicles **12** follow the commands initiated by leader vehicle **100**. In this exemplary embodiment, if leader vehicle **100** commands are not within the predetermined value, then convoy vehicles **12** can be configured to not follow the commands initiated by leader vehicle **100**. In an exemplary embodiment, leader vehicle **100** can be configured with an override switch to disengage the ability of convoy vehicle **12** to not follow the commands of leader vehicle **100**.

In an exemplary embodiment, the commands from leader vehicle **100** are not within the predetermined value when these leader vehicle **100** commands would damage convoy vehicle **12**. In this exemplary embodiment, damage could occur because convoy vehicle **12** sense an obstacle, terrain, an enemy and/or a threat (e.g., landmines) that is not sensed by leader vehicle **100**.

In an exemplary embodiment, leader vehicle **100** transmits a first command **14** to first convoy vehicles **12**A. In this exemplary embodiment, first convoy vehicles **12**A are directly adjacent to leader vehicle **100**. In an exemplary embodiment, first convoy vehicles **12**A transmit a second command **16** and a first validation command **16**A to a second convoy vehicles **12**B and leader vehicle **100** respectively. In an exemplary embodiment, leader vehicle **100** receives first validation command **16**A and compares first validation command **16**A to first command **14**. If first validation command **16**A and first command **14** are within predetermined parameters and/or mission parameters, then leader vehicle **100** can be configured to refrain from reissuing first command **14**, according to an exemplary embodiment. If first validation command **16**A and first command **14** are not within predetermined parameters and/or mission parameters, then leader vehicle **100** can be configured to reissue first command **14**, according to an exemplary embodiment. In another exemplary embodiment, leader vehicle **100** can reissue first command **14** or another command signal to modify convoy vehicles **12** actions when first validation command **16**A is not identical to first command **14**.

In an exemplary embodiment, second convoy vehicles **12**B transmit a third command **18** to a third convoy vehicles **12**C and a second validation command **18**A to first convoy vehicles **12**A. If second validation command **18**A and second command **16** are within predetermined parameters and/or mission parameters, then first convoy vehicles **12**A can be configured to refrain from reissuing second command **16**, according to an exemplary embodiment. If second validation command **18**A and second command **16** are not within predetermined parameters and/or mission parameters, then first convoy vehicles **12**A can be configured to reissue second command **16**, according to an exemplary embodiment. In another exemplary embodiment, first convoy vehicle **12**B can reissue second command **16** or another command signal to modify convoy vehicles **12** actions when second validation command **18**A is not identical to second command **16**.

In another exemplary embodiment, second validation command **18**A can be transmitted to leader vehicle **100**. In this exemplary embodiment, leader vehicle **100** can be configured to reissue first command **14** to first convoy vehicle **12**A, reissue first command **14** to second convoy vehicle **12**B, issue a modified command to first convoy vehicle **12**A and/or issue a modified command to second convoy vehicle **12**B.

In an exemplary embodiment, third convoy vehicles **12**C transmit a fourth command **20** to a fourth convoy vehicles **12**D and a third validation command **20**A to second convoy vehicles **12**B. If third validation command **20**A and third command **18** are within predetermined parameters and/or mission parameters, then second convoy vehicles **12**B can be configured to refrain from reissuing third command **18**, according to an exemplary embodiment. If third validation command **20**A and third command **18** are not within predetermined parameters and/or mission parameters, then second convoy vehicles **12**B can be configured to reissue third command **18**, according to an exemplary embodiment. In another exemplary embodiment, second convoy vehicle **12**B can reissue third command **18** or another command signal to modify convoy vehicles **12** actions when third validation command **20**A is not identical to third command **18**. In another exemplary embodiment, third validation command **20**A can be transmitted to leader vehicle **100**. In this exemplary embodiment, leader vehicle **100** can be configured to reissue first command **14** to first convoy vehicle **12**A, reissue first command **14** to second convoy vehicle **12**B, reissue first command **14** to third convoy vehicle **12**C, issue a modified command to first convoy vehicle **12**A, issue a modified command to second convoy vehicle **12**B and/or issue a modified command to third convoy vehicle **12**C. In exemplary embodiments, the communication system can be closed loop (see FIGS. **1** and **2**) or the communication system can be open loop (see FIG. **3**).

In FIG. **2**, another illustration of a lead vehicle in communication with follower vehicles in a leader-follower convoy is shown, according to an exemplary embodiment. In an exemplary embodiment, convoy **10** can include leader vehicle **100**, which initiates commands to convoy vehicles **12**. In this exemplary embodiment, leader vehicle **100** is in the middle of convoy **10**. In an exemplary embodiment, leader vehicle **100** transmits a first command **14** to first convoy vehicles **12**A. In this exemplary embodiment, first convoy vehicles **12**A are directly adjacent to leader vehicle **100**. In an exemplary embodiment, first convoy vehicles **12**A transmit a second command **16** and a first validation command **16**A to a second convoy vehicles **12**B and leader vehicle **100** respectively. In an exemplary embodiment, leader vehicle **100** receives first validation command **16**A and compares first validation command **16**A to first command **14**. If first validation command **16**A and first command **14** are within predetermined parameters and/or mission parameters, then leader vehicle **100** can be configured to refrain from reissuing first command **14**, according to an exemplary embodiment. If first validation command **16**A and first command **14** are not within predeter-

mined parameters and/or mission parameters, then leader vehicle **100** can be configured to reissue first command **14**, according to an exemplary embodiment. In another exemplary embodiment, leader vehicle **100** can reissue first command **14** or another command signal to modify convoy vehicles **12** actions when first validation command **16**A is not identical to first command **14**.

In an exemplary embodiment, second convoy vehicles **12**B transmit a third command **18** to a third convoy vehicles **12**C and a second validation command **18**A to first convoy vehicles **12**A. If second validation command **18**A and second command **16** are within predetermined parameters and/or mission parameters, then first convoy vehicles **12**A can be configured to refrain from reissuing second command **16**, according to an exemplary embodiment. If second validation command **18**A and second command **16** are not within predetermined parameters and/or mission parameters, then first convoy vehicles **12**A can be configured to reissue second command **16**, according to an exemplary embodiment. In another exemplary embodiment, first convoy vehicle **12**B can reissue second command **16** or another command signal to modify convoy vehicles **12** actions when second validation command **18**A is not identical to second command **16**. In another exemplary embodiment, second validation command **18**A can be transmitted to leader vehicle **100**. In this exemplary embodiment, leader vehicle **100** can be configured to reissue first command **14** to first convoy vehicle **12**A, reissue first command **14** to second convoy vehicle **12**B, issue a modified command to first convoy vehicle **12**A and/or issue a modified command to second convoy vehicle **12**B. It should be noted that in this exemplary embodiment, leader vehicle **100** was positioned in the middle of convoy **10**, which required one less command (e.g., fourth command **20**) being communication in comparison to the exemplary embodiment shown in FIG. **1**. In an exemplary embodiment, leader vehicle **100** can be configured to determine the position in convoy **10** which requires the least amount of commands to be transmitted to convoy vehicles **12** and position leader vehicle **100** accordingly. In an exemplary embodiment, leader vehicle **100** can be configured to determine the position in convoy **10** which requires the highest amount of validation commands to be issued and position leader vehicle **100** accordingly. In this exemplary embodiment, the communication system would have the most amount of redundancy to ensure the proper commands were being received.

In FIG. **3**, another illustration of a lead vehicle in communication with follower vehicles in a leader-follower convoy is shown, according to an exemplary embodiment. In an exemplary embodiment, leader vehicle **100** transmits first command **14** to first convoy vehicles **12**A. In this exemplary embodiment, first convoy vehicles **12**A are directly adjacent to leader vehicle **100**. In an exemplary embodiment, first convoy vehicles **12**A transmit second command **16** to second convoy vehicles **12**B. In an exemplary embodiment, second convoy vehicles **12**B transmit third command **18** to third convoy vehicles **12**C. In an exemplary embodiment, third convoy vehicles **12**C transmit fourth command **20** to fourth convoy vehicles **12**D. In exemplary embodiments, the communication system can be closed looped (see FIGS. **1** and **2**) or the communication system can be opened looped (see FIG. **3**).

In FIG. **4**, an illustration of leader vehicle **100** in communication with follower vehicles based on the difference distance between leader vehicle **100** and the follower vehicles, according to an exemplary embodiment. Leader vehicle **100** transmits a first command signal **30**. First command signal **30** has a first transmission range **32**, according to an exemplary embodiment. In an exemplary embodiment, any follower vehicles within first transmission range **32** receive first command signal **30**. In an exemplary embodiment, a retransmission vehicle **12***e* may be within first transmission range **32**. Retransmission vehicle **12***e* retransmits first command signal **30** as a second command signal **34**, according to an exemplary embodiment. In an exemplary embodiment, second command signal **34** has a second transmission range **36**. Second transmission range **36** reaches a first follower vehicle outside of first transmission range **12***g*, according to an exemplary embodiment. In an exemplary embodiment, a potential retransmission vehicle **12***f* may transmit a third command signal (not shown) to reach a second follower vehicle outside of first transmission range **12***h*. It should be noted that first follower vehicle outside of first transmission range **12***g*, second follower vehicle outside of first transmission range **12***h* or any other follower vehicle may be configured to retransmit first command signal **30**.

In FIGS. **5**A-**5**C, illustrations are shown of the lead vehicle changing positions based on the detection of a hazard, according to exemplary embodiments. In FIG. **5**A, a first view of convoy **50** shows that leader vehicle **100** is positioned in the first row of the convoy as convoy approaches a threat **52**. In exemplary embodiments, threat **52** can be obstacles (e.g., hills, mountain, landmines, water, enemy forces, trees or other hazardous terrains). In FIG. **5**B, a second view of convoy **54** shows that leader vehicle **100** has moved into the second row of the convoy utilizing a first path **58** as convoy approaches threat **52**. It should be noted that the movement can be physical or virtual. In the virtual mode, the leader function is electronically switched to another vehicle. It should also be noted that leader vehicle **100** can be moved to any position in the convoy either physically or virtually.

In FIG. **5**C, a third view of convoy **56** shows that leader vehicle **100** is positioned in the front row of convoy as convoy approaches threat **52**. In this exemplary embodiment, leader vehicle **100** has utilized a second path **60** to move to the second row. In this exemplary embodiment, follower vehicles have utilized a third path **62**, a fourth path **64** and a fifth path **66** to change locations. In this exemplary embodiment, follower vehicles have changed location to increase the complexity for the enemy to determine leader vehicle **100**.

In FIG. **6**A, an illustration of a vehicle control center **400** utilizing a master screen **402** and a plurality of secondary screens **404** is shown, according to an exemplary embodiment. In an exemplary embodiment, vehicle control center **400** includes a driver seat **418**, a steering wheel **416**, a control panel **412** and a video screen **410**. In an exemplary embodiment, control panel **412** includes a plurality of control devices **414**. Control devices can be switches, levers, pushbuttons, and/or knobs. In an exemplary embodiment, video screen **410** includes a combination of plurality of secondary screens **404** and master screen **402**. Secondary screens **404** and/or master screen **402** may be a touch-screen display, while in other exemplary embodiments, may be any other non-touch sensitive display. In still other exemplary embodiments, secondary screens **404** and/or master screen **402** may be of any technology (e.g. LCD, DLP, plasma, CRT), configuration (e.g. portrait or landscape), or shape (e.g. polygonal, curved, curvilinear).

In an exemplary embodiment, vehicle control center **400** can allow the operator to utilize master screen **402** to monitor the convoy. The operator can control any of the follower vehicles from vehicle control center **400** by issuing commands and/or taking over control of the follower vehicle. In an exemplary embodiment, the operator takes over control of the follower vehicle utilizing steering wheel **416** and control

panel **412**. In this exemplary embodiment, steering wheel **416** may be configured to engage control of the follower vehicle and disengage control of leader vehicle **100**. For example, steering wheel **416** may be configured to normally control the direction of leader vehicle **100**; however, under operator command steering wheel **416** may no longer control the direction of leader vehicle but instead control follower vehicle.

In another exemplary embodiment, plurality of secondary screens **404** may be configured to monitor one or more of the follower vehicles. In an exemplary embodiment, plurality of secondary screens **404** may include a caution screen **406** and a warning screen **408**. In this exemplary embodiment, caution screen **406** occurs when one of plurality of secondary screens **404** determines that a potential threat is within a predetermined range (e.g., 1-50 miles away) of one or more follower vehicles. The potential threat may be terrain obstacles, enemy vehicles, enemy personnel, vehicle performance factors outside of tolerance (e.g., engine speed, oil pressure, tire pressure, engine temperature, transmission speed, water level, and/or torque) and/or any other source of potential harm to follower vehicle. In this exemplary embodiment, caution screen **406** can be transferred to master screen **402** automatically or by operator command. Operator command can be audio or tactile.

In another exemplary embodiment, plurality of secondary screens **404** may include warning screen **408**. In this exemplary embodiment, warning screen **408** occurs when one of plurality of secondary screens **404** determines that a potential threat is within predetermined range (e.g., under 1 mile) of one or more follower vehicles. The potential threat may be terrain obstacles, enemy vehicles, enemy personnel, vehicle performance factors outside of tolerance (e.g., engine speed, oil pressure, tire pressure, engine temperature, transmission speed, water level, and/or torque) and/or any other source of potential harm to follower vehicle. In this exemplary embodiment, caution screen **406** can be transferred to master screen **402** automatically or by operator command. Operator command can be audio or tactile.

In FIG. **6**B, an illustration of vehicle control center **400** utilizing a single master screen **420** is shown, according to an exemplary embodiment. In this exemplary embodiment, any portion of the convoy can be shown on single master screen **420** in significant detail.

In FIG. **6**C, an illustration of vehicle control center master **400** utilizing a second master screen **424** where all of the vehicles are displayed on second master screen **424** is shown, according to an exemplary embodiment. In this exemplary embodiment, all of follower vehicles **12** and leader vehicle **100** can be shown on one screen in significant detail.

In FIG. **6**D, an illustration of vehicle control center master screen **426** where the display image is a composite image **430** based on data received from multiple vehicles in the convoy is shown, according to an exemplary embodiment. In an exemplary embodiment, each vehicle (e.g., leader vehicle **100** and follower vehicle **12**) in the convoy can be configured to include sensors that enable the collect of data related to the environment surrounding the convoy (see FIGS. **7**A-**7**C). In an exemplary embodiment, each vehicles transmits environmental data gather from the vehicle's sensor to vehicle control center **400**. Vehicle control center **400** includes a processing engine, terrain database engine, graphics engine and display drive that allows vehicle control center **400** to create composite image **430** of the environment in and around the convoy.

In an exemplary embodiment, composite image **430** includes a first section of the convoy **401***a*, a second section of the convoy **401***b*, an obstacle **436**, a water obstacle **432**, a first level of terrain **434**, a steep terrain decline **438**, a second level of terrain **440** and a third level of terrain **442**.

In FIG. **6**E, an illustration of vehicle control center master screen **426** where the operator can select a subset of the convoy **444** and initiate a mission for this selected subset of the convoy **444** is shown, according to an exemplary embodiment. In an exemplary embodiment, subset of the convoy **444** may be commanded by leader vehicle **100** to draw enemy fire away from the main convoy. This could be accomplished by maneuvering subset of the convoy **444** toward an enemy location, towards an enemy target area or away from the enemy. Subset of the convoy **444** could be maneuvered away from the enemy in a manner that would make subset of the convoy **444** appear to be a critical element of the convoy. In an exemplary embodiment, subset of the convoy **444** could appear to include leader vehicle **100**. In this exemplary embodiment, one of the vehicles in subset of the convoy **444** could be maneuvered in a manner that indicates that this vehicle is being protected by the other vehicles in subset of the convoy **444**. The enemy would see this protection scheme and may conclude that leader vehicle **100** is within subset of the convoy **444**. This may cause the enemy to focus the enemy's attack on subset of the convoy **444** while the real leader vehicle **100** escapes. In exemplary embodiments, the maneuvering of subset of the convoy **444** could be performed by a predetermined program that is implemented automatically, implemented manually by leader vehicle **100** or a combination of both. In an exemplary embodiment, the predetermined value could be damage to leader vehicle **100**, the amount of damage to convoy **10**, exceeding a threshold convoy damage percentage, communication interruption, duration of attack, duration of mission, fuel supply, weapon supply or any other criteria known to a person of ordinary skill in the art.

In another exemplary embodiment, subset of the convoy **444** can be commanded by leader vehicle **100** to diverge from the main mission to location and/or transport personnel, machinery, and/or supplies (e.g., weapons, fuel, food, medication, clothing, and surveillance equipment). Subset of the convoy **444** may be one vehicle that is directed to maneuver into a field that potentially contains a threat (e.g., minefield). In this exemplary embodiment, subset of the convoy **444** maneuvers into the field while transmitting the exact path that subset of the convoy **444** has traveled. If subset of the convoy **444** successfully traverses the field, the main convoy utilizes the coordinates transmitted by subset of the convoy **444** to traverse the field. If subset of the convoy **444** is initially unsuccessful, then the process can be repeated until a path that traverses the field is determined or leader vehicle **100** can command the convoy to take a different path to the objective.

In FIG. **6**F, an illustration of a composite vehicle control center master screen **446** where the display image includes a composite image **452** based on data received from multiple convoy vehicles and an image generated by a terrain database is shown, according to an exemplary embodiment. In an exemplary embodiment, composite image **452** includes a convoy data image **448** and a database image **450**. Convoy data image **448** is based on data received from one of the convoy vehicles, a few convoy vehicles, a plurality of convoy vehicles or all of the convoy vehicles (see FIGS. **7**A-**7**C), according to exemplary embodiments. Database image **450** is based on data received from at least one terrain database.

Convoy data image **448** includes a first water hazard **454**, a first field **458**, a first obstacle **466**, and a first steep terrain decline **462**, according to an exemplary embodiment. Database image **450** includes a second water hazard **450**, a second field **460**, a second obstacle **468**, and a second steep terrain decline **464**, according to an exemplary embodiment. In this

exemplary embodiment, first water hazard **454** and second water hazard **450**, first field **458** and second field **460**, first obstacle **466** and second obstacle **468**, and first steep terrain decline **462** and second steep terrain decline **462** are all configured to depict the same terrain and/or obstacle source. In other words, first water hazard **454** should be identical or substantially similar to second water hazard **450**. In an exemplary embodiment, an obstacle source and/or terrain image from convoy data image **448** may be different than the same obstacle source and/or terrain image from database image **450**. In this exemplary embodiment, when the image on convoy data image **448** differs from the image on database image **450** by a predetermined threshold value (e.g., percentage, feet, inches, and/or miles) an alert will be issued. In another exemplary embodiment, a discrepancy report will be generated which may be sent to leader vehicle **100**, a central command station or a central database.

In an exemplary embodiment, first obstacle **466** and second obstacle **468** differ by a value that is greater than the predetermined threshold value (e.g., 5 percent). In this exemplary embodiment, first obstacle **466** has a first section of first obstacle **470** that is significantly (e.g., greater than the predetermined threshold value) different than a first section of second obstacle **472**. In exemplary embodiments, differences in the images on convoy data image **448** and database image **450** can be resolved by automatically or manually selecting a primary image which may be either convoy data image **448** or database image **450**. In another exemplary embodiment, convoy data image **448** can be automatically or manually selected based on the distance of the obstacle source and/or terrain from vehicles in the convoy. When the distance is less than a predetermined amount (e.g., 10 feet, 100 feet, 1,000 feet, or 5,000 feet) convoy data image **448** can be selected because the actual sensor data is determined to be more reliable than the database data, according to an exemplary embodiment. When the distance is greater than a predetermined amount (e.g., 5,000 feet) database image **450** can be selected because the database data is determined to be more reliable than the sensor data, according to an exemplary embodiment.

In FIGS. **7**A-**7**C, an illustration of the convoy utilizing an object detection system to avoid an obstacle is shown, according to an exemplary embodiment. In FIG. **7**A, an image of convoy at a first position **474** is shown, according to an exemplary embodiment. Image of convoy at a first position **474** includes a convoy **403**, obstacle **436**, water obstacle **432**, first level of terrain **434**, steep terrain decline **438**, second level of terrain **440** and third level of terrain **442**. Convoy **403** includes follower vehicles **12** and leader vehicles **100** (see FIG. **1**) in a column-row configuration, according to an exemplary embodiment. The column-row configuration includes three rows and five columns. A vehicle in column three row three can be designated $vehicle_{33}$. Convoy **403** includes a vehicle, **476**, a $vehicle_{21}$ **478**, a $vehicle_{31}$ **480**, a $vehicle_{41}$ **482**, and a $vehicle_{51}$ **484**. In this exemplary embodiment, convoy **403** is at a first distance from obstacle **436**.

In an exemplary embodiment, one vehicle, a few vehicles, a plurality of vehicles or all of the vehicles in convoy **403** transmit electromagnetic radiation (e.g., LIDAR, radar) in a predetermined pattern. It should be noted that the predetermined pattern can be the same for all the vehicle, the predetermined pattern can be different for a subset of the vehicle (e.g., the vehicle in front of the convoy could have different patterns than vehicles in the middle of the convoy). The predetermined pattern could be different from every vehicle. It should also be noted that the transmit of electromagnetic radiation could be in pattern that is not predetermined but selected by operator on an ad hoc basis. The operator can change or override any predetermined pattern.

For simplicity and clarity only a few electromagnetic radiation signals will be shown in the following exemplary embodiments. It should be noted that more or less electromagnetic radiation signals could be shown and/or utilized with this disclosure.

In an exemplary embodiment, $vehicle_{11}$ **476** transmits a first signal **486** and a second signal **488**. First signal **486** does not generate a return signal because first signal **486** does not contact an obstacle and/or terrain, according to an exemplary embodiment. The system processes this information and determines that the path covered by first signal **486** is clear of any obstacles and/or the terrain has not significantly changed. Second signal **488** generates a first return signal **490** because second signal **488** contacts obstacle **436**. The system processes this information to determine at least one data point for obstacle **436**.

$Vehicle_{21}$ **478** transmits a third signal **492**, which generates a second return signal **494** because third signal **492** contacts obstacle **436**, according to an exemplary embodiment. The system processes this information to determine at least one data point for obstacle **436**. Similarly, $vehicle_{31}$ **480** transmits a fourth signal **496**, which generates a third return signal **498** because fourth signal **496** contacts obstacle **436**. The system processes this information to determine at least one data point for obstacle **436**. $Vehicle_{41}$ **482** transmits a fifth signal **500**, which returns as a fourth return signal **502**. The system processes this information to determine at least one data point for obstacle **436**. $Vehicle_{51}$ **484** transmits a sixth signal **504** and a seventh signal **508**, according to an exemplary embodiment. Sixth signal **504** does not generate a return signal because six signal **504** does not contact an obstacle and/or terrain, according to an exemplary embodiment. The system processes this information and determines that the path covered by six signal **504** is clear of any obstacles and/or the terrain has not significantly changed. The system processes all the obstacle data points generated by the return signals to create a composite image of obstacle **436**, according to an exemplary embodiment. In an exemplary embodiment, seventh signal **508** generates a fifth return signal **506** because seventh signal **508** contacted a change in the terrain. The system processes the data positions generated by seventh signal **508**, along with other data positions generated in a similar manner as described above to determine a composite image of steep terrain decline **438**.

In FIG. **7**B, an image of convoy at a second position **514** is shown, according to an exemplary embodiment. In an exemplary embodiment, convoy at second position is closer to obstacle **436** than convoy at first position. In an exemplary embodiment, $vehicle_{11}$ **476** transmits an eighth signal **510**, which generates a sixth return signal **512** because eighth signal **510** contacted water obstacle **432**. The system processes the data positions generated by eighth signal **510**, along with other data positions generated in a similar manner as described above to determine a composite image of water obstacle **432**.

In FIG. **7**C, an image of convoy at a third position **516** is shown, according to an exemplary embodiment. Convoy **403** (see FIGS. **7**A and **7**B) has split up into a left subsection **518** and a right subsection **520**. Convoy **403** has split up into left subsection **518** and right subsection **520** based on the composite image of obstacle **436** generated by the data position information collected in FIGS. **7**A and **7**B. In an exemplary embodiment, the composite image of the obstacle **436** generated by the data position information collected by convoy **403** can be overlaid with terrain data provided by at least one

terrain database. In other exemplary embodiments, the overlaid image can be display as a perspective view, a wireframe view and/or as a synthetic image in a synthetic vision system. It should be noted that any process for displaying an image known to a person skilled in the art can also be used with this disclosure.

In FIGS. **8**A-**8**D, an illustration of a subset of the convoy reaching an obstacle and initiating maneuvers to circumvent the obstacle is shown, according to an exemplary embodiment. In FIG. **8**A, an image of convoy at fourth position **522** is shown, according to an exemplary embodiment. Image of convoy at a fourth position **522** includes convoy **403**, obstacle **436**, water obstacle **432**, first level of terrain **434**, steep terrain decline **438**, second level of terrain **440** and third level of terrain **442**.

In an exemplary embodiment, vehicle$_{11}$ **476** transmits first signal **486** and second signal **488**. The system processes this information and determines that the path covered by first signal **486** is clear of any obstacles and/or the terrain has not significantly changed. Second signal **488** generates first return signal **490**, which is utilized by the system to determine at least one data point for obstacle **436**. Vehicle$_{21}$ **478** transmits third signal **492**, which generates second return signal **494** that the system utilizes to determine at least one data point for obstacle **436**. Similarly, vehicle$_{31}$ **480** transmits fourth signal **496**, vehicle$_{41}$ **482** transmits fifth signal **500**, and vehicle$_{51}$ **484** transmits sixth signal **504** and seventh signal **508**, which are utilized by the system similar to the process discussed for FIG. **7**A.

In FIG. **8**B, an image of convoy at a fifth position **524** is shown, according to an exemplary embodiment. In an exemplary embodiment, convoy at fifth position is closer to obstacle **436** than convoy at fourth position. In an exemplary embodiment, vehicle$_{11}$ transmission and how the system processes this information is discussed in FIG. **7**B.

In FIG. **8**C, convoy **403** has divided into left subsection **518** and right subsection **520** because of obstacle **436**, according to an exemplary embodiment. In an exemplary embodiment, left subsection **518** and right subsection **520** continue to transmit signal to locate obstacles and/or changes in the terrain. In this exemplary embodiment, right subsection **520** transmits a ninth signal **528** and a tenth signal **530**, which generate a seventh return signal **530** and an eighth return signal **532**. Seventh return signal **530** and eighth return signal **532** are processed, along with other data positions, to determine that an obscured obstacle **536** is blocking right subsection's **520** path, according to an exemplary embodiment. In exemplary embodiments, obscured obstacle **536** can be an obstacles outside of the vehicle sensor range when convoy **403** was at first position, second position and/or third position. In other exemplary embodiments, obscured obstacle **536** may be a new obstacle, such as a tree falling, a mud slide, a rock slide, landmines, enemy vehicles and/or enemy personnel.

In FIG. **8**D, right subsection **520** maneuvers from an impeded position **540** to an unimpeded position **542**, according to an exemplary embodiment. Right subsection **520** and left subsection **518** determine a right subsection course, a left subsection course, and a relative speed of right subsection **520** to left subsection **518** to minimize the time required for right subsection **520** to rejoin left subsection **518**, according to an exemplary embodiment.

In FIGS. **9**A-**9**B, an illustration of a convoy vehicle becoming separated from the main convoy and traversing the landscape to rejoin the convoy is shown, according to an exemplary embodiment. In an exemplary embodiment, right subsection **520** has maneuvered too close to steep terrain decline **438**. Follower vehicle **12** has slide down to a position on steep terrain decline **546**, according to an exemplary embodiment. In this exemplary embodiment, follower vehicle **12** is incapable of ascending steep terrain decline **438**. Leader vehicle **100** (see FIG. **1**) commands follower vehicle to a position on second level terrain **548**.

In FIG. **9**B, leader vehicle **100** commands follower vehicle **12** to maneuver from position on second level terrain **548** to a position on first level terrain **554** along a path **552**, according to an exemplary embodiment. Follower vehicle **12** maneuvers from position on first level terrain **554** to a position inside of convoy **558** as convoy **556** approaches position on first level terrain **554**, according to an exemplary embodiment. In another exemplary embodiment, follower vehicle **12** can be programmed to automatically determine a path back to convoy **556** utilizing a terrain database, a global positioning system, a location signal from convoy **556** and/or follower vehicle **12** sensors.

In FIGS. **10**A-**10**C, an illustration of convoy vehicles with different load factors and traveling on different inclines while maintaining convoy formation is shown, according to an exemplary embodiment. In FIG. **10**A, a first vehicle **602**, a second vehicle **604** and a third vehicle **606** are part of a convoy. First vehicle **602**, second vehicle **604** and third vehicle **606** are all producing a first engine output **616**, according to an exemplary embodiment. In this exemplary embodiment, first vehicle **602** is not carrying any equipment, supplies, or personnel. First vehicle **602** is traveling on a flat surface **610**, according to an exemplary embodiment. Second vehicle **604** is lightly loaded with a cargo **608**, according to an exemplary embodiment. In this exemplary embodiment, cargo **608** can be equipment, supplies and/or personnel. Second vehicle **604** is traveling on a moderate incline surface **612**, according to an exemplary embodiment. Third vehicle **606** is heavily loaded with cargo **608** and is traveling on a steep incline surface **614**, according to this exemplary embodiment.

In FIG. **10**B, the distances between first vehicle **602**, second vehicle **604**, and/or third vehicle **606** has increased because first vehicle **602**, second vehicle **604**, and/or third vehicle has maintained first engine output **616**. In this exemplary embodiment, first vehicle **602** can travel at a higher rate of speed than either second vehicle **604** and/or third vehicle **606** with first engine output **616** because first vehicle **602** is not loaded with cargo **608** and is traveling on flat surface **610**. Similarly, second vehicle **604** can travel at a higher rate of speed than third vehicle **606** with first engine output **616** because second vehicle **604** is less loaded with cargo **608** than third vehicle **616** and is traveling on a surface with less of an incline. In this exemplary embodiment, first vehicle **602**, second vehicle **604**, and/or third vehicle **606** may separate from the convoy by maintaining first engine output **616**, which may place the separated vehicle at increased risk of attack, damage, and/or becoming lost.

In FIG. **10**C, first vehicle **602**, second vehicle **604** and third vehicle **606** have separated by a distance that is greater than a threshold distance, according to an exemplary embodiment. In this exemplary embodiment, if the separation distance is greater than a predetermined threshold, then leader vehicle **100** operator and/or a computer program calculates a second engine output **618**. First vehicle **602** is commanded to operate at second engine output **618**, which is less than first engine output **616**. In this exemplary embodiment, there can be numerous engine outputs with the objective of reducing the separation distance in an optimal time. In this exemplary embodiment, once second vehicle's **604** distance from first vehicle **602** has been reduced to a predetermined amount, then second vehicle **604** is commanded to operate at a third

engine output **622**. Third engine output **622** minimizes the relative distance comparison between the delta third vehicle **606** and second vehicle **604** distance as compared to the delta second vehicle **604** and first vehicle **602** distance.

In FIG. **10**D, a diagnostic vehicle comparison is shown, according to an exemplary embodiment. In this exemplary embodiment, first vehicle **602**, second vehicle **604** and third vehicle **606** are traveling on flat surface **610**. First vehicle **602** and second vehicle **604** have first engine output **616**, while third vehicle **606** has a fourth engine output **615**, according to an exemplary embodiment. Since first vehicle **602**, second vehicle **604** and third vehicle **606** are traveling on the same terrain (e.g., flat surface **610**), operational information regarding first vehicle **602**, second vehicle **604** and third vehicle **606** should be similar and/or identical. In this exemplary embodiment, the on-board diagnostics system of each vehicle should be observing similar health and operational parameters. In this exemplary embodiment, if disparities are detected in the data generated at one of the vehicles relative to the data generated at the other vehicles, this may be a sign that a component of the vehicle is in poor health. Therefore, faults may be detected in components that would otherwise appear to be within normal operating parameters (e.g., maintenance schedule, life expectancy etc.). In should be noted that vehicle health and/or performance characteristics can be oil pressure, tire pressure, engine torque output, engine speed, fuel consumption, engine temperature, coolant level, transmission temperature, transmission speed, transmission fluid level, motor temperature, motor output, motor speed, and/or any other vehicle parameter known to a person skilled in the art.

In an exemplary embodiment, a discrepancy report can be generated based on any detected variations in vehicle performance characteristics. In another exemplary embodiment, a maintenance schedule can be generated based on the discrepancy report.

In FIG. **11**, a flow diagram of the convoy operation procedures **700** is shown, according to an exemplary embodiment. The system is initiated (step **702**). The system determines the number of vehicles to be controlled (step **704**). The system prioritizes the importance of each vehicle (step **706**). The system configures the convoy based on the importance of each vehicle (step **708**). The system controls the vehicles (step **710**). If the system receives a new or modified mission (step **712**), then the system accepts the new or modified mission (step **714**) and returns to step **704**. If the system does not receive a new or modified mission (step **712**), then the system monitors the vehicles' performance (step **716**). Based on the system monitoring the vehicles' performance, the system detects vehicle performance outside of system parameters (step **718**). The system will correct for errors and/or vehicle performance outside of system parameters (step **720**).

Referring to FIG. **12**, one embodiment of an autonomous vehicle **102** is shown. In an exemplary embodiment, vehicle **102** is a tactical wheeled vehicle that may be used in a military context to transport troops, supplies, or any other goods. In an exemplary embodiment, vehicle **102** can have eighteen inches of ground clearance and be capable of traversing rugged terrain. Vehicle **102** may have features such as all-wheel drive, all-wheel steering, independent suspension (all or some of the wheels), and a central tire inflation system. Many of these features make it easier for vehicle **102** to operate autonomously. For example, since vehicle **102** is relatively large, the addition of all-wheel steering allows vehicle **102** to maneuver quickly and with more agility to avoid obstacles, pass through tunnels, etc. Also, the central tire inflation system may be used to help vehicle **102** get unstuck by reducing the air pressure in the tires and thereby increasing the traction of vehicle **102**.

In an exemplary embodiment, vehicle **102** may also be configured to handle about 60% grades and about 30% side slopes while the vehicle **102** is fully loaded. In an exemplary embodiment, vehicle **102** may be capable of carrying about a seven ton payload off-road and about a fifteen ton payload on-road. In another exemplary embodiment, vehicle **102** may also be capable of fording five feet of water, traveling up to and above about 65 miles per hour, and cruising for a range of about 300 miles or more.

In an exemplary embodiment, vehicle **102** may be provided in a dump truck configuration where the bed pivots upward to unload material in the bed of the truck. In another exemplary embodiment, vehicle **102** may also be configured as a wrecker vehicle that is capable of towing disabled vehicles such as tanks or other trucks to be repaired. In another exemplary embodiment, vehicle **102** may also include a flat bed and an articulated lifting system. The lifting system may be configured to move supplies or other goods onto the flat bed. The lifting system folds up near the end of the bed in a stowed position while vehicle **102** is traveling. In an exemplary embodiment, vehicle **102** may include a load handling system that is capable of receiving and securely transporting standard or custom sized shipping containers. In one embodiment, vehicle **102** may be the medium tactical vehicle replacement (MTVR) manufactured by Oshkosh Truck Corporation, Oshkosh, Wis. In this exemplary embodiment, vehicle **102** may include any of the various commercial embodiments of the MTVR such as the cargo truck embodiment (regular and extended), dump truck embodiment, wrecker embodiment, HIMARS resupply vehicle embodiment, tractor embodiment, and/or load handling system embodiment. It should be noted that vehicle **102** can be any vehicle that can utilize the autonomous and/or semi-autonomous features described in this disclosure. It should also be noted that vehicle **102** can be any vehicle that can be deployed in a convoy and/or utilize a leader-follower communication system.

In a military context there are some challenges to and advantageous of using an autonomous vehicle. For example, one of the challenges is that many of the technologies used to sense the terrain around the vehicle rely on the transmission of electromagnetic radiation (e.g., LIDAR, radar). The radiation can be detected by the enemy and used as a signal to guide bombs or other munitions to the autonomous vehicle. Also, the enemy may be able to jam the signals and cause the vehicle to crash or otherwise be disabled. The principle advantage of an autonomous vehicle in a military context is that fewer people need to be put in danger in order to transport supplies and goods.

Although vehicle **102** is described in the context of a military vehicle, it should be appreciated that the subject matter described herein may be used with any of a number of suitable vehicles regardless of whether they are civilian or military vehicles, heavy duty or light duty vehicles, or large or small vehicles. For example, the subject matter described herein may be used with the firefighting vehicles described in some of the documents that are incorporated by reference above.

In an exemplary embodiment, vehicle **102** may be configured to be easily switched from manual operation to autonomous operation. The switchover may be as simple as pressing a button or may involve some amount of mechanical or electrical reconfiguration. In exemplary embodiments, the switchover can occur and/or be initiated remotely. In another exemplary embodiment, the switchover can occur and/or be initiated within vehicle **102** that is part of the convoy. In an

exemplary embodiment, allowing vehicle **102** to be used in both manual and autonomous mode increases the usability of vehicle **102**. For example, in a military context, if vehicle **102** is inoperable in autonomous mode due to enemy fire, vehicle **102** may still be capable of being operated manually. Also, vehicle **102** may be capable of being operated by an operator until vehicle **102** enters a dangerous area (e.g., vehicle approaches the enemy, vehicle **102** enters a hazardous waste area) at which point vehicle **102** may be operated autonomously.

In an exemplary embodiment, vehicle includes a differential GPS unit **154**, a single-plane LIDAR sensors **162**, a multi-plane LIDAR sensors **166**, a first camera **168**, a second camera **170**, a third camera **172**, a roll bar or roll cage **180**, a bumper **182**, a sun shade **186**, and a reflector **188**.

FIG. **13** is a block diagram schematically illustrating a vehicle control system **100** for use with vehicle **102**, according to an exemplary embodiment. In an exemplary embodiment, vehicle control system **100** may include a terrain detection system **104**, a vehicle management system **106**, and a system manager **108**. In an exemplary embodiment, vehicle control system **100** may also includes a plurality of vehicle subsystems **110**, a position sensors **150**, and a terrain sensors **160**. In an exemplary embodiment, vehicle control system **100** can be configured to acquire and process vehicle position information and terrain information from position sensors **150** and terrain sensors **160** to control vehicle **102** autonomously.

Referring to FIG. **20**, certain hardware components of vehicle control system **100** may be positioned under passenger seat **101** of vehicle **102**, according to an exemplary embodiment. In an exemplary embodiment, the hardware components may be packaged in a shock absorbing rack that fits inside passenger seat **101**. In one embodiment, vehicle **102** may include a temperature control system that is configured to heat and/or cool the hardware components. For example, vehicle **102** may be configured to air condition the space under passenger seat **101** to prevent the microprocessors from overheating. In this exemplary embodiment, vehicle **102** may be configured to heat and/or cool the space that contains the hardware components using the heating and cooling systems used to control the climate in the cab of vehicle **102**.

In an exemplary embodiment, terrain detection system **104** (see FIG. **13**) is used to detect obstacles around vehicle **102** (e.g., rocks, sudden drop-offs, trees, and so forth) and/or detect a path for vehicle **102** to travel (e.g., detect a road). In this exemplary embodiment, terrain detection system **104** receives and analyzes input from terrain sensors **160** to identify obstacles and a path for vehicle **102** to follow. Terrain data from the various terrain sensors **160** is merged into a single database that is used to plan the path of vehicle **102**.

In an exemplary embodiment, terrain detection system **104** includes a first LIDAR system **103**, a second LIDAR system **105**, and a vision system **107**. In an exemplary embodiment, first LIDAR system **103** receives input from two single-plane LIDAR sensors **162**, **164** coupled to vehicle **102**. In an exemplary embodiment, second LIDAR system **105** receives input from two multi-plane LIDAR sensors **166** coupled to vehicle **102**. In this exemplary embodiment, vision system **107** receives input from three cameras **168**, **170**, **172** coupled to the front of vehicle **102**. It should be appreciated that the number, configuration, and types of terrain sensors used to provide input to terrain detection system **104** may be varied widely. For example, terrain detection system **104** may include a radar system, or may include additional LIDAR systems, or may include a rotating array of LIDAR sensors to provide a 360° view of the surrounding terrain. Likewise, terrain sensors **160** may include a radar antenna, various cameras (still and/or video cameras), and multiple LIDAR sensors (e.g., single plane or multi-plane LIDAR systems). Also, vehicle **102** may include any of these sensors in any configuration coupled to the rear of vehicle **102** to facilitate operation of vehicle **102** in reverse.

In an exemplary embodiment, terrain sensors **160** may be mounted to vehicle **102** using any suitable mounting structure. For example, as shown in FIG. **23**, terrain sensors **160** may be mounted to vehicle **102** using telescopically adjustable mounts **157** that move in and out via a threaded engagement system. In an exemplary embodiment, adjustable mounts **157** allow for precise adjustment of terrain sensors **160** but also keep terrain sensors **160** in a fixed position after the adjustment has been performed. In an exemplary embodiment, adjustable mounts **157** may be used to hold any of terrain sensors **160** and/or position sensors **150** in place. In an exemplary embodiment, terrain sensors **160** and/or position sensors **150** may be coupled to roll bar or roll cage **180** of vehicle **102**. In an exemplary embodiment, roll bar **180** may also serve as a protective conduit for the sensor communication wires and power wires to travel.

As shown in FIGS. **14** and **15**, LIDAR sensors **162**, **164** are coupled to the outside edges of roll bar **180** at the front of vehicle **102**, according to an exemplary embodiment. In an exemplary embodiment, LIDAR sensors **162**, **164** are positioned so that they point about 10 degrees down and about 25 degrees outward to the side of vehicle **102**. In this exemplary embodiment, positioning of LIDAR sensors **162**, **164** in this fashion provides good coverage of the terrain to the front and the side of vehicle **102**. In this exemplary embodiment, the positioning of LIDAR sensors **162**, **164** in this fashion allows vehicle **102** to make tight turns while still having some information regarding the terrain in the direction that vehicle **102** is turning. It should be appreciated that LIDAR sensors **162**, **164** may be positioned at any suitable position to provide the most useful information to vehicle control system **100**. To some extent, the orientation of LIDAR sensors **162**, **164** depends on the type of vehicle **102** being used (e.g., taller vehicles may require the LIDAR sensors to be pointed down more). In an exemplary embodiment, LIDAR sensors **162**, **164** may be configured to be positioned about 0 to 20 degrees down and about 0 to 90 degrees outward to the side of vehicle **102**. In another exemplary embodiment, LIDAR sensors **162**, **164** may be configured to scan a 100 degree scan area with a 1 degree resolution. Suitable LIDAR sensors may be obtained from SICK, Inc., having an office in Minneapolis, Minn. located at 6900 West 110^{th} street, as model number SICK LMS-291.

In an exemplary embodiment, first LIDAR system **103** may be configured to detect positive obstacles (e.g., obstacles that protrude upward) and negative obstacles (e.g., road edges, cliffs, etc.). In an exemplary embodiment, the positioning of LIDAR sensors **162**, **164** can be configured to allow for detection of both positive and negative obstacles. In an exemplary embodiment, first LIDAR system **103** processes the scan data from LIDAR sensors **162**, **164** to identify positive and negative obstacles. In an exemplary embodiment, positive obstacles may be detected by translating the raw scan data from a sensor level coordinate framework to a local level coordinate framework and comparing the relative heights of neighboring scan points. In an exemplary embodiment, a history of scan data can be used to effectively map the surface in front of vehicle **102**. In an exemplary embodiment, an obstacle is identified if the surface as detected by LIDAR sensors **162**, **164** protrudes upward above a threshold amount.

In this exemplary embodiment, the detection threshold may be set at a minimum obstacle height based on the capabilities of vehicle **102**. For example, vehicle **102** as shown in FIG. **12** may be configured to have a detection threshold of about eighteen inches since vehicle **102** can drive over any obstacle that is under eighteen inches, according to an exemplary embodiment. In an exemplary embodiment, a convex hull algorithm may be used to define the outermost edge of the obstacle. Once the obstacle and its outermost edges have been identified, vehicle control system **100** can store the obstacle in the database.

In an exemplary embodiment, first LIDAR system **103** may detect negative obstacles in a manner that is similar to detecting positive obstacles. In an exemplary embodiment, the data map of the surface in front of vehicle **102** may be searched using an algorithm that identifies any negative height discontinuities. In this exemplary embodiment, any identified negative height discontinuities are evaluated further to determine if the edge of the discontinuity is a continuation of a previously detected edge.

It should be appreciated that many aspects related to first LIDAR system **103** and single-plane LIDAR sensors **162**, **164** may be modified in a variety of ways. For example, instead of using single-plane LIDAR sensors, multi-plane LIDAR sensors may be used. It should also be noted that more or less than two LIDAR sensors **162**, **164** may be used (e.g., one or more additional LIDAR sensors may be coupled to the rear of vehicle **102** to assist with backing vehicle **102**). Also, LIDAR sensors **162**, **164** may be coupled to vehicle **102** at any suitable location such as the cab, fender, and so forth.

Referring to FIGS. **14**, **16**, and **18**, multi-plane LIDAR sensors **166** used with second LIDAR system **105** are coupled to vehicle **102** near bumper **182**, according to an exemplary embodiment. In an exemplary embodiment, each of LIDAR sensors **166** are four plane scanner devices that are used primarily for positive obstacle detection at long and close range. In an exemplary embodiment, each LIDAR sensor **166** is positioned horizontally so that two planes scan toward the ground and two planes scan toward the sky. In an exemplary embodiment, LIDAR sensors **166** each have a range of about 80 meters, a resolution of about 0.25 degrees, and a 170 degree scan area. In an exemplary embodiment, the large scan area allows LIDAR sensors **166** to be used to identify obstacles around upcoming turns.

As shown in FIG. **12**, vehicle **102** may be configured to include only a single LIDAR sensor **166**. However, it may be desirable to include at least two LIDAR sensors **166** so that in case one of LIDAR sensors **166** is damaged or otherwise unable to be used, the remaining LIDAR sensor **166** can still provide information to vehicle control system **100**.

In an exemplary embodiment, second LIDAR system **105** is configured to receive scan data from LIDAR sensors **166** and identify obstacles by searching for large positive slopes in the scan data. In an exemplary embodiment, the obstacle detection algorithm used to process the scan data in first LIDAR system **103** is similar to the obstacle detection algorithm used to process the scan data in second LIDAR system **105**. In one embodiment, the same algorithm may be used to process scan data from both sources. In an exemplary embodiment, second LIDAR system **105** may be configured to translate the scan data from the coordinate frame of the particular LIDAR sensor **166** to a local level coordinate frame and stored in the database. In an exemplary embodiment, since LIDAR sensors **166** are multi-plane devices, the scan data from each plane may be compared to each other to aid in detecting obstacles and false positives. In an exemplary embodiment, since the scan data has been translated into a local level coordinate frame, the position of obstacles identified in the scan data from LIDAR sensors **166** can be compared to the position of obstacles identified using the other terrain sensors **160** and to the position of vehicle **102**.

In an exemplary embodiment, LIDAR sensors **162**, **164** and LIDAR sensors **166** may be configured to scan the same area or different areas in front of vehicle **102**. In one embodiment, LIDAR sensors **162**, **164**, **166** are used to scan overlapping areas in front of and to the side of vehicle **102**. In another embodiment, LIDAR sensors **162**, **164** may be configured to scan for obstacles that are 0 to 20 meters in front of vehicle **102** and LIDAR sensors **166** may be configured to scan for obstacles that are 20 to 60 meters in front of vehicle **102**. In an exemplary embodiment, obstacles detected by LIDAR sensors **162**, **164**, **166** may be put into an obstacle database that vehicle control system **100** uses to plan the path of vehicle **102**.

In an exemplary embodiment, vision system **107** may be based on a multi stereoscopic vision system. In this exemplary embodiment, vision system **107** can receive inputs from cameras **168**, **170**, **172**, which are coupled to a horizontal portion of roll bar **180**. In an exemplary embodiment, cameras **168**, **170**, **172** are coupled to vehicle **102** in a secure manner to prevent cameras **168**, **170**, **172** from becoming dislodged during operation of vehicle **102**. This may especially be a problem when vehicle **102** operates in an off-road environment.

In an exemplary embodiment, cameras **168**, **170**, **172** are coupled to vehicle **100** so that they are asymmetrically spaced apart from each other. As shown in FIG. **15**, cameras **168**, **172** are positioned about 1.5 meters apart from each other while camera **170** is positioned about 0.5 meters from camera **168**. In one embodiment, cameras **168**, **170**, **172** may be video cameras that transmit images using ordinary light to vision system **107**. In another embodiment, cameras **168**, **170**, **172** may be still cameras that periodically take pictures at the same time. The pictures may be transmitted to vehicle control system **100** where the pictures are processed to identify obstacles and/or find a path for vehicle **102**. In yet another embodiment, cameras **168**, **170**, **172** may be infrared cameras (either video or still). In yet another embodiment, cameras **168**, **170**, **172** may be video cameras capable of providing video streams at 10 Hz (640×480, color with Bayer pattern).

In an exemplary embodiment, the orientation of cameras **168**, **170**, **172** may be calibrated using a graduated grid. This may be done to fix the three degrees of freedom specifying cameras **168**. **170**, **172** orientation to known values. In one embodiment, the yaw and roll angles of cameras **168**, **170**, **172** are fixed at zero. This may help to reduce the processing requirements of the images taken by cameras **168**, **170**, **172**. In an exemplary embodiment, the pitch angle of cameras **168**, **170**, **172** may be chosen so that cameras **168**, **170**, **172** frame a small portion over the horizon (to limit direct sunlight) and frame the terrain at about four meters from vehicle **102**.

It should be appreciated that cameras **168**, **170**, **172** may be coupled to vehicle **102** in any suitable fashion and location. For example, additional cameras may be coupled to the rear and side of vehicle **102** to facilitate backing and turning of vehicle **102**. Also, the pitch, yaw, and roll of cameras **168**, **170**, **172** may be adjusted in any suitable fashion.

As shown in FIG. **13**, cameras **168**, **170**, **172** send three video streams to vision system **107** via fire wire connections. In an exemplary embodiment, vision system **107** selects which stereo pair of video streams to use depending on the speed of vehicle **102**. In an exemplary embodiment, by selecting different pairs of cameras, vision system **107** can obtain images from stereo pairs of cameras having different base-

lines (e.g., the distance between the cameras). It is desirable to have the ability to vary the baseline because when the baseline is wider, vision system **107** is able to more accurately determine the distance to an object, but as the baseline increases, it makes it more difficult to stereo match objects (especially close objects) in the images because the objects are viewed at very different angles. Therefore, vision system **107** is configured to receive the video streams from cameras **168**, **172** when vehicle **102** is traveling at high speeds so that vision system **107** can accurately identify and measure the distance of obstacles that are a long distance away, according to an exemplary embodiment. In an exemplary embodiment, when vehicle **102** is traveling at medium speeds and obstacles are not approaching as quickly, vision system **107** is configured to receive the video streams from cameras **170**, **172**. In another exemplary embodiment, when vehicle **102** is traveling at slow speeds, vision system **107** is configured to receive the video streams from cameras **168**, **170** in that order. This configuration allows vision system **107** to obtain images from cameras having a wide baseline when vehicle **102** is moving at high speeds, obtain images from cameras having a medium baseline when vehicle **102** is moving at medium speeds, and obtain images from cameras having a short baseline when vehicle **102** is moving at slow speeds.

In an exemplary embodiment, the use of at least three cameras **168**, **170**, **172** fixed in position provides a mechanically robust system that is capable of providing images from different combinations of cameras **168**, **170**, **172**. In other embodiments, vision system **107** may be configured to receive input from two cameras where at least one of the cameras rotates and tilts as the speed of vehicle **102** changes instead of using the three camera configuration. In this exemplary embodiment, the moving cameras provide more accurate distance estimation and better object matching versus a two camera configuration where the cameras do not move. However, the configurations that use at least three fixed cameras allows vision system **107** to receive different combinations of video streams from cameras having different baselines and they do not rely on movement of the cameras—an area that is more prone to failure and/or that may introduce variations in the video streams.

It should be appreciated that vehicle control system **100** may include additional LIDAR systems or may combine first LIDAR system **103** and second LIDAR system **105** into a single LIDAR system. It should also be appreciated that the data from the LIDAR and vision systems may be processed by a single processor and/or single software program. It should also be appreciated that in other embodiments the data from each LIDAR system and vision system may be initially processed using a separate system. The output from each system may then be compared to create a database of obstacles. It should also be appreciated that each of these systems may be provided as a separate module that may optionally be included with the vehicle control system **100**. Providing each system as a separate module may allow for greater flexibility in selecting the components of vehicle control system **100** to use with a particular type of vehicle.

In an exemplary embodiment, vision system **107** may be used to detect obstacles and detect a path of travel for vehicle **102**. In an exemplary embodiment, the images provided by the video streams are subjected to V-disparity image analysis to determine the average terrain slope in front of vehicle **102**. In an exemplary embodiment, slope information is then used for both obstacle detection and path detection. Any significant deviation from the average smooth slope detected previously is identified as an obstacle, according to an exemplary embodiment. The exact location of the obstacles is then obtained via stereo triangulation between the two views of the obstacle, according to this exemplary embodiment. This method provides a fairly precise position of the obstacle. However, vehicle control system **100** may also compare the position of the obstacle as determined by vision system **107** with the position of the obstacle as determined by first LIDAR system **103** and/or second LIDAR system **105** to provide an even more accurate position of the obstacle, according to an exemplary embodiment.

In this exemplary embodiment, vision system **107** can detect thin vertical posts such as fence posts. Although vision system **107** may be capable of detecting small obstacles, vision system **107** may be tuned with high thresholds to reduce the number of false positives, according to an exemplary embodiment. In other words, the capability of detecting small obstacles may be traded for a higher robustness of detection, according to an exemplary embodiment.

In an exemplary embodiment, vision system **107** may also uses image disparity analysis as the initial step in detecting a path for vehicle **102** to travel. Image disparity analysis is used to compute the area in front of vehicle **102** which features a smooth slope, which is known as the free-space, according to an exemplary embodiment. In an exemplary embodiment, free space is obtained using standard image warping to localize deviations from a smooth road surface.

In an exemplary embodiment, vision system **107** combines the free space with other features of the images such as similarity in texture, similarity in color, similarity in shape to construct a representation of a path to follow. The path detection algorithm of vision system **107** is also configured to indicate whether the path is straight so that vehicle **102** may increase speed, according to an exemplary embodiment. When a curved path is present, vehicle **102** is configured to slow down, according to an exemplary embodiment.

In an exemplary embodiment, cameras **168**, **170**, **172** may be configured to compensate for different lights levels using automatic gain control, which allows cameras **168**, **170**, **172** to sense the environment including direct sunlight into cameras **168**, **170**, **172**. In an exemplary embodiment, obstacles may be detected up until they enter the oversaturated area. In an exemplary embodiment, cameras **168**, **170**, **172** may also be provided with sun shades **186** which reduce the amount of direct sunlight that hits cameras **168**, **170**, **172** to avoid oversaturation and reflections due to dirty glass. In an exemplary embodiment, vehicle **102** may also include shields or reflectors **188** that reflect sunlight away from the area of cameras **168**, **170**, **172** and LIDAR sensors **162**, **164** to prevent these devices from becoming too hot. In one embodiment, shield **188** is a reflective diamond plating material (e.g., aluminum or steel). Additional shields **189** may be provided in the vicinity of LIDAR sensors **166**, according to an exemplary embodiment.

In an exemplary embodiment, vehicle **102** may include a cleaning system that is configured to clean the lenses on cameras **168**, **170**, **172** and/or the lenses of LIDAR sensors **162**, **164**, **166**. In an exemplary embodiment, the cleaning system may include one or more nozzles that are aimed at the lenses. The nozzles may be configured to dispense any suitable gas or liquid onto the lens to clean it, according to exemplary embodiments. In one embodiment, the cleaning system may be configured to include an air knife that directs high velocity bursts of air onto the lenses to remove any dust or other debris. The use of air may be desirable since liquids may attract dust and dirt and/or leave spots on the lenses. In another embodiment, the cleaning system may be configured to direct water or another liquid (e.g., windshield washer fluid, and so forth) towards the lens. The cleaning system may

then direct air over the lens to quickly dry the lens and remove the water, according to an exemplary embodiment. The air may be supplied by a compressed air system that is included as part of vehicle **102**, according to an exemplary embodiment. In another embodiment, the cleaning system may comprise a cleaning controller, one or more valves (e.g., an array of valves), and a washer tank. The cleaning controller may be configured to electronically control the valves to direct liquid and/or air through the nozzles and onto the lenses, according to another exemplary embodiment.

Referring to FIG. **13**, vehicle management system **106** includes a path planning module **200**, a vehicle control module **202**, a navigation module **204**, and an information database **206**, according to an exemplary embodiment. In an exemplary embodiment, vehicle management system **106** is configured to receive input from terrain detection system **104** and control vehicle **102** to reach a desired location. Vehicle management system **106** may also include a modeling and simulation system that is used to determine the capabilities of vehicle **102** under different circumstances, according to an exemplary embodiment. The modeling and simulation system may be similar to that described in U.S. Prov. Pat. App. No. 60/723,363, entitled "Vehicle Control System and Method," filed on Oct. 4, 2005, which is hereby incorporated herein by reference in its entirety.

In an exemplary embodiment, navigation module **204** may be configured to compute the present position of vehicle **102** and perform dead reckoning navigation. Dead reckoning navigation may be needed when vehicle **102** is unable to receive GPS signals (e.g., when vehicle **102** is in a tunnel, etc.), according to an exemplary embodiment. In an exemplary embodiment, navigation module **204** may also include navigation related information such as maps (e.g., road maps, topographical maps, and the like), aerial photographs, a list of GPS waypoints, and the like. This information may be utilized by navigation module **204** to drive vehicle **102** to its destination, according to an exemplary embodiment. In one embodiment, each mission may be planned out by setting a plurality of GPS waypoints and a preferred path of travel that vehicle **102** should take until it reaches its final destination. The GPS waypoints and preferred path may be loaded into navigation module **204** prior to vehicle **102** embarking on the mission, according to an exemplary embodiment. During the mission, vehicle control system **100** is configured to drive vehicle **102** to successive waypoints while trying to stay on the preferred path as much as possible while still avoiding any obstacles that may present themselves, according to an exemplary embodiment.

In an exemplary embodiment, navigation module **204** receives input from position sensors **150**. In the embodiment shown in FIG. **13**, position sensors **150** include dual GPS/inertial measurement units (IMU) **152** and differential GPS unit **154**. In an exemplary embodiment, GPS/IMU units **152** may include a six-axis inertial measurement system which includes three angular rate sensors (gyros) and three accelerometers. The three accelerometers are all mounted at 90 degrees to each other, and the three angular rate sensors are mounted at the same angles as their respective accelerometers, according to an exemplary embodiment. Together they give full 3D motion measurement of vehicle **102**. In an exemplary embodiment, GPS/IMU units **152** are also capable of receiving GPS signals directly from GPS satellites and differential GPS information from differential GPS unit **154**. The information provided to navigation module **204** is used to chart the course of vehicle **102** at a high level, according to an exemplary embodiment. In an exemplary embodiment, vehicle **102** attempts to follow the course as much as possible while avoiding obstacles and attempting to stay on a road or other path.

In an exemplary embodiment, input from the inertial measurement system may be used by vehicle control system **100** to perform dead reckoning navigation. The inertial position information provided to vehicle control system **100** may be supplemented with other data such as wheel speed and time traveled (e.g., to determine distance traveled during dead reckoning navigation), wheel speed and steering angle (e.g., to determine direction the vehicle **102** is going during dead reckoning navigation), or any other information that may be useful to determine the position of vehicle **102**. Also, the inertial position information may be used to measure the pitch and roll of vehicle **102**, according to an exemplary embodiment. In one embodiment, vehicle control system **100** may be configured to perform dead reckoning navigation using sensed wheel speed and wheel angle for those situations where the GPS and IMU units are not operational. In an exemplary embodiment, GPS/IMU units **152** may be positioned on the approximate centerline of vehicle **102** (e.g., in the floor of the cab). In one embodiment, GPS/IMU units **152** may be obtained from Oxford Technical Solutions, Ltd., having an office in Dearborn, Mich., as part number OXTS RT3100.

In the embodiment shown in FIG. **13**, vehicle **102** includes two GPS/IMU units **152**. In this exemplary embodiment, two of the units **152** may be provided so that the position information (both GPS and inertial) received from each unit can be averaged to provide a more accurate and robust calculation of the position of vehicle **102**. Also, if one of GPS/IMU units **152** fails, remaining GPS/IMU unit **152** could still be used to provide position information to vehicle control system **100**, according to an exemplary embodiment. In another exemplary embodiment, vehicle control system **100** may be able to determine that one of GPS/IMU units **152** has failed when, for example, unit **152** stops providing input or the input is so different from the position information provided by the other position sensors **150** and terrain sensors **160** that the input can no longer be trusted. If vehicle control system **100** determines that one of GPS/IMU units **152** has failed, vehicle control system **100** uses the remaining GPS/IMU unit **152**, according to an exemplary embodiment.

In an exemplary embodiment, differential GPS unit **154** is configured to receive differential corrections and send them to GPS/IMU units **152**. In an exemplary embodiment, differential GPS unit **154** may be configured to receive Beacon, SBS/WAAS, and/or Omnistar corrections, as well as any other suitable corrections. It should be appreciated that the combination of GPS units may be varied widely. For example, GPS/IMU units **152** may be capable of receiving the differential corrections directly without using a separate receiver. Likewise, GPS/IMU units **152** may be split into two units so that the GPS unit is separate from the IMU unit.

In an exemplary embodiment, vehicle control module **202** is configured to interface with vehicle subsystems **110** to allow the vehicle components to be controlled by vehicle management system **106**. As shown in FIG. **13**, vehicle subsystems **110** may include a steering system **112**, a braking system **116**, a throttle system **120**, and a transmission system **124**.

In an exemplary embodiment, steering system **112** may include a servo drive **113** and a corresponding servomotor **114** that is in communication with servo drive **113**. Servo drive **113** may be configured to receive and process position commands from vehicle control system **100** and provide corresponding outputs (e.g., an analog voltage or current) to

servomotor **114**, according to an exemplary embodiment. In response, servomotor **114** may drive one or more associated wheels of vehicle **102** to a desired steering angle, according to an exemplary embodiment. In an exemplary embodiment, steering system **112** may also include one or more wheel angle sensors that are used to determine the steering angle of a wheel of vehicle **102** and provide feedback to vehicle control system **100** as to the current steering angle of the wheel. In another embodiment, servomotor **114** may include an integrated high-resolution encoder that is used to control the steering angle of vehicle **102**. It should also be appreciated that the encoder may be coupled to steering system **112** at any location that is capable of providing a reliable and accurate measurement of the steering angle of the wheels (e.g., steering column, etc.).

In one embodiment, servomotor **114** is coupled directly to the steering gearbox of vehicle **102**. The steering gearbox may be configured to have dual inputs so that servomotor **114** and the hand wheel can both be connected to the steering gear, according to an exemplary embodiment. This allows steering control of vehicle **102** to be switched between manual mode (operated by a driver) and autonomous mode without disassembling the steering system, according to an exemplary embodiment.

In an exemplary embodiment, steering system **112** may also be an all-wheel steering system, or in the case of 6×6 wheeled vehicles, 8×8 wheeled vehicles and so on, steering system **112** may be configured to steer one, two, three, four, or more sets of wheels. In an exemplary embodiment, steering system **112** may be configured similarly to any of the steering systems described in U.S. Pat. No. 6,882,917 (incorporated by reference herein previously).

In an exemplary embodiment, braking system **116** may include an anti-lock brake system. The anti-lock brake system may include an anti-lock brake control system and anti-lock brakes coupled to one or more wheels of vehicle **102**, according to an exemplary embodiment. In an exemplary embodiment, braking system **116** may be configured to receive braking commands, such as a "brake ON" command, from vehicle control system **100**. In response, braking system **116** may apply braking pressure to one or more wheels of vehicle **102** to, for example, reduce the speed of vehicle **102** or bring vehicle **102** to a stop. According to an exemplary embodiment, braking pressure for braking system **116** may be provided by a compressed-air system. The compressed-air system may include, for example, an air compressor coupled to the power train of vehicle **102** (such as via gears, v-belt, etc. to convey rotational mechanical energy to the air compressor to be converted to air pressure), and one or more air pressure tanks for storing compressed air from the air compressor.

It should be noted that for purposes of this disclosure, the term "coupled" means the joining of two members directly or indirectly to one another. Such joining may be stationary in nature or movable in nature. Such joining may be achieved with the two members or the two members and any additional intermediate members being integrally formed as a single unitary body with one another or with the two members or the two members and any additional intermediate member being attached to one another. Such joining may be permanent in nature or alternatively may be removable or releasable in nature.

As shown in FIG. **13**, vehicle control system **100** may be configured to communicate with braking system **116** via Ethernet to a proportional voltage to pressure valve, according to an exemplary embodiment. In an exemplary embodiment, braking system **116** may be configured to apply the service brakes in an amount that is proportional to the deviation between the actual speed of vehicle **102** and the desired speed of vehicle **102**. It should be appreciated, however, that numerous other configurations may also be used to control braking system **116**. For example, vehicle control system **100** may be configured to control braking system **116** using more mechanical components such as a hydraulic actuator that operates the brakes through the system, according to an exemplary embodiment.

In an exemplary embodiment, braking system **116** may also include an engine brake. Braking system **116** in combination with throttle system **120** may be used to control the speed of vehicle **102**, according to an exemplary embodiment. Typically, the speed of vehicle **102** is controlled solely using the throttle. However, the service brakes and the engine brake may be used to control the speed of vehicle **102** on steep grades and/or to manage the speed that vehicle **102** decelerates.

In an exemplary embodiment, throttle system **120** may include an engine control module and a throttle actuator. The engine control module may be configured to receive and process throttle commands from vehicle control system **100** and provide corresponding outputs (e.g., an analog voltage or current) to the throttle actuator, according to an exemplary embodiment. In response, the throttle actuator may adjust the rotational speed of an engine coupled to the drive train of vehicle **102** to achieve a desired speed of vehicle **102**, according to an exemplary embodiment. The engine control module may be configured to determine the speed of vehicle **102** (e.g., using a tachometer feedback signal) and provide feedback to vehicle control system **100** as to the current speed of vehicle **102**, according to an exemplary embodiment. In other embodiments, the speed of vehicle **102** may be determined using feedback from transmission system **124** or by measuring the rotation of a drive shaft, or some other component of the power train of vehicle **102**. In one embodiment, vehicle control system **100** and/or the engine control module may use a pulse width modulated (PWM) signal to provide very precise control of the throttle.

In an exemplary embodiment, throttle system **120** may be configured so that reset conditions to the throttle position are provided for transmission up shift and down shift and to activate the engine brake. In an exemplary embodiment, since the engine brakes are activated when the engine is idling, throttle position overrides are used whenever the engine brakes are active. Throttle position faders are used to reactivate the throttle position control when the engine brake is disabled, according to an exemplary embodiment.

In an exemplary embodiment, transmission system **124** may include the engine control module and a transmission mechanically coupled to the engine of vehicle **102**. In combination, transmission system **124** and the engine of vehicle **102** form the power train of vehicle **102**. The engine control module may be configured to receive and process gear change commands from vehicle control system **100** and provide corresponding outputs (e.g., an analog voltage or current) to transmission system **124**. In response, the transmission may change gears to achieve a desired rotational speed of the power train of vehicle **102**. In another embodiment, transmission system **124** may include a transmission control module that is separate from the engine control module. The transmission control module may be in communication with the engine control module so that information required for shifting gears and so forth can be communicated between the transmission control module and the engine control module.

As shown in FIG. **13**, vehicle subsystems **110** may also include an emergency stop functionality **127**, according to an exemplary embodiment. In an exemplary embodiment, emer-

gency stop functionality **127** may be any suitable switch configured to provide, for example, stop, pause, or run commands to vehicle control system **100** to either stop, temporarily interrupt, or initiate the operation of vehicle **102**. In one embodiment, emergency stop functionality **127** may cause a full brake command to be provided to braking system **116**. The full brake command results in the service brakes being applied in full to stop vehicle **102** as quickly as possible, according to an exemplary embodiment.

In an exemplary embodiment, vehicle subsystems **110** may also include an odometer **128**. In this exemplary embodiment, odometer **128** may be used to provide information regarding the movement of vehicle **102** (e.g., distance traveled) to vehicle control system **100** in order to enhance the ability of vehicle control system **100** to determine the position or movement of vehicle **102**. In an exemplary embodiment, odometer **128** may also be used by vehicle control system **100** to perform dead reckoning navigation.

In an exemplary embodiment, path planning module **200** is configured to determine the desired trajectory of vehicle **102** and provide that trajectory to vehicle management system **106**. In an exemplary embodiment, the trajectory of vehicle **102** includes a desired path along the ground as well as the desired speeds and boundary area. The desired trajectory may be determined using path and speed constraints defined before vehicle **102** begins operating autonomously (e.g., premission planning stage), according to an exemplary embodiment. As mentioned above in connection with navigation module **204**, the route that vehicle **102** follows may be defined beforehand and loaded into vehicle control system **100**, according to an exemplary embodiment. For example, the route may be defined in terms of a series of waypoints that define a path along the ground, a path boundary, and/or speed constraints for each section of the path. In an exemplary embodiment, path planning module **200** provides reactive path corrections to this nominal path to account for current conditions, such as vehicle dynamic limits, obstacles (positive obstacles such as large rocks, trees, etc. and negative obstacles such as road edges, drop-offs, and cliffs), terrain grade, and so forth.

In one embodiment, path planning module **200** may be configured to use a tree algorithm that branches from the base at the current waypoint. The tree build function may be constrained by the pre-defined path boundary and/or speed so that the resulting tree is not too large to process. Branches of the tree are computed using a model of vehicle **102** (e.g., steering system and vehicle dynamics) to ensure that the candidate paths are drivable. One potentially suitable model is described in U.S. Prov. Pat. App. No. 60/723,363, entitled "Vehicle Control System and Method," filed on Oct. 4, 2005, which is hereby incorporated herein by reference in its entirety. The tree algorithm may be derived from the Rapidly-exploring Random Tree (RRT) path planner where the growth of the tree is limited to a fixed number of branches (levels), according to an exemplary embodiment.

In an exemplary embodiment, the tree represents a series of candidate paths for vehicle **102** to travel along. In an exemplary embodiment, vehicle control system **100** selects a path from the various candidate paths based on a scoring algorithm that considers distance from the route centerline, path curvature, obstacle avoidance, boundary area constraints, and so forth. Path planning module **200** may generate at least 100 candidate paths, at least 1000 candidate paths, or at least about 2000 candidate paths each planning cycle, according to exemplary embodiments. In an exemplary embodiment, path planning module **200** performs a path analysis each time a waypoint is reached. Path planning module **200** may also be configured to adjust the maximum speed of vehicle **102** to account for path geometry and current conditions, according to an exemplary embodiment. Path planning module may further be configured to adjust the maximum speed of at least one of a single vehicle, a few vehicles, multiple vehicles, and/or a plurality of vehicles to account for at least one of a single vehicle, a few vehicles, multiple vehicles, and/or a plurality of vehicles attempting to reenter the convoy.

In an exemplary embodiment, the initial desired speed may be set to the maximum determined during the pre-mission planning stage. The speed management component of path planning module **200** may be configured to adjust the initial set speed depending on conditions, according to various exemplary embodiments. In one embodiment, the speed management component of path planning module **200** may be configured to reduce the maximum speed of each section of the path depending on the current conditions (e.g., obstacles, complex terrain, hazardous terrain, at least one vehicle has separated from the convoy, a threat being detected and/or any combination thereof.).

In another embodiment, path planning module **200** may be configured to continually calculate and adjust the path while vehicle **102** is traveling (e.g., real-time path planning). In yet another embodiment, path planning module **200** may be configured to reevaluate the path if vehicle **102** encounters a situation that prevents vehicle **102** from continuing on the original path (e.g., a washed out road, fallen tree, rock slide, etc.). In this situation, path planning module **200** may be configured to determine the best way for vehicle **102** to proceed to the waypoint. Path planning module **200** may include or have access to some of the same information that may be included in navigation module **204** such as topographical maps, road maps, aerial or satellite images, and so forth, to allow path planning module **200** to determine the best path for vehicle **102**. It should be noted that the various embodiments with a vehicle could be utilized with one vehicle, a few vehicles, multiple vehicles, a plurality of vehicle or a convoy of vehicles.

FIG. **24** shows a graphical representation of a path generated by path planning module **200**, according to an exemplary embodiment. In FIG. **24**, vehicle **102** is represented by the long rectangular box. In an exemplary embodiment, a sequence of boxes **208** represents the path that is loaded into vehicle management system **106** before vehicle **102** begins operating autonomously. In an exemplary embodiment, a first real-time path **210** generated by path planning module **200** is shown. FIG. **24** also shows obstacles **212** detected by terrain detection system **104**. As shown in FIG. **24**, first real-time path **210** of vehicle **102** is adjusted to an actual path **225** by moving to the right the center of the pre-loaded path to avoid obstacles in the turn. The data boxes (e.g., control data, command response, state data, path data) in FIG. **24** show data associated with first real-time path **210**, actual path **225**, vehicle state, and control state of vehicle **102**.

In FIG. **25**, an illustration of a second real-time path **224** generated by path planning module **200**, which shows obstacles **222** detected using first LIDAR system **103**. Similarly, FIG. **26** is an illustration of a third real-time path generated by path planning module **200**, which shows obstacles **228** detected using second LIDAR system **105**.

In an exemplary embodiment, vehicle management system **106** controls the movement of vehicle **102** along the path by providing wheel angle commands to steering system **112**. In an exemplary embodiment, the wheel angle commands move vehicle **102** along the path defined by path planning module **200**. This may be accomplished by computing deviations

from the desired path and converting the deviations into steer angle commands that are sent to the steering servo, according to an exemplary embodiment.

In an exemplary embodiment, vehicle management system **106** may include a capture steering mode and a track steering mode. The capture steering mode refers to the steering mode that is used based on the pre-loaded path data, according to an exemplary embodiment. The track steering mode refers to the steering mode that is used during normal operation, according to an exemplary embodiment. Capture and track steering modes may be automatically selected based on current conditions, according to an exemplary embodiment.

In an exemplary embodiment, the capture steering mode uses course error as the control parameter. In another exemplary embodiment, vehicle management system **106** creates a steer angle command that aligns the ground track of vehicle **102** with the direct bearing to the next waypoint. This type of control may be referred to as homing control. In an exemplary embodiment, capture steering mode will be used when vehicle **102** first begins autonomous operation.

The track steering mode uses linear cross track deviation and cross track deviation rate to align vehicle's **102** path along the ground with the waypoint course, according to an exemplary embodiment. Track angle error and steer angle command limiters may be used to limit the commanded steer angle to values that are achievable by vehicle **102**, according to an exemplary embodiment. In another exemplary embodiment, the command limiters incorporate vehicle **102** dynamic limits with margins built in to ensure that vehicle **102** does not get into an unsafe condition. This may also mean that vehicle **102** operates at levels below its maximum dynamic capability when in autonomous mode, according to this exemplary embodiment. In another exemplary embodiment, vehicle management system **106** may also anticipate turns so that the transition between traveling between waypoints may be accomplished without overshoots.

In an exemplary embodiment, vehicle management system **106** is configured to monitor and dynamically change to conditions using information from path planning module **200**, navigation module **204**, vehicle control module **202**, and information database **206**. In another exemplary embodiment, vehicle management system **106** may be configured to handle a number of situations that may arise during autonomous operation. When the situation occurs, vehicle management system **106** is configured to proceed through certain operations to address the situation.

In exemplary embodiments, examples of situations that may arise include:

(1) transition to and from e-stop state—when the e-stop is activated, vehicle management system **106** is configured to stop vehicle **102**. When the e-stop is deactivated, vehicle management system **106** is configured to initiate normal operation;

(2) no valid path ahead—vehicle **102** is commanded to stop and wait for vehicle management system **106** to obtain a valid path. If no valid path is found vehicle management system **106** will back vehicle **102** up and try again;

(3) obstacle detected behind vehicle **102** while backing up—vehicle management system **106** stops vehicle **102** and initiates normal operation of vehicle **102** to find a valid path ahead;

(4) a large course change requiring a back up maneuver—vehicle management system **106** operates vehicle **102** around a three point turn;

(5) narrow tunnel—vehicle management system **106** guides vehicle **102** through the tunnel primarily using LIDAR systems **103**, **105**; and

(6) stuck between obstacles—vehicle management system **106** implements the stuck behavior when vehicle **102** cannot make progress along the route because it is continually going back and forth so that it is stuck between obstacles. Vehicle management system **106** positions vehicle **102** at different angles to search for a valid path. If no valid path is found, then vehicle management system **106** ignores low confidence obstacles in an attempt to eliminate low confidence obstacles. The last resort is to go forward along the pre-loaded route ignoring all obstacles.

In an exemplary embodiment, vehicle control system **100** may also be configured to detect a collision involving vehicle **102**. Upon detection of a collision, vehicle control system **100** may be configured to run a diagnostic check on each input and output device that is part of vehicle control system **100** to determine if all of them are online and functional, according to an exemplary embodiment.

In an exemplary embodiment, the functionality of vehicle management system **106** may be similar to the Distributed Architecture for Mobile Navigation (DAMN) where vehicle **102** ordinarily follows the path generated by path planning module **200** but the path can be overwritten depending on the current conditions. However, in some embodiments, the DAMN architecture may be modified to use a rules-based decision logic (instead of a complex voting scheme) to determine when the path should be overwritten. The use of rules-based decision logic may be more deterministic and robust than other solutions, which may render itself more useful in fleet applications.

In an exemplary embodiment, system manager **108** is the module of vehicle control system **100** that allows a user to interface with vehicle control system **100** to execute control commands and review the status of various systems and devices. In this exemplary embodiment, system manager **108** is also configured to continuously monitor the status of the various applications included in vehicle control system **100**. If system manager **108** determines that an application is no longer functioning normally, system manager **108** is configured to stop and restart the application to return normal functionality, according to an exemplary embodiment. In another exemplary embodiment, vehicle control system **100** may be configured so that if system manager **108** fails, vehicle control system **100** can continue operating.

In the context of a convoy of vehicles **102**, first vehicle **102** in the convoy may be configured to operate autonomously. The remainder of vehicles **102** may operate autonomously as well, but instead of actively sensing and avoiding obstacles, each of the remaining vehicles **102** may be configured to follow the one in front of it. This way there are not a large number of vehicles **102** in the convoy operating to independently find the best path to a destination, according to an exemplary embodiment. In an exemplary embodiment, vehicles **102** may be configured so that if the lead vehicle **102** is disabled, vehicle **102** behind the lead vehicle **102** may take over leading the convoy.

In an exemplary embodiment, in the context of a convoy of vehicles **102**, any vehicle **102** can be the lead vehicle **102**. In an exemplary embodiment, the remainder of vehicles **102** may operate autonomously and actively sense obstacles to avoid. In this exemplary embodiment, all of data obtain by the sensors of the plurality of vehicles **102** can be combined to generate a composite image, analysis, control signal, command signal, reporting signal, status signal and/or report.

In FIGS. **21-23**, a second vehicle **302** which includes vehicle control system **100** is shown, according to an exemplary embodiment. In an exemplary embodiment, second

vehicle **302** may be a heavy duty tactical military vehicle. Second vehicle **302** may be configured to function as a cargo truck (e.g., multiple configurations of a cargo truck that can carry different types and amounts of cargo), a fuel servicing truck, a load handling system truck (e.g., includes a lift arm that loads pallets onto the vehicle), a bridge transport vehicle, and a recovery vehicle (e.g., wrecker vehicle) with cranes and winches, according to exemplary embodiments. In an exemplary embodiment, second vehicle **302** may be configured so that it is capable of being transported by a C130 airplane.

The terms recited in the claims should be given their ordinary and customary meaning as determined by reference to relevant entries (e.g., definition of "plane" as a carpenter's tool would not be relevant to the use of the term "plane" when used to refer to an airplane, etc.) in dictionaries (e.g., consensus definitions from widely used general reference dictionaries and/or relevant technical dictionaries), commonly understood meanings by those in the art, etc., with the understanding that the broadest meaning imparted by any one or combination of these sources should be given to the claim terms (e.g., two or more relevant dictionary entries should be combined to provide the broadest meaning of the combination of entries, etc.) subject only to the following exceptions: (a) if a term is used herein in a manner more expansive than its ordinary and customary meaning, the term should be given its ordinary and customary meaning plus the additional expansive meaning, or (b) if a term has been explicitly defined to have a different meaning by reciting the term followed by the phrase "as used herein shall mean" or similar language (e.g., "herein this term means," "as defined herein," "for the purposes of this disclosure [the term] shall mean," etc.). References to specific examples, use of "e.g.," use of the word "invention," etc., are not meant to invoke exception (b) or otherwise restrict the scope of the recited claim terms. Accordingly, the subject matter recited in the claims is not coextensive with and should not be interpreted to be coextensive with any particular embodiment, feature, or combination of features shown herein. This is true even if only a single embodiment of the particular feature or combination of features is illustrated and described herein. Thus, the appended claims should be read to be given their broadest interpretation in view of the prior art and the ordinary meaning of the claim terms.

As used herein, spatial or directional terms, such as "left," "right," "front," "back," and the like, relate to the subject matter as it is shown in the drawing FIGS. However, it is to be understood that the subject matter described herein may assume various alternative orientations and, accordingly, such terms are not to be considered as limiting. Furthermore, as used herein (e.g., in the claims and the specification), articles such as "the," "a," and "an" can connote the singular or plural. Also, as used herein, the word "or" when used without a preceding "either" (or other similar language indicating that "or" is unequivocally meant to be exclusive—e.g., only one of x or y, etc.) shall be interpreted to be inclusive (e.g., "x or y" means one or both x or y). Likewise, as used herein, the term "and/or" shall also be interpreted to be inclusive (e.g., "x and/or y" means one or both x or y). In situations where "and/or" or "or" are used as a conjunction for a group of three or more items, the group should be interpreted to include one item alone, all of the items together, or any combination or number of the items. Moreover, terms used in the specification and claims such as have, having, include, and including should be construed to be synonymous with the terms comprise and comprising.

Although specific steps are shown and described in a specific order, it is understood that the method may include more, fewer, different, and/or a different ordering of the steps to perform the function described herein.

The exemplary embodiments illustrated in the figures and described herein are offered by way of example only. Accordingly, the present application is not limited to a particular embodiment, but extends to various modifications that nevertheless fall within the scope of the appended claims. The order or sequence of any processes or method steps may be varied or re-sequenced according to alternative embodiments.

The present application contemplates methods, systems and program products on any machine-readable media for accomplishing its operations. The embodiments of the present application may be implemented using an existing computer processor, or by a special purpose computer processor for an appropriate system, incorporated for this or another purpose or by a hardwired system.

It is important to note that the construction and arrangement of the autonomous and/or semi-autonomous vehicle and/or the convoy as shown in the various exemplary embodiments is illustrative only. Although only a few embodiments of the present application have been described in detail in this disclosure, those skilled in the art who review this disclosure will readily appreciate that many modifications are possible (e.g., variations in sizes, dimensions, structures, shapes and proportions of the various elements, values of parameters, mounting arrangements, use of materials, colors and orientations) without materially departing from the novel teachings and advantages of the subject matter recited in the claims. For example, elements shown as integrally formed may be constructed of multiple parts or elements, the position of elements may be reversed or otherwise varied, and the nature or number of discrete elements or positions may be altered or varied. Accordingly, all such modifications are intended to be included within the scope of the present application as defined in the appended claims. The order or sequence of any process or method steps may be varied or re-sequenced according to alternative embodiments. In the claims, any means-plus-function clause is intended to cover the structures described herein as performing the recited function and, not only structural equivalents, but also equivalent structures. Other substitutions, modifications, changes and omissions may be made in the design, operating conditions and arrangement of the exemplary embodiments without departing from the scope of the present application as expressed in the appended claims.

As noted above, embodiments within the scope of the present application include program products comprising machine-readable media for carrying or having machine-executable instructions or data structures stored thereon. Such machine-readable media can be any available media which can be accessed by a general purpose or special purpose computer or other machine with a processor. By way of example, such machine-readable media can comprise RAM, ROM, EPROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to carry or store a desired program code in the form of machine-executable instructions or data structures and which can be accessed by a general purpose or special purpose computer or other machine with a processor. When information is transferred or provided over a network or another communications connection (either hardwired, wireless, or a combination of hardwired or wireless) to a machine, the machine properly views the connection as a machine-readable medium. Thus, any such connection is properly termed a machine-readable medium. Combinations of the above are also included within

the scope of machine-readable media. Machine-executable instructions comprise, for example, instructions and data which cause a general purpose computer, special purpose computer, or special purpose processing machines to perform a certain function or group of functions.

It should be noted that although the diagrams herein may show a specific order of method steps, it is understood that the order of these steps may differ from what is depicted. Also, two or more steps may be performed concurrently or with partial concurrence. Such variation will depend on the software and hardware systems chosen. It is understood that all such variations are within the scope of the application. Likewise, software implementations of the present application could be accomplished with standard programming techniques with rule-based logic and other logic to accomplish the various connection steps, processing steps, comparison steps and/or decision steps.

The foregoing description of embodiments of the application has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the application to the precise form disclosed, and modifications and variations are possible in light of the above teachings, or may be acquired from practice of the application. The embodiments were chosen and described in order to explain the principles of the application and its practical application to enable one skilled in the art to utilize the application in various embodiments and with various modifications as are suited to the particular use contemplated.

What is claimed is:

1. A convoy of vehicles comprising:

a leader vehicle in communication with a plurality of autonomous follower vehicles, the leader vehicle configured to receive a first autonomous follower vehicle data from a first autonomous follower vehicle, the leader vehicle configured to compare the first autonomous follower vehicle data to at least one of a leader vehicle data, a second autonomous follower vehicle data from a second autonomous follower vehicle, and a threshold value;

wherein the first autonomous follower vehicle data, the leader vehicle data, the second autonomous follower vehicle data and the threshold value relate to a vehicle performance characteristic,

wherein the leader vehicle is configured to transmit a first command to the first autonomous follower vehicle, wherein the first autonomous follower vehicle is configured to transmit a second command to the second autonomous follower vehicle, and wherein the first autonomous follower vehicle is configured to transmit the first autonomous follower vehicle data to the leader vehicle, and

wherein the first autonomous follower vehicle and the second autonomous follower vehicle are configured to receive the first command from the leader vehicle and the second command from the first autonomous follower vehicle, respectively, compare the first command and the second command, respectively, to a predetermined tolerance range, follow the first command and the second command, respectively, if the first command and the second command, respectively, are within the predetermined tolerance range, and disregard the first command and the second command, respectively, if the first command and the second command, respectively, are not within the predetermined tolerance range, the predetermined tolerance range including at least one of a cargo load capacity, a speed, a turning radius, a number of revolutions per minute, a temperature maximum value, and a temperature minimum value.

2. The convoy of vehicles in claim **1**, wherein at least one of the first autonomous follower vehicle data, the leader vehicle data and the second autonomous follower vehicle data is generated by an on-board diagnostics system.

3. The convoy of vehicles in claim **1**, wherein a discrepancy report is generated based on a detected disparity between a comparison of the first autonomous follower vehicle data to at least one of the leader vehicle data, the second autonomous follower vehicle data and the threshold value.

4. The convoy of vehicles in claim **3**, wherein a maintenance schedule is generated based on the discrepancy report.

5. The convoy of vehicles of claim **1**, wherein the first autonomous follower vehicle is adjacent to the leader vehicle and the second autonomous follower vehicle is adjacent to the first autonomous follower vehicle, but not adjacent to the leader vehicle.

6. The convoy vehicles of claim **1**, wherein the first autonomous follower vehicle is within a first transmission range of the leader vehicle and the second autonomous follower vehicle is within a second transmission range of the second autonomous follower vehicle, but outside of the first transmission range of the leader vehicle.

7. A convoy of vehicles comprising:

a leader vehicle in communication with a plurality of autonomous follower vehicles, the leader vehicle configured to receive autonomous follower vehicle data, the leader vehicle configured to transmit at least one command signal to the plurality of autonomous follower vehicles;

wherein the plurality of autonomous follower vehicles are configured to compare a command value associated with the command signal to a predetermined tolerance range, and wherein the plurality of autonomous follower vehicles are configured to implement the at least one command signal when the command value is within the predetermined tolerance range and not implement the at least one command signal when the command value is not within the predetermined tolerance range,

wherein the leader vehicle is movable at least one of physically by moving the leader vehicle to another location and electronically by switching a leader vehicle command function from the leader vehicle to at least one of the plurality of autonomous follower vehicles, and

wherein the leader vehicle comprises an override mode configured to force the plurality of autonomous follower vehicles to implement the command signal regardless of whether the command value is within the predetermined tolerance range.

8. The convoy of vehicles in claim **7**, wherein an off-course follower vehicle receives a course data to rejoin the convoy.

9. The convoy of vehicles in claim **7**, wherein the leader vehicle and the plurality of autonomous follower vehicles obtain data related to at least one of a terrain, an obstacle, an enemy installation and enemy personnel.

10. The convoy of vehicles in claim **9**, wherein the obtained data is utilized to generate a first representative image of an area surrounding the convoy.

11. The convoy of vehicles in claim **10**, wherein the leader vehicle is configured to receive a second representative image of the area surrounding the convoy from a terrain database.

12. The convoy of vehicles in claim **11**, wherein the leader vehicle further comprises a control center configured to display a composite image of the first representative image of the area surrounding the convoy and the second representative image of the area surrounding the convoy.

13. The convoy of vehicles in claim **12**, wherein the control center includes a screen configured to facilitate selecting a

subset of the convoy in the composite image and changing the location of the subset of the convoy in the composite image; and

wherein the leader vehicle is configured to transmit a command signal to maneuver the subset of the convoy to correspond to a change in location of the subset of the convoy in the composite image.

14. The convoy of vehicles of claim **7**, wherein the predetermined tolerance range is a mission specific tolerance range received by the plurality of autonomous follower vehicles prior to starting a current mission.

15. The convoy of vehicles of claim **7**, wherein the predetermined tolerance range is a tolerance range programmed into the plurality of autonomous follower vehicles during a manufacturing process of the plurality of autonomous follower vehicles.

16. The convoy of vehicles of claim **7**, wherein the plurality of autonomous follower vehicles are configured to determine, based on the comparison of the command value to the predetermined tolerance range, that at least one of the plurality of autonomous follower vehicles may be damaged if the command signal is implemented by the at least one autonomous follower vehicle, and wherein the at least one autonomous follower vehicle is configured to not implement the command signal based on the determination that doing so may cause the at least one autonomous follower vehicle to be damaged.

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