

TITLE OF INVENTION

AUTONOMOUS VEHICLES FOR HERDING ANIMALS

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TECHNICAL FIELD

The present invention pertains to the field of animal husbandry, specifically to the use of automated systems and vehicles for managing and herding animals. “Animal” refers to a species in the Clade Euungulate, particularly those in the Artiodactyla order, commonly known as “herd” animals,” such as cattle, sheep, and pigs.

BACKGROUND

[0001] The art of animal husbandry, an age-old practice integral to agricultural societies worldwide, has continually evolved, embracing innovations that enhance efficiency and effectiveness in managing livestock. One of the perennial challenges in this field is the management of herds, specifically ensuring that all animals remain within the safety of the herd. The separation of animals from their group not only poses risks to the stray but can also lead to significant losses for farmers and herders due to predation, accidents, or health issues arising from isolation.

[0002] Cattle and other ruminants tend to move in the opposite direction when an intruder such as a handler, another type of animal or a machine moves into their flight zone. Which way they move depends on where the intruder is with respect to the animal's point of balance. The point of balance is usually at the animal's shoulder, and it is determined by the animal's wide angle vision. All species of livestock will move forward if the intruder is positioned behind the point of balance. They will back up if the intruder is positioned in front of the point of balance.

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Animals exhibit similar behavior when the flight-zone intruder is not a human being but a dog or a vehicle.

[0003] Historically, the task of herding animals and retrieving those that stray has been the responsibility of cowboys, shepherds, and herding dogs, whose training and instincts have been invaluable. Cowboys often move about on horseback to attain speeds necessary to move among herd and strays. These methods, while effective, are labor-intensive and require constant vigilance. Furthermore, the reliance on human or canine herders limits the scalability of these operations and can be impractical in vast, rugged, or inaccessible terrains.

[0004] The advent of mechanization in agriculture introduced the use of vehicles for various tasks, enabling innovations in herd management as well. Early attempts to mechanize herding included the simple use of vehicles to transport human herders more efficiently across their lands, allowing them to monitor and manage their herds more effectively. These methods, however, still heavily relied on human labor and did not fundamentally change the approach to managing strays.

[0005] The wide availability of inexpensive consumer drones with sophisticated control and navigation systems, formally known as unmanned aircraft systems, has fueled inventive energy to develop specific drone applications, often by after-market entrepreneurs and innovators.

[0006] The development of autonomous vehicles and advancements in robotics and artificial intelligence have paved the way for a more sophisticated approach to herding. By equipping vehicles with sensors and AI algorithms, it has become possible to identify, track, and manage individual animals within a herd autonomously. This technological leap has the potential to revolutionize herd management by automating the detection and retrieval of stray animals, reducing labor costs, and improving the safety and well-being of the animals.

[0007] Global positioning satellite technology has evolved to the point that many vendors offer cheap global positioning satellite (GPS) receivers, some of them integrated with inertial measuring units (IMU), capable of sending data to vehicle control systems.

[0008] Image acquisition benefits from commercially available and relatively inexpensive camera-Lidar fusion devices, which integrate images obtained by optical cameras and Laser ranging units to improve resolution of digital images.

[0009] Image matching enabled by machine learning techniques have been applied to large learning databases of human faces and animal images, resulting in the development of commercially available repositories, which constitute enrolled data bases against which live

images can be matched. Several vendors make available repositories of animal images that include images of herd animals such as cattle and sheep.

[0010] The system and method described in the patent claims represent a culmination of these advancements in disparate fields, which heretofore have not been connected, offering a comprehensive solution to the challenge of herding stray animals back into their groups. By obtaining and utilizing herding vehicles equipped with the capability to locate both the herd and the stray, identify the necessary path and movements, and generate noises and movements to motivate the stray animal's return, this method leverages pieces of modern technology to address an ancient problem in animal husbandry.

[0011] This innovation stands on the shoulders of centuries of agricultural practice and decades of technological advancement. It not only signifies a leap forward in the efficiency and effectiveness of herd management but also illustrates the potential for technology to enhance and transform traditional practices in agriculture and beyond.

[0012] Hundreds of years of herding animals have taught herders, ranchers, and animal husbandry scientists that certain principles of animal behavior permit animals to be herded by properly positioned herders. Traditionally, the herders for cattle were cowboys positioned around the herd at point, swing, flank, and drag positions. At first, cowboys walked and ran, then they rode horses, then they rode all terrain vehicles (ATVs). While their means of movement have changed, the principles of herding have not. The key concepts are flight zone and point of balance.

[0013] The effect of the handler's position on animal movement depends on whether the handler is inside or outside the flight zone. To stimulate movement forward, for example, the handler must be behind the point of balance and inside the flight zone. To simulate movement backward, the handler must be ahead of the point of balance and inside the flight zone.

[0014] According to the studies and experiments, a point of balance is usually at an animal's shoulder and is monitored by the animal's wide angle vision. All species of livestock move forward if a handler stands behind the point of balance. They back up if the handler stands in front of the point of balance.

[0015] Animal movement stimulated by handler position with respect to flight zone and point of balance spreads throughout a herd. Alternating pressure on the flight zone is more effective than continuous pressure. A handler backs out of the flight zone after a herd begins moving in

the correct direction. If the herd stops or slows down, the handler enters the flight zone to apply pressure again.

[0016] A group of animals has a group flight zone which can be determined by experimentation on the particular herding occasion.

[0017] These principles apply to herds of cattle in fields and on ranges, but they also apply to cattle handling in pens and in chutes.

[0018] Long cattle drives of hundreds of miles do not occur as they did in the nineteenth century. But cattle still are allowed to graze on open ranges and in large enclosures and must be rounded up and herded to feedlots and to trucks to transport them for slaughter. The same herding techniques are involved, regardless of the length of the drive.

[0019] Autonomous vehicle technology has progressed to the point that unmanned aerial vehicles, popularly known as drones, and ground vehicles of the all-terrain vehicle (ATV) type regularly perform functions in various industries supplementing and replacing human workers. These vehicles, as they are delivered off the shelf, have sophisticated navigation and control systems that allow them to know their location from a combination of global positioning system (GPS) signals, inertial measurement units (IMUs) and data from cameras, sonar sensors, and Lidar. They respond to commands from a remote control devices and can be programmed to execute particular maneuvers with respect to a defined object. Vendors of these systems provide application program interfaces (APIs) allowing users to write computer code widely accessible programming languages, such as Python, that supplements the vehicle's built-in navigation and control systems, thus permitting the vehicles to perform specialized tasks suitable for application in particular industries.

[0020] Typical off-the-shelf systems allocate computational responsibility between remote control devices and autonomous vehicles to minimize harmful latency and to maximize efficient use of radio links. Typically, remote control devices send high-level commands, such as destinations or speed limits, over the radio link to the vehicle, relying on the vehicle's onboard systems to translate these commands into detailed execution instructions for actuators and propulsion systems. This allocation of responsibility minimizes the data transmission required between the controller and the vehicle, reducing latency and enhancing responsiveness. It also allows the remote device to maintain a simpler, more intuitive user interface, and relieves the remote control device from processing large amounts of sensor data required for real-time navigation and obstacle avoidance.

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[0021] Remote control devices delivered with herding vehicles have navigation and control systems that work in conjunction with on board vehicle systems to translate user commands into detailed signals for actuators that control vehicle movement and stability.

[0022] Off-the-shelf commercially available battery replacement stations are capable of receiving a herding vehicle on a landing pad, removing its battery, and replacing the battery with a fully charged one suitable for the vehicle. The stations have a source of electrical power, and components that charge batteries.

[0023] Separate from these developments in autonomous vehicle technology, developers have deployed machine learning techniques to develop algorithms that enable image recognition systems capable of determining whether a newly obtained image depicts a particular animal or group of animals such as a cow or a cattle herd.

[0024] In the livestock industry managers of herds, known variously as herders, cowboys, and drovers, make use of a deep knowledge of innate animal behavioral characteristics and learn the kinds of actions by them that will influence animal movement. An experienced herder knows how to position himself and how to move so as to cause an individual animal to move in a particular direction at a desired speed. Experienced herders know how to position themselves around a herd of animals so to control it—to keep it bunched up, to cause strays to return to the herd, to cause a herd to move in a particular direction, to turn left or right, to speed up, to slow down, and to stop.

[0025] Animal husbandry research and experience teaches that certain movements, sounds, and visual stimuli such as light flashes are effective in motivating animal movement. Experienced herders and researchers in animal behavior also have learned the kinds of sounds, light flashes, and movements of vehicles and other objects most likely to be effective to reinforce directions to individual animals and to herds. For example, a vehicle might move rapidly left and right and in and out (referred to herein as “buzzing” or “buzz”); an audio device can simulate human shouts such as “Hi-yah,” “Yee-hah,” or “Yip, yip, yip!”; an audio device can simulate an animal utterance such as a particular type of “moo” signifying distress, contentment, or other conditions. A light on the vehicle can flash rapidly.

[0026] These disparate developments in autonomous vehicle technology, animal behavior, animal image recognition enabled by artificial intelligence, and signaling by herders animals have not been combined so as to achieve practical automated herding systems.

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[0027] The invention covered by U.S. Patent No. 12,102,060, Autonomous Vehicle and Method for Detecting Strays and Managing Herds, took a first step in filling this gap. It describes an automated vehicle, a drone in one embodiment, and a land-based vehicle in another, that make use of off the shelf vehicles, off the shelf repositories of animal images, descriptions of sounds light signals, and movements, and knowledge of flight zones and points of balance as means of detecting animals that have strayed from a herd and to cause such animals to return to the herd.

[0028] This invention covered by U.S. Patent No. 12,153,451, Autonomous Vehicle Formation System and Method for Herding Animals, improved on U.S. Patent No. 12,102,060, by deploying multiple vehicles described in that application in formation to control entire herds.

SUMMARY OF INVENTION

[0029] An advanced autonomous herding system and method for managing and retrieving stray animals using a formation of autonomous vehicles, integrating technologies from U.S. Patent US 12,102,060 and US 12,153,451. The system employs a fleet of autonomous herding vehicles, each equipped with advanced navigation, propulsion, and sensory technology, including optical-LiDAR sensors, global navigation satellite systems, and machine-learning-derived image templates. These vehicles collaborate to detect, locate, and guide stray animals back to their herd using strategic movements, visual cues, and audio signals. The system operates in two modes: a roundup mode for gathering scattered animals into a cohesive herd, and a herding mode for maintaining herd cohesion and directing movement toward a target destination.

[0030] The vehicles are positioned in traditional herding formations, such as point, swing, flank, and drag, to effectively control the herd's movement. The system also includes a battery replacement station to ensure continuous operation by automatically swapping depleted batteries with fully charged ones. The trail boss module, a central control unit, coordinates the vehicles' actions, leveraging animal behavior models, flight zone principles, and point-of-balance strategies to optimize herd management. This integrated approach reduces labor costs, minimizes animal stress, and enhances the efficiency and safety of livestock management, representing a significant advancement in smart farming and autonomous agricultural technology. The invention is an automated system and related method for herding stray animals back into their herd. This system comprises an autonomous herding vehicle equipped with

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various modules for detecting and guiding stray animals. The herding vehicles can be either ground vehicles of the ATV type or aerial, such as unmanned rotorcraft (drones). Each vehicle has:

[0031] A sensor module with optical-LiDAR fusion sensors, radio receivers to interact with a global navigation system, and inertial measurement units.

[0032] An animal detection module that processes sensor signals to create images, then compares those images to animal templates in a repository derived from machine learning to identify members of the herd.

[0033] A location module for calculating positions of the vehicle, the herd, and the stray animal.

[0034] A herding module to determine the vectors representing the paths for the stray follow to rejoin the herd and to position the herding vehicle accordingly.

[0035] A navigation module that computes the course the vehicle must take to approach the stray and guide it back.

[0036] A propulsion module that causes the vehicle move at an appropriate speed along the desired direction.

[0037] A suspension module, which supports the ground version of the vehicle and lifts the aerial version of the vehicle.

[0038] An alerting module that uses visual (a pivoting flag) and audio signals (including a loud horn, distressed animal sounds, and cowboy shouts) to influence the stray's movements.

[0039] The method specifies the steps necessary for utilizing the herding vehicles to identify and herd the stray animals using both visual and audio cues to motivate them to return to the herd.

[0040] The described system integrates technology and animal behavior knowledge to manage a herd and prevent the loss of animals autonomously. It is a sophisticated approach to livestock management that reduces the need for human intervention in the herding process,

[0041] The system and method uses autonomous vehicles to detect strays and to drive them back into a herd. The herding vehicles can be off-the-shelf, commercially available autonomous aerial vehicles, popularly known as drones, delivered with remote control devices, or they can be off-the-shelf, commercial available autonomous all-terrain vehicles delivered with remote

control devices. This invention describes a formation of such autonomous vehicles organized so as to control and drive an entire herd.

[0042] It comprises a formation of herding vehicles with an onboard maintain-station subsystems that receive, via radio links, commands from a trail boss module and interfaces those commands with onboard navigation and control systems delivered with the vehicles.

[0043] The trail boss module receives data and commands from a human operator defining the initial position for herd collection, target destination for the herd, the mode of operation, whether roundup or herding, and any desired changes in herd speed or heading. If any of these values have been set by the autonomous system, the human operator has the power to change them.

[0044] The trail boss module uses information about animal images derived from off-the-shelf machine learning systems, information about animal behavior derived from research and experimentation about the behavior of herding animals, and information about movements, sounds, and visual cues most effective in causing particular animal behaviors. It combines this information with data received from the vehicles about their position with respect to the herd to compute commands regarding new vehicle positions, speeds, and alerts.

[0045] The trail boss module positions the herding vehicles at stations in the formation so that they collectively surround the herd and so that their individual movements cause the herd to stay together than to move in the desired direction at the desired speed.

[0046] Each herding vehicle monitors its electrical charge remaining and signals the trail boss module when the remaining charge is less than a pre-determined level—15% in the preferred embodiment. Upon receiving such a signal, the trail boss module commands the vehicle to go to a battery replacement station, which automatically extracts the nearly depleted battery and replaces it with a fully charged one. The trail boss module commands one of the other vehicles to take up the station vacated by the vehicle having its battery replaced and reassigns the returning fully-charged vehicle to another station.

[0047] The system and method operate in two modes: a roundup mode and a herding mode. In the roundup mode, the trail boss commands individual herding vehicles to approach discrete animals or small groups and to herd them together with other animals until a herd is formed.

[0048] In the herding mode the system and method use models of animal behavior derived from research and experience to position herding vehicles in traditional herder positions with

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respect to a herd and to move so as to keep the herd together and to cause it to move in desired directions and speeds toward an arbitrary target destination.

[0049] The herding vehicles may be ground vehicles such as ATVs, or they may be aerial vehicles such as drones.

TERMS AND DEFINITIONS

[0050] "API" refers to an application program interface, a data structure that permits one digital subsystem to communicate with another by exchanging data.

[0051] "Autonomous" refers to the capability to perform a defined mission without receiving detailed commands from a human operator. It does not exclude human commands to begin and to terminate a mission.

[0052] "Azimuth" refers to the angle between an arbitrary reference, such as magnetic, north and a line drawn to a target.

[0053] The terms "corral," "drive," and "bunch" have the same meaning: causing an animal to move in a particular direction or to a particular place.

[0054] The terms "course" and "heading" mean the same thing: the direction of a path over the ground expressed as degrees from North.

[0055] "Data bus" refers to a connection among multiple digital subsystem that allows the subsystems to exchange data by sending electric signals of prescribed levels and formats to the data bus.

[0056] "Equal" or "equal to" means the same.

[0057] "Global navigation system" refers to a system comprising multiple satellites in earth orbit that send radio signals to the surface of the Earth, designed to permit systems receiving those signals to determine their latitude, longitude, and altitude.

[0058] For efficiency in explanation, the herding vehicle—point is frequently referred to at the "point;" the herding vehicle—left swing is frequently referred to as the "left swing;" the herding vehicle—left flank is frequently referred to as the "left flank;" the herding vehicle—drag is frequently referred to as the "drag;" the herding vehicle—right flank is frequently referred to as the "right flank;" the herding vehicle—right swing is frequently referred to as the "right swing;" and a herding vehicle—stray catcher is frequently referred to as a "stray catcher."

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[0059] “Hover” means to remain in a fixed position and a fixed altitude while aloft.

[0060] "Program" refers to a plurality of coded instructions that cause a digital computer to carry out particular operations. “RF refers to ”radio frequency" signals.

[0061] "Radio" refers to a device for transmitting and/or receiving electromagnetic waves in the radio spectrum and interpreting them for human understanding.

[0062] “Range” refers to the distance between a sensor and a target.

[0063] “Stray” refers to an animal that has separated from a herd.

[0064] “Vector” refers to a virtual object in mathematics and physics that has direction as well as magnitude. Vectors typically are represented by values for each of two or three axes, corresponding to orthogonal directions, such as latitude, longitude, and altitude.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

To identify the discussion of any particular element or act easily, the most significant digit or digits in a reference number refer to the figure number in which that element is first introduced.

[0065] FIG. 1 provides a macroscopic view of the system with a single herding vehicle.

[0066] FIG. 2 shows the main components of a single herding vehicle.

[0067] FIG. 3 provides more detail on the computerized data-processing aspects of the system.

[0068] FIG. 4 illustrates the vectors defining the paths to be followed by the Herding vehicle and the Stray.

[0069] FIG. 5 depicts the stray with the Flight Zone around it and the angle representing the Point of balance.

[0070] FIG. 6 illustrates a method for herding stray animals back into a herd.

[0071] FIG. 7 is an overview of the formation of herding vehicles at their stations surrounding the herd.

[0072] FIG. 8 depicts the roundup process

[0073] FIG. 9 illustrates the herd edges and course.

[0074] FIG. 10 depicts the movements of the herding vehicles when the herd is to be turned to the right.

- [0075]** FIG. 11 depicts the herding vehicle movements to speed the herd up.
- [0076]** FIG. 12 depicts a stray chaser vehicle herding a stray back into the herd.
- [0077]** FIG. 13 depicts a stray chaser vehicle entering the flight zone of a stray and using its buzzing movements and audio sounds to corral the stray back into the herd.
- [0078]** FIG. 14 depicts a herding vehicle leaving its station and proceeding to the battery replacement station for a new, fully charged battery.
- [0079]** FIG. 15 depicts the onboard herding vehicle module.
- [0080]** FIG. 16 depicts the trail boss module.
- [0081]** FIG. 17 is a flow chart depicting the roundup and herding modes.
- [0082]** FIG. 18 is a flow chart depicting the battery replacement process.

DETAILED DESCRIPTION OF EMBODIMENTS

[0083] The system uses one or more herding vehicles 106 to keep a herd 102 together and to drive it to a destination . A single herding vehicle 106 may be used to keep a herd 102 together or to drive an animal to a gate, chute, or entrance to a structure. A plurality of vehicles may be used to drive a herd to a destination.

[0084] When a single herding vehicle 106 is used, the system comprises a herd 102, a stray 104, a herding vehicle 106, an extension of the stray-to-herd vector 108, and a stray-to-herd vector 110. The herding vehicle 106 is a commercially available ground vehicle, of the ATV type, in one embodiment and a commercially available unmanned aerial vehicle (UAV) in another, comprising a plurality of modules, which collectively enable the vehicle autonomously to detect animals 104 that have strayed from a herd 102, called “strays,” to approach those strays 104 and to position the vehicle 106 to take advantage of the stray's 104 instinctive flight response to drive it back into the herd 102.

[0085] The remote control device 226 translates human operating control movements into commands to the herding vehicle 106, which are transmitted via the radio link 204 to the herding vehicle 106 causing it to begin or a terminate an autonomous mission.

[0086] The system comprises modules including a sensor module 206, an animal detection module 314, a location module 316, a herding module 318, a navigation module 320, a propulsion module 214, a suspension module 216, and an alerting module 208. Each module

has an application program interface (API) 230 that contains data structures for inputs and outputs specific to that module. The modules communicate with each other through these APIs, which are mutually connected through the data bus 228. The system also comprises a global navigation system 202, a GPS RF link 212, a radio link 204, a computer 210, and a remote control device 226.

[0087] In one embodiment, the propulsion module 214 is an off-the-shelf subsystem for an ATV or farm vehicle programmed to accept course and speed commands from the Navigation module 320 and translates them into steering and power commands for the motors and steering apparatus. The Propulsion module 214 utilizes a CAN bus to convey signals from the navigation module to the propulsion module. These signals conform to ANSI's ISO 11898-Road Vehicles Controller Area Network—to control the throttle, braking system, and steering control subsystems on the herding vehicle.

[0088] In another embodiment, the propulsion module 214 is an off-the-shelf subsystem for an autonomous UAV of the rotorcraft type. A rotorcraft is an aerial vehicle in which lift and thrust are provided by means of one or more rotors rather than by wings and separate thrust devices. All of the modules on the aerial vehicle in this embodiment work similarly to their counterparts on the ground vehicle embodiment, except that the vectors are three-dimensional, enabling the Herding vehicle 106 to use altitude as well as latitude and longitude to trigger the desired movement of the stray 104. The UAV accepts as inputs vector information from the Navigation module 320 and translates it into commands for vehicle motion necessary to place it on the extension of the stray-to-herd vector 108 and to fly along that vector until it is within 25 feet of the stray 104 and then to reduce its speed as it begins to drive the stray 104 back into the herd 102. The propulsion module expresses the commands in the form of control inputs and rotor RPM and pitch commands.

[0089] The suspension module 216 is a suspension system appropriate for the vehicle. A suspension system on a ground-based vehicle comprise the mechanisms that connect elements such as a plurality of wheels with tires or tracks to the body of the vehicle, typically comprising springs, shock absorbers, and steering linkages. On an aerial vehicle, the suspension system comprises the lifting means such as wings and a plurality of rotors, and the mechanisms for altering the amount of lift such means generate, and the direction in which it is exerted. It calculates appropriate lift vectors and translates them into commands for rotor RPM and pitch.

[0090] The suspension module 216 and propulsion module 214 are built into commercially available vehicles, whether they be designed for operation across the ground or for operation through the air.

[0091] The Sensor module 206 makes use of off-the-shelf camera-lidar fusion devices, such as the ones offered by Kyocera and Beamagine. “Camera-lidar fusion devices” refer to commercially available units that combine digital images captured by cameras and Lidar sensors integrated with circuitry that provides digital output in the form of digital images with enhanced resolution and range information with respect to the object in the image. The Sensor module 206 also makes use of off-the-shelf GPS-IMU hardware combining global navigation system radio receivers and inertial measuring units, such as the ones manufactured by Navtech and Life Performance Research. The Sensor module 206 contains a control signal radio receiver for the purpose of receiving commands from a Remote control device 112 to begin or to end a mission. Sensor data is updated at periodic intervals, every one second in the preferred embodiment.

[0092] The herding vehicles contain an alerting module 208 which is capable of commanding rapid movements back and forth, in and out, flashing lights, sounds of cowboy shouts, and sounds of distressed animals. The alerting module contains a loudspeaker and a mechanism such as a pole for waving a flag or generating other prominent movements and audio algorithms and data for generating sounds, including simulated human voice sounds. The alerting module 208, upon receiving a signal from the navigation module 320, generates rapid movements and loud sounds from its loudspeaker such as replicas of human cowboys shouting “ha-yah!” and animals mooing to encourage the stray 104 to return to the herd 102. The alerting module 208 receives its activation signal from the navigation module 320 when the herding vehicle 106 is within the flight zone 502 of the stray 104.

[0093] The data bus 302, a memory 304, an API 306, a computer 312, an animal detection module 314, a location module 316, a herding module 318, and a navigation module 320 work in combination to cause the system to perform its herding function.

[0094] Algorithms and data necessary for computation are stored in and retrieved from a Memory 304, which is a component of the computer 312. The memory 304 combines random-access and non-volatile semiconductor chips capable of storing the data generated and manipulated by the various modules and capable of retaining parameters for types of animal to be herded and types of herding vehicle.

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[0095] The Sensor module 206 sends images of what its camera and lidar “see” and data on the Herding vehicle's 106 latitude and longitude to the animal detection module 314 and to other modules through its API 306 and the Data bus 302.

[0096] The animal detection module 314 is a computer program executed on the Computer 312, which identifies an animal that has strayed from the herd by matching the image acquired by the Sensor module 206 to a template of an individual animals and herds. The animal detection module 314 module makes use of machine learning to recognize herds 102 and strays 104. It compares camera-lidar-device captured images with images in internally stored repositories of particular species. Each repository comprises an enrolled database-a collection of templates against which live images captured by the camera lidar device are matched. An enrolled database is a database, distinguished from a learning database, used in machine learning animal recognition systems. An enrolled database uses algorithms developed from the learning database to define templates against which live images can be matched. The animal detection module 314 computes range and azimuth of the herd 102 and the stray 104 with respect to the herding vehicle 106 and sends that range and azimuth information to the location module 316.

[0097] The location module 316 is a computer program executed on the computer 312, which locates the stray and the herd by taking the latitude and longitude of the herding vehicle and using vector arithmetic to combine the range and azimuth information received from the animal detection module 314 to compute the latitude and longitude of the herd 102 and the stray 104.

[0098] The herding module 318 is a computer program executed on the computer 312, which calculates the stray-to-herd vector 110 (the second vector), the Extension of the stray-to-herd vector 108 (the third vector), and the latitude and longitude of points on the circle defining the flight zone 502, calculates the latitude and longitude of the points defining the point of balance 504 and outputs those to the data bus 302 through its API 306.

[0099] The navigation module 320 is a computer program executed on the computer 312, which takes the data computed by the herding module 318 and uses them to compute the vehicle-to-stray vector 402 (the first vector) and the extension of the stray-to-herd vector 108 necessary to cause the herding vehicle 106 to close on the stray 104 and then to position itself on the extension of stray-to-herd vector 108 within the stray's Flight Zone 502 such that the stray 104 is caused to move back into the herd 102.

[0100] Following these commands, the Herding vehicle 106 proceeds toward the stray 104 on the vehicle-to-stray vector 402 until it gets to the edge of the Flight Zone 502. Once the vehicle 106 reaches the edge of the Stray's 104 Flight Zone 502, it follows the circumference of the Flight Zone 502 to intercept the Extension of the stray-to-herd-vector 108, positions itself on to that vector, and then turns to follow the extension of the stray-to-herd vector 108 to approach the stray 104. Once the vehicle enters the Stray's 104 Flight Zone 502, it proceeds at a reduced speed above (toward the head) or below (toward the tail) the point of balance 504 as appropriate to cause the stray 104 to return to the herd 102 along the stray-to-herd vector 108, adjusting the vehicle's speed so it does not make contact with the stray 104. Once the herding vehicle 106 enters the flight Zone 502, it sends a signal to the alerting module 208, causing it to generate noises and movement to reinforce the stray's motivation to return to the herd 102, stimulated initially by the proximity of the herding vehicle 106.

[0101] FIG. 4 illustrates the vectors defining the paths to be followed by the herding vehicle 106 and the stray 104 when the vehicle first begins its movement to close on the stray and to cause it to return to the Herd 404: a vehicle-to-stray vector 402 (the “first vector”), a stray-to-herd vector 110 (the “second vector”), and an extension of the stray-to-herd vector 108 (a “third vector”).

[0102] The navigation module 320 transforms vector information received from the herding module 318 into commands for the propulsion module 214, sent via its API 306 and the Data bus 302, according to a closed-loop automatic control system. An automatic control system, implements a decision process, also called the control law, that dictates the appropriate control actions to be taken for the speed and direction of the herding vehicle to be maintained within acceptable tolerances. These decisions are taken based on how different the actual speed and direction are from the desired, called the error, and on the knowledge of the vehicle's response to changes in the propulsion and suspension modules. Error signals are fed back to the automatic control system, which produces the requisite commands to the propulsion and suspension modules to reduce or eliminate the error.

[0103] The foundation of the navigation module 220 is vector arithmetic, which takes latitude and longitude data and vectors as its inputs, and from those data computes a Vehicle-to-stray vector 402 and, as the herding vehicle 106 moves, determines an error function representing the deviation between the herding vehicle's position and the Vehicle-to-stray vector 402, and then the circumference of the flight zone 502, and finally on the extension of the stray-to-herd

vector 108 on which the herding vehicle 106 positions itself to cause the stray 104 to move back toward the herd 102.

[0104] FIG. 5 depicts a stray 104 with its flight zone 502 around it, and an angle 506, representing a point of balance 504.

[0105] Empirical research into the behavior of herd animals shows that a Flight Zone 502 exists. “Flight zone” refers to the area around an animal, typically represented by a circle of a particular diameter, that, when entered by a human being, a different type of animal, or a large object such as a vehicle, causes the animal to move away. When an intruder such as an animal a human, or a machine enters the flight zone, the herd animal instinctively moves away from the intruder. “Intruder” refers to a human, an animal, or an object such as a vehicle that has moved into an animal's flight zone. Human cowboys have learned where the flight zone exists around cattle and makes use of it to herd cattle. The Flight Zone 502 for cattle varies from 25 feet in diameter for tame animals to 300 feet in diameter for less tame ones. The foundation of the herding module 318 is a behavioral model of an animal—in the preferred embodiment a cow, bull, or steer. The model depicted in FIG. 5, reflects empirical data on how an animal of that type responds to visual, oral, and tactile stimuli. Typically, an accurate but simple model has the animal moving away from any large object placed within a distance of 10 feet more or less (the Flight Zone 502) and within an arc defined by a line extended from the animal's head and neck and a line extending from it shoulder at an Angle 506 of about 60°. From a centerline drawn through the nose (the Point of balance 504). The speed with which the animal moves away from the object is inversely proportional to the distance between the object and the animal. Thus, a herding vehicle can cause an animal to move in a particular direction at a desired speed by positioning itself correctly within the flight zone, forward or back of the point of balance.

[0106] The herding module 318 calculates a circle defining an animal's flight zone and a ray at a particular angle from an animal that defines its point of balance. The navigation module 320 computes vectors representing paths the vehicle must follow to drive strays back into a herd.

[0107] A fourth vector represents a path the herding vehicle 106 follows to position itself within or without the Flight Zone 502 and forward or aft of the point of balance 504

[0108] FIG. 6 illustrates a method 600 for driving a stray 104 back into a herd 102, comprising:

- [0109]** obtaining herding vehicle 602;
- [0110]** locating the herding vehicle 604;
- [0111]** identifying a herd of animals 606;
- [0112]** identifying an animal that has strayed from the herd 608;
- [0113]** locating the herd 610;
- [0114]** locating the stray 612;
- [0115]** determining the path necessary for the herding vehicle to close on the stray 614;
- [0116]** determining the movements of the herding vehicle necessary to cause the stray to return to the herd 102; and
- [0117]** generating noises and movements 614 necessary to reinforce the stray's motivation to return to the herd 102.
- [0118]** Although the example method 600 depicts a particular sequence of operations, the sequence may be altered without departing from the scope of the present disclosure. For example, some of the operations depicted may be performed in parallel or in a different sequence that does not materially affect the function of the method 600. In other examples, different components of an example device or system that implements the routine 600 may perform functions at substantially the same time or in a specific sequence.
- [0119]** This system and method use a formation of herding vehicles, 704, 706, 708, 710, 712, and 714, to control an entire herd 102 of animals, placing the vehicles in positions with respect to the herd that animal husbandry research and experience teach are effective. The collection of herding vehicles is the “formation.” Each position in the formation is a “station.”
- [0120]** The herding vehicles in this application are identical one with another, regardless of the station to which they have been assigned in the formation. Thus the herding vehicle-point 714 is identical to the herding vehicle-drag 712, and both are identical to the herding vehicle-left swing 704 and to the herding vehicle-right flank 710.
- [0121]** (24) This method and system extend knowledge gained from animal husbandry to apply a variety of visual, audible, and movement signals to exercise detailed control of a herd.
- [0122]** (25) The system comprises maintain-station modules on board the herding vehicles, a trail boss module integrated with the remote control devices delivered with off-the-shelf vehicles, and an off-the shelf battery replacement system.

[0123] The formation comprises a herding vehicle-left swing 704, a herding vehicle- 706, a herding vehicle- 708, a herding vehicle- 710, a herding vehicle - drag 712, and a herding vehicle-point 714, and a direction of travel 716.

[0124] FIG. 8 depicts the system in roundup mode, with a herding vehicle 802 driving a stray 816, a herding vehicle 804 driving a stray 814, a herding vehicle 806 driving a stray 818, a herding vehicle 808 driving a stray 820, a herding vehicle 810 driving a stray 822, a herding vehicle 812 driving a Stray 824 together to form a herd 826.

[0125] To understand the control of the Herd 826, it is helpful to understanding terminology: The a leading edge of herd 902, a trailing edge of herd 904, a left edge of herd 908, a right edge of herd 912, and a herd course 916.

[0126] Each edge is defined by the latitude and longitude of the point connecting it with the next orthogonal edge. For example, the leading edge of the herd 902 is defined by the latitude and longitude of the point connecting it to the right edge of the herd 912, and the latitude and longitude of the point connecting it to the left edge of the herd 908.

[0127] FIG. 10 depicts the movements of the herding vehicles 704, 706, 708, 710, 712, and 714 when they operate to move the herd to the right: a direction of travel 1016, a right turn direction 1020, the movement of the right swing vehicle 1022, the movement of the right flank vehicle 1024, the movement of the left swing vehicle 1026, the movement of the left flank vehicle 1028, and the movement of the point vehicle 1030.

[0128] FIG. 11 depicts the movements of the herding vehicles 704, 706, 708, 710, 712, and 714 when they operate to slow the herd down. Each of the herding vehicles slows down--1118, 1120, 1122, and 1124, thus slowing the herd itself down while still moving in the original direction 1126.

[0129] Each herding vehicle's sensors, machine-learning derived templates, and algorithms permit it to identify a herd and to locate it by its latitude and longitude. Each herding vehicle communicates the latitude and longitude of each edge of the herd to the trail boss computer 1602.

[0130] FIG. 12 depicts the operation of the formation when a stray is detected. The original six herding vehicles, 704, 706, 708, 710, 712, and 714, remain in position, while a herding vehicle - stray catcher 1224 drives 1228 the Stray 1222 back into the herd 102.

[0131] More than one herding vehicle - stray catcher 1224 may be provided, depending on the embodiment.

[0132] When a stray 104 is slow to respond to the presence of a herding vehicle - stray catcher 1224 within its Flight Zone 502, the trail boss computer 1602 sends an alerter command to that herding vehicle, causing the herding vehicle to engage in rapid back-and-forth movements and minor altitude changes (buzz), to emit flashing lights (flash), to emit sounds of animals in distress (moo) and human cowboys sounds (shout). The sounds are commanded serially, but the light flashes, vehicle movements, and sounds may occur simultaneously. As depicted in FIG. 13, a stray catcher approaches a stray and reinforces the effect of its entry into the stray's Flight Zone 502 by rapid back 1332 and forth 1334 movements, by light flashes, and by human cowboy sounds emitted over its loudspeaker, such as "ha-yah!" "Yee-hah" and "yip-yip-yip," interspersed with mooing sounds of distressed animals.

[0133] The system and method provide for the continuous operation of the herding vehicles by allowing them to leave their positions in the formation and travel to a battery replacement station 1420, where their batteries are automatically replaced with fully charged ones. This aspect of the system comprises a battery replacement station 1420 and the usual herd 102 and herding vehicles 704, 706, 708, 710, 712, 714, and 1224.

[0134] Each herding vehicles configured for operation in a formation comprises a maintain station computer 1502, a delivered navigation and control system 1504, an API bus 1506, a radio bus 1508, a radio link 204, and a herding vehicle data structure 1518, comprising slots for data elements, 1512, 1520, 1522, 1524, 1526, 1528, 1530, 1532, and 1534.

[0135] The data structures computer and delivered navigation and control system 1504 are connected through the data buses and radio links. The maintain-station module on each herding vehicle communicates with computer and navigation and control systems built into the vehicle and delivered with it through the API bus 1506. The maintain station computer 1502 in each herding vehicle communicates with a trail boss computer 1602 and the battery replacement station 1420 by means of a radio link 204. The radio busses and radio links handle digital messages comprising telemetry data and reports from and commands to herding vehicles.

[0136] Access to the data busses and to the radio busses is controlled by the well-known Carrier Sense Multiple Access/Collision Detection (CSMA/CD) protocol. Particular elements of maintain-station modules, the trail boss module, and the battery replacement station are addressed according to the value of an address field in a radio message.

[0137] Program code pursuant to which the maintain station computer 1502 interacts with the delivered remote control computer 1604 and pursuant to which the trail boss computer 1602 interacts with the delivered remote control devices is written in a common programming language such as Python and interfaced through APIs defined in the herding-vehicle vendor's software development kit (SDK).

[0138] Formation operation is controlled by a trail boss computer 1602, a delivered remote control computer 1604, a remote control API bus 1606, a trail boss radio bus 1608, three data structures, and a radio link 204.

[0139] The three data structures comprise copies of the herding vehicle data structures 1614, a trail boss data structure 1618, and a herd data structure 1622. These components interact with the computer built into and delivered with the remote control device for the herding vehicles via a remote control API bus 1606. They communicate with all of the herding vehicles by means of a radio link 204.

[0140] Three data structures collectively represent the state of the system and its components at any point in time. Each instance of the copies of the herding vehicle data structure 1614 corresponds to one herding vehicle. The structure has slots for: vehicle number, assigned station, target position, current position, speed, heading, battery charge remaining, alert, and status. Position slots accommodate three-dimensional vectors, comprising latitude, longitude, and altitude. The status slot contains values signifying on-station, receiving charge, and relieved. Additional slots may be provided in other embodiments.

[0141] The herd data structure 1622 contains slots for herd target location 1638, initial herd gathering location 1640, herd present location 1642, herd speed 1644, and herd bearing 1646. Values for the herd location variables comprise latitude, longitude, and altitude for each corner of the herd defining its edges. Additional slots may be provided in other embodiments.

[0142] The trail boss data structure 1618 contains slots for flight-zone radius 1624, point-of-balance 1626, herd target location 1628, an index of herding vehicle assigned stations 1638, an index of herding vehicle status 1632, battery-replacement station location 1634, and stray locations 1636. The flight-zone radius and point-of-balance are single-value variables derived from animal husbandry science and experience and adjustable by the human user depending on his knowledge of the nature of the herd and the conditions of its environment. The stray location slot 1636 accommodates a list containing multiple stray locations. Additional slots may be provided in other embodiments.

[0143] In some embodiments, the trail boss module computer is independent; in other embodiments its functionality is provided by the computer supplied with the delivered remote control device. Whichever computer is employed performs the necessary arithmetic and trigonometric computations, applies the supplied machine learning derived templates and models of herd behavior to develop location commands and alert signals.

[0144] The intelligence, data, and algorithms pertinent to the entire herd are maintained by the trail boss computer 1602: intelligence, algorithms, and data from single vehicle sensors, to determine locations and movements, are maintained on board the vehicles.

[0145] Once the trail boss module has received position data from the herding vehicles about the current position of the herd, it uses its models of flight zone and point of balance to calculate latitude and longitude offsets from the edges, which define each station. The flight zone for the entire herd is defined by a circle with a diameter determined from animal husbandry research and experience. The point of balance for the entire herd is represented by two rays from the herd at an angle from its head, usually about thirty degrees and two-hundred-ten degrees clockwise. The arithmetic combination of the offsets with the current herd position represents the latitude and longitude values for the current position of each herding vehicle, which values are entered into the herding vehicle data structures 1518.

[0146] Once all the herding vehicles are on station, the trail boss module commands them to begin to move the herd. The herd is put in motion by the drag's 712 entering the flight zone of the animals at the rear, the point's 714 increasing its distance from the front of the herd to make sure it is not in the herd's flight zone, the flank and swing vehicles' 704, 706, 708, and 710, closing in so they are within the flight zone and behind the point of balance of animals on the side, and the stray catchers' moving so as to reinforce the movements of the drag and the swing and flank vehicles.

[0147] Once the herd is moving, the point 714 drops back and maintains a position just forward the flight zone of the leading animals of the herd, the drag 712 drops back and periodically enters the flight zones of the animals at the rear of the herd to keep the herd moving with the proper speed, and the flank and swing vehicles, 704, 706, 708, and 710, aided by the stray catchers 1224 deal with laggard animals or animals that appear to be drifting away from the main herd by entering their flight zones at the appropriate position with respect to their points of balance.

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[0148] The effect resembles a moving virtual cocoon surrounding the herd, keeping it together and keeping it moving in the desired direction toward the herd's target position.

[0149] If a herding vehicle detects a stray not more than a prescribed distance—ten feet away, in the preferred embodiment—from its current position, it drives that stray back into the herd. If the stray is more than that distance away from the herding vehicle, the herding vehicle reports the stray's location to the trail boss module, which assigns a straight catcher to drive that stray back into the herd.

[0150] During this process, any animal that moves more than a predefined distance, ten feet in the perverted embodiment, away from the main herd is treated as a stray and handled by the nearest stray catcher.

[0151] After a stray is detected, the trail boss module assigns it to the nearest stray catcher, unless it is within the prescribed distance of the herding vehicle that that detected it, in which case the trail boss module assigns the stray to that herding vehicle. No other herding vehicle chases that stray or undertakes to drive it back into the herd.

[0152] At least three radio channels connect the herding vehicles with the trail boss module and the delivered remote control devices: the control channel delivered with the vehicle and the delivered remote control device, usually a separate channel for video and other types of imagery, and the radio link 204. The system and method use the radio link 204 for telemetry from the herding vehicles and herding commands to the herding vehicles to make sure of adequate bandwidth, which might be limited on the other two channels.

[0153] The trail boss module comprises a video display touchscreen on which a human operator can see the position of the herd, the position of all of the herding vehicles, and the state of those vehicles with respect to battery replacement. This human interface permits the operator to change target location for the herd and to provide herd direction change commands to follow terrain features as desired in input devices comprising the touchscreen, a keyboard, a mouse, and a microphone driving speech-to-text translation processes.

[0154] Each command in the command set is expressed in a radio message comprising an address field, a command field, and fields for parameters suitable to the command. In the following examples, Xx signifies the address of a particular vehicle, TB signifies the address of the trail boss module, and Bdcast signifies a message addressed to all the vehicles and to the trail boss module. The words inside the parentheses following the commands comprise allowable values for that command, not the parameter to hold those values. For example, the

herd speed command has one parameter, the values of which can be slow down or speed up. When the command is given, one of these values comprises the argument.

[0155] The trail boss module can cause the herding vehicles to form around the herd, by sending an assignment message to each of them, in the form:

[0156] Xx, assign (station), where Xx is the address of the herding vehicle; e.g., 104, assign is the command, and station is the parameter, with a value of: point, left swing, left flank, drag, right flank, right swing, stray catcher no. 1, stray catcher no. 2, or recharge. A herding vehicle-104 may be reassigned to another station by sending it an assign comment with a different station value.

[0157] When a stray is detected, the herding vehicle first detecting it broadcasts a message in the form: Bdcast, straydetected(lat, long). The trail boss module then sends a message to the stray catcher closest to the stray in the form: Xx, chasestray(lat,long). The stray catcher thus commanded uses the systems and methods outlined in this disclosure to corral the stray back into the herd.

[0158] Each herding vehicle can transmit the following telemetry reports, among others: Bdcast, herdposition(frontEdge, leftEdge, rightEdge, trailingEdge); Bdcast, herddestination(lat, long); Bdcast, herdcourse(degrees); Bdcast, mode(roundUp, herding).

[0159] When a herding vehicle 106 detects that it has a low battery level, 15% in the preferred embodiment, it sends a message to the trail boss module in the form: TB, replacement(request). After a herding vehicle goes to the battery replacement station 820 and receives a fully charged battery, it sends a message to the trail boss module in the form: TB, replacement(received), whereupon the trail boss module issues an appropriate assign command to the vehicle.

[0160] When the system wants to change the herd's direction, say to the right, as depicted in FIG. 10, either to adjust its course to reach the target location, or to avoid some obstacle. It calculates a new commanded heading for the herd and issues the following command over the radio link 204

[0161] Turn(right, 92°), to the herding vehicle point, where 92° is an example of one possible new heading.

[0162] Flight zone(enter), to the left swing and left flank herding vehicles

[0163] Flight zone(withdraw) to the right swing and right flank herding vehicles

[0164] Flightzone(withdraw), to the draft herding vehicle

[0165] Each vehicle receiving these commands employs its onboard sensor data and logic to alter direction and speed as appropriate to carry out the commands.

[0166] The point 714 moves in the desired direction, to the right in the figure, and the right swing herding vehicle-right swing 706 and right flank herding vehicle 710 do the same, increasing the distance between them and the herd. The left swing 704 and left flank 708 also move right, entering the flight zone of the animals on the herd's left. The drag 712 follows the herd as it turns. The result is that the herd turns to the right, motivated primarily by the entry of the left swing and left flank into the flight zone of the animals on the herd's left periphery. The right swing and right flank move to the right primarily to stay out of the flight zone of the animals on the herd's right periphery as it turns.

[0167] The left swing and the right swing move more to the right than the left flank and the right flank in order to cause the animals in the front of the herd to move more to the right than those in the back of the herd.

[0168] The system causes the herd to turn to the left by similar movements except, that the vehicles move to the left rather than to the right.

[0169] When the system wants to cause the herd to speed up, the left swing, left flank, right swing and right flank and drag vehicles slow down. This causes the herd to speed up, and the point vehicle also speeds up to stay out of the flight zone of the lead animals in the herd. This counterintuitive phenomenon occurs, because of the herd's instinct to move away from the vehicles, which they do as the herd speeds up while the vehicles (except for the point) slow down. The command is Xx, pointofbalance(back) to speed the herd up.

[0170] Similarly if the system wants the herd to slow down, the left swing, left flank, right swing, right flank speed up. The drags slows down to avoid the flight zone of the animals in the back of the herd. That causes the herd to slow down. The point vehicle slows down to maintain its original distance from the leading animals of the herd. The herd slows down to move away from the herding vehicles. The command is: s are: Xx, pointofbalance(forward), to cause the herd to slow down.

[0171] The trail boss module comprises logic that enables herding vehicles to corral strays back into the herd and that enables herding vehicles leaving the formation to receive a fresh battery to be replaced temporarily.

[0172] When the system detects that an animal has strayed from the herd, the stray catcher module deploys the closest stray catcher vehicle to close on the stray and to corral it back into the herd.

[0173] The system is capable of operating in either one of two modes: a roundup mode or a herding mode. The roundup mode is used when no animals or only a few animals have formed into a herd. It frees up herding vehicles to take up stray catcher positions to round up individual animals and to drive them into a herd. In the roundup mode, the location of the herd is defined arbitrarily as a particular location.

[0174] The round up mode coordinates multiple herding vehicles with stray detection and herding capabilities.

[0175] FIG. 17 illustrates the method for using the system and the relationship between the roundup mode and the herding mode. Initially, the system is set to roundup mode 1702, and a herd location 1704 is specified where the herd is to be formed. Then the several stray catchers identify strays 1706, the trail boss module sends the closest stray chaser 1708 to drive stray to the herd location 1710. That process is repeated 1736 until all the strays have been rounded up.

[0176] Then, the herd transitions to herding mode 1712, and the trail boss module dispatches the herding vehicles to their various stations 1714 to 1728. Once all the herding vehicles are on station, the trail boss module commands them to put the herd in motion 1730. Thereafter, the trail boss module issues the necessary commands to adjust herd heading and speed 1732, and the system simultaneously monitors for and corrals strays 1734 back into the herd.

[0177] In one embodiment of roundup mode, at most two vehicles are assigned to control the building herd, one herding vehicle-point 714 and one herding vehicle-drag 712, which move in semi-circles around the front and back of the herd respectively. Collectively and moving thus, the two are capable of keeping a small herd together. The other herding vehicles, 704 to 710 and 1224, are assigned as stray catchers. As the herd builds, the stray catchers are reassigned to herding stations.

[0178] At the beginning, all the animals are strays 814-824 with respect to the, initially empty, herd 102 position. As the stray catchers are launched, they roam until they detect an animal not in the herd location. They then send a message to the trail driver with that strayed animal's position, and the trail boss module directs the nearest stray catcher vehicle among herding vehicle 802 to herding vehicle 812 to herd that stray into the herd 102 position.

[0179] When the herd has been assembled, the roundup mode is complete and the system transitions into the herding mode. In the herding mode, the herding-vehicle stations are defined as follows with respect to the herd, which is moving in the direction of travel 716 indicated in FIG.7 The point is typically in front of the herd, 10 to 50 feet away from the leading edge of herd 902, just outside the flight zone. The drag is behind the herd, typically 10 to 50 feet away from the trailing edge of herd 904, just outside the flight zone, and constantly moving sideways from left to right and back. The left swing is on the left side of the herd toward the front. The left flank is on the left side of the herd toward the rear, both typically 10 to 50 feet away from the left edge of the herd 908, just outside the flight zone. The right flank is on the right edge of herd 912 toward the rear, and the right swing is on the right edge of herd 912 toward the front, typically 10 to 50 feet away from the right edge of the herd 1112, just outside the flight zone. The stray chasers have no fixed position but roam in the vicinity, remaining proximate to the herd so they are available to identify strays and corral them back into the herd as necessary.

[0180] At the option of the user, spare herding vehicles can be provided and remain at or near the battery-replacement station to be deployed to replace any original vehicle that has malfunctioned.

[0181] Once the trail boss module has assigned a herding vehicle to a particular station in the formation, the herding vehicle assumes responsibility for maintaining that station and reporting strays; in other words, whatever computation is necessary is performed on board the vehicle, in the maintain station computer 1502, eliminating the need for repeated telemetry or command radio signals until and unless a herding vehicle's station is changed, it needs a fresh battery, or the herd is redirected. The onboard maintain station computer 1502 places values for the target position of the vehicle on the API bus 1506 of that vehicle, from which they are retrieved by the delivered navigation and control system 1504 and translated into pitch, yaw, roll, and thrust commands appropriate to cause the vehicle to close on the target position.

[0182] The maintain station computer 1502 constantly recomputes the target position for the vehicle from updated information about the position of the herd. It applies flight zone and point of balance information in that computation. As the current position of the vehicle differs from the target position, the maintain-station module sends appropriate speed and heading commands to the built-in navigation system of the vehicle, which translates them into actuator commands for the propulsion, suspension, and steering subsystems of the vehicle.

[0183] The trail boss computer 1602 communicates with one or more remote control devices delivered with the herding vehicle. In one embodiment, a remote control device delivered with a herding vehicle is modified to make it capable of communicating with any or all of the remote control vehicles comprising a formation by addressing them individually over the radio link or by addressing all of them. This modified remote control device is physically connected to the trail boss module in an appropriate enclosure. In an alternative embodiment, each herding vehicle has its own remote control device delivered with the vehicle, in which case the trail boss module sends data to and receives data from each remote control device separately for its assigned vehicle.

[0184] The trail-boss module maintains a copy of each vehicle's data structure 1614 and updates it periodically, once per second in one embodiment. The trail-boss module also maintains a data structure for the herd 1622 and similarly updates it at the same frequency. The trail-boss module has templates for each station in the formation, derived from research and experience in animal husbandry. Those templates contain values for distance from the edge of the herd and angle with respect of the herd, representing flight zone and point of balance. It uses these templates to calculate assigned positions for station and transmits the position value to the herding vehicle assigned to that station. Each vehicle maintains and updates the position data thereafter through its maintain-station computer 902. The trail-boss module transmits the entire contents of the template for each herding vehicle to that vehicle and transmits an updated copy whenever the values change.

[0185] Values are read onto the remote control API bus 1606 from the herding vehicle data structure 1614, from whence they are read into the herding vehicle's delivered navigation and control system 1504. Values for current location, speed, and heading are placed onto the API bus by the supplied navigation and control system and read into the herding vehicle data structure.

[0186] Commands from the trail boss module are read from the radio bus 1508 into the herding vehicle data structure 1614. These include assigned station, commanded position, and alert. These values are taken from the data bus and read into the maintain station computer 1502 and transformed as necessary into values for handling by the the delivered navigation and control system 1504.

[0187] FIG. 18 depicts the battery-replacement process. The battery-replacement station is a commercially available off-the-shelf automatic-landing-zone, battery-charger and battery-

replacement system (the “battery battery-replacement station”) capable of directing a vehicle to dock in the proper place on the landing zone, after which it removes the nearly depleted battery and places it on the charging apparatus. The apparatus inserts a fully charged battery into the vehicle.

[0188] When a vehicle detects that its battery is getting low—below 15% in the preferred embodiment—1802, it sends a message to the trail boss module 1804. The message causes the trail boss module to command the vehicle to leave formation and go to battery replacement station 1806. The trail boss module then sends a message to the nearest stray catcher vehicle instructing it to take up the station vacated by the vehicle that has left to receive a fresh battery 1808. The battery replacement station extracts the low battery and connects it to charging apparatus 1810 and installs a fully charged battery 1812. The herding vehicle then sends a message to the trail boss 1814, the trail boss commands vehicle launch 1816 and assigns the vehicle to a new station 1818, typically to the newly vacated stray catcher position.

[0189] The battery-replacement station can handle only one herding vehicle at a time, so the initial round of charging must be staggered lest all of the vehicles reach their critical charge point at the same time and require a visit to the battery-replacement station. The trail boss module is programmed to command an initial round charging, in which one vehicle is selected arbitrarily to visit the battery-replacement station and have its battery replaced, even though it may have 85 to 90% of a charge remaining. Then that vehicle, with a fully charged battery, returns to the formation, and a next vehicle is selected arbitrarily to visit the battery-replacement station for a battery replacement. This process proceeds until all of the vehicles have fresh batteries. After this initial round of battery replacement, the timing of battery depletion will be staggered. The first vehicle to have visited the battery-replacement station will reach the critical threshold first and visit again to receive a fresh battery, and so on through the entire collection of herding vehicles.

[0190] The battery-replacement station must be able to handle the initial round of charging with a sufficient number of fully charged batteries. No more batteries should be required than the total number of herding vehicles in the system.

[0191] The source of electrical power must be adequate to handle the total number of batteries. The battery-replacement station is powered by solar panels of appropriate size, approximately three square feet in area in the preferred embodiment. An auxiliary gasoline or diesel engine backs up the solar power in one embodiment. Fixed batteries in the battery-

replacement station serve as a buffer and storage medium between the electrical source and the vehicle-battery charging apparatus.

INDUSTRIAL APPLICABILITY

[0192] The system and method apply technology-based solutions to enhance the efficiency, safety, and effectiveness of herding stray animals back into their designated herds. They integrate advancements in autonomous vehicle technology, artificial intelligence, GPS and sensor-based localization, and behavioral science to automate the process of detecting, approaching, and guiding stray animals back to their herds without the need for direct human intervention.

[0193] Within the broader context of agricultural technology and smart farming, the system and method address a specific yet critical aspect of livestock management. They offer a novel approach to solving the age-old problem of managing strays, which is a common challenge in the farming of cattle, sheep, goats, and other herd animals. By automating the herding process, this system and method not only aim to reduce labor costs and dependency on human or canine herders but also seeks to minimize the stress and potential harm to animals during the retrieval process.

[0194] The system and method can be used efficiently on different sized ranching and farming operations, with different numbers of animals. In small operations, including feedlots, one herding vehicle can be useful to corral strays and to direct animals into chutes and vehicles. In larger operations, multiple vehicles can control entire herds of substantial size and drive them to destinations over considerable distances.

[0195] While operations of intermediate size can use fewer than eight herding vehicles, this disclosure and the figures illustrate how a full eight can be used. A smaller operation needing more than one but fewer than eight can adapt the system and method using knowledge of the operation's particular needs. Larger operations can use more than eight. The system and method operate at the intersection of several areas of technology and agriculture: robotics and autonomous vehicles, artificial intelligence and machine learning, animal behavior and welfare, and GPS and sensor technology. They represent a significant step forward in the application of technological innovations to traditional farming practices, contributing to the evolution of smart farming techniques that can lead to more sustainable, efficient, and humane agricultural practices.

CLAIMS

I claim:

1. A system for detecting stray animals and driving them back into a herd, comprising:
 - an autonomous herding vehicle configured to identify a herd of animals and a stray;
 - a global navigation system;
 - the autonomous herding vehicle comprising:
 - a sensor module; a computer, comprising:
 - an animal detection module, which uses image templates derived from machine learning;
 - a location module;
 - a herding module, which uses models of animal flight behavior to calculate:
 - a circle representing a stray's flight zone, wherein the radius of said circle being equal to a distance from the stray such that the autonomous herding vehicle moving closer to the animal than that distance will cause the stray to move away from the autonomous herding vehicle;
 - a stray's point of balance, wherein the stray's point of balance is a point such that: when the autonomous herding vehicle moves to a location to position the head of the stray between the autonomous herding vehicle and the stray's point of balance will cause the stray to move backwards, and when the autonomous herding vehicle moves to a location to position the tail of the stray between the autonomous herding vehicle and the stray's point of balance will cause the stray to move forward;
 - a navigation module comprising:
 - a program that computes:
 - a first vector representing a course the herding vehicle must follow to close on the stray;
 - a second vector representing a path the stray must follow to return to the herd; and
 - a third vector connecting said animal flight zone and animal point of balance to the herding vehicle;
 - a fourth vector representing a path the autonomous herding vehicle must follow to position the vehicle within the stray's flight zone and forward or back of its point of balance to cause the stray to return to the herd; and
 - a communications module;

- a propulsion module;
- a suspension module;
- an alerting module;
- a data bus connecting the modules; and
- a commercially available remote control device, delivered with the vehicle, capable of transmitting and receiving radio signals comprising commands to the vehicle; generating movement of the autonomous herding vehicle to follow said fourth vector.

2. The system of claim 1, wherein the sensor module comprises:

- a camera-LiDar fusion device;
- a global navigation system radio receiver;
- an inertial measurement unit; and
- a control signal radio receiver.

3. The system of claim 1, wherein the animal detection module comprises:

- a program that integrates the signals received from the sensor module to form a sensed image;
- a machine-learning-derived repository of animal images for comparison with images obtained by the sensor module, wherein the repository is developed by applying algorithms learned from large learning databases of animal images; and
- a program that compares the sensed image to animal images from the repository comprising the herd and sets a flag when it recognizes the sensed image as representing such an animal.

4. The system of claim 1, wherein the location module comprises:

- a program that calculates the position of the herding vehicle on which it is installed;
- a program that calculates the position of the herd;
- a program that calculates the position of the stray with respect to the herd; and
- a program that calculates the position of the herding vehicle with respect to the stray.

5. The system of claim 1, wherein the propulsion module comprises:

- a commercially available unmanned aerial vehicle of the rotorcraft type, comprising:
 - a plurality of rotors and flight controls sufficient to cause the vehicle to leave the ground and hover and travel at up to 35 miles per hour through the air;

an on-board sensor module and navigation module necessary to control the vehicle; and
a radio link with a remote control module capable of sending control commands to the vehicle.

6. The system of claim 1, wherein the herding vehicle comprises:

a commercially available ground vehicle of the ATV type, comprising:
a plurality of wheels, axles, and steering mechanisms to cause the vehicle to travel at up to 35 miles per hour over the ground;
on-board sensors and navigation subsystems necessary to control the vehicle; and
a radio link to a remote control device.

7. The system of claim 1, wherein the herding vehicle comprises: a commercially available unmanned aerial vehicle of the rotorcraft type.

8. The system of claim 5, wherein the alerting module comprises:

data links to the location, navigation, and herding modules;
a visual signaling device; a loudspeaker; a computer; and
a computer program capable of generating one of audio signals comprising:
a loud horn sound;
a replica of the sound of an animal in distress, derived from empirical animal data; and
a replica of the sound of a human cowboy shouting “Ha-yah! Ha-yah!”, derived from empirical animal data; and
visual signals comprising flashes of light; and
rapid movements of physical signaling devices and of the herding vehicle causing the herding vehicle to fly rapidly left, right, forward and back within a circle having a diameter of about 6 feet; and

logic that causes the computer program to send an audio signal to the loudspeaker with one of the horn sound, the sound of the animal in distress, and or the “Ha-yah! Ha-yah” sound and to send a visual signal to the visual signaling device when the computer program receives an activation signal from the navigation and location modules.

9. A method for herding stray animals back into a herd, comprising:

obtaining a herding vehicle; locating the herding vehicle; identifying a herd of animals;
identifying an animal that has strayed from the herd;

locating the herd;

locating the stray;

determining a path necessary for the herding vehicle to close on the stray;

determining a circle representing a stray's flight zone, wherein the radius of said circle being equal to a distance from the stray such that the herding vehicle moving closer to the animal than that distance will cause the stray to move away from the herding vehicle;

determining a stray's point of balance, wherein the stray's point of balance is a point such that: when the herding vehicle moves to a location to position the head of the stray between the herding vehicle and the stray's point of balance will cause the stray to move backwards, and when the herding vehicle moves to a location to position the tail of the stray between the herding vehicle and the stray's point of balance will cause the stray to move forward;

determining the movements of the herding vehicle necessary to position the vehicle within the stray's flight zone and forward or back of its point of balance to cause the stray to return to the herd; and

generating a specific noise or movement derived from empirical animal data to induce the stray's motivation to return to the herd.

10. The method of claim 9, wherein locating the herding vehicle comprises the steps of:

acquiring signals from a global navigation system; and

determining the latitude and longitude of the herding vehicle.

11. The method of claim 9, wherein identifying a herd of animals comprises the steps of:

selecting a type of animal;

acquiring images from a camera and lidar fusion device;

comparing those images to templates of selected animals derived by machine learning, wherein the templates are developed by applying algorithms learned from large learning databases of animal images; and

computing distance and azimuth from herding vehicle to matching images.

12. The method of claim 9, wherein identifying an animal that has strayed from the herd comprises:

identifying a single animal at a distance of more than 50 feet from the herd; and

determining the location of the animal.

13. A system for herding animals comprising:

- a plurality of autonomous herding vehicles, assigned to stations; each equipped with a maintain-station module; a trail-boss module; a battery replacement station;
- radio links allowing the trail boss module and the plurality of autonomous herding vehicles to exchange digital messages;
- computing devices configured to
 - launch the plurality of autonomous herding vehicles;
 - locate individual animals and groups of animals;
 - round up said individual animals and groups of animals and bunching them into a herd;
 - determine a herd destination;
 - operate a first autonomous vehicle of the plurality of autonomous herding vehicles to be positioned on the left side of the herd;
 - operate a second autonomous vehicle of the plurality of autonomous herding vehicles to be positioned behind the herd;
 - operate a third autonomous vehicle of the plurality of autonomous herding vehicles to be positioned to the right of the herd;
 - operate a fourth autonomous vehicle of the plurality of autonomous herding vehicles to roam in the vicinity of the herd;
 - determine a desired herd speed;
 - cause the herd to move toward the destination at the desired speed by commanding one or more of the plurality of autonomous herding vehicles to enter the herd's flight zone, and
 - positioning the plurality of autonomous herding vehicles forward of the herd's point of balance to cause the herd to move backwards or positioning the plurality of autonomous herding vehicles with back of the herd's point of balance to cause the herd to move forward;
 - allow a vehicle of the plurality of autonomous vehicles to leave its position and move to the battery-replacement station automatically to receive a new fully charged battery;
 - replace the vehicle that has left the formation to receive a new battery with another vehicle of the plurality of autonomous vehicles;
 - detect one or more animals that has strayed from the herd; and
 - send the fourth autonomous vehicle-to corral the strayed animal back into the herd.

14. The system for herding animals of claim 13, wherein the stations comprise:

- at least one point;
 - at least one left swing;
 - at least one left flank; at least one drag;
 - at least one right flank; at least one right swing;
 - at least one stray chaser; and
 - optionally, one or more spares.
15. The system for herding animals of claim 13, wherein the autonomous herding vehicles are commercially available autonomous aerial vehicles.
16. The system for herding animals of claim 13, wherein the battery replacement station comprises:
- a commercially available landing pad, capable of:
 - receiving a herding vehicle;
 - removing the herding vehicle's battery;
 - replacing the battery with a fully charged battery suitable for the herding vehicle; and
 - accepting the herding vehicle's battery and charging it;
 - a source of electrical power; and
 - components that charge batteries.
17. The system for herding animals of claim 13, wherein the trail boss module comprises:
- a computer;
 - a radio bus;
 - a radio link;
 - an API bus that communicates with a navigation and control system part of a remote control device associated with the plurality of autonomous herding vehicle; and
 - logic that enables the plurality of autonomous herding vehicles to direct and control the movements of the herd by movements of the plurality of autonomous herding vehicles, sounds, and visual cues.
18. A method for herding animals comprising:
- obtaining a landing pad and battery replacement station;
 - obtaining a plurality of autonomous herding vehicles;
 - launching the plurality of autonomous herding vehicles;

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locating individual animals and groups of animals;
rounding up said individual animals and groups of animals and bunching them into a herd;
determining a herd destination;
operating a first autonomous vehicle of the plurality of autonomous herding vehicles to be positioned on the left side of the herd;
operating a second autonomous vehicle of the plurality of autonomous herding vehicles to be positioned behind the herd;
operating a third autonomous vehicle of the plurality of autonomous herding vehicles to be positioned to the right of the herd;
operating a fourth autonomous vehicle of the plurality of autonomous herding vehicles to roam in the vicinity of the herd;
determining a desired herd speed;
causing the herd to move toward the destination at the desired speed by commanding one or more of the plurality of autonomous herding vehicles to enter the herd's flight zone, and
positioning the plurality of autonomous herding vehicles forward of the herd's point of balance to cause the herd to move backwards or positioning the plurality of autonomous herding vehicles with back of the herd's point of balance to cause the herd to move forward;
allowing a vehicle of the plurality of autonomous vehicles to leave its position and move to the battery-replacement station automatically to receive a new fully charged battery;
replacing the vehicle that has left the formation to receive a new battery with another vehicle of the plurality of autonomous vehicles;
detecting one or more animals that has strayed from the herd; and
sending the fourth autonomous vehicle to corral the strayed animal back into the herd.

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TITLE OF INVENTION

AUTONOMOUS VEHICLES FOR HERDING ANIMALS

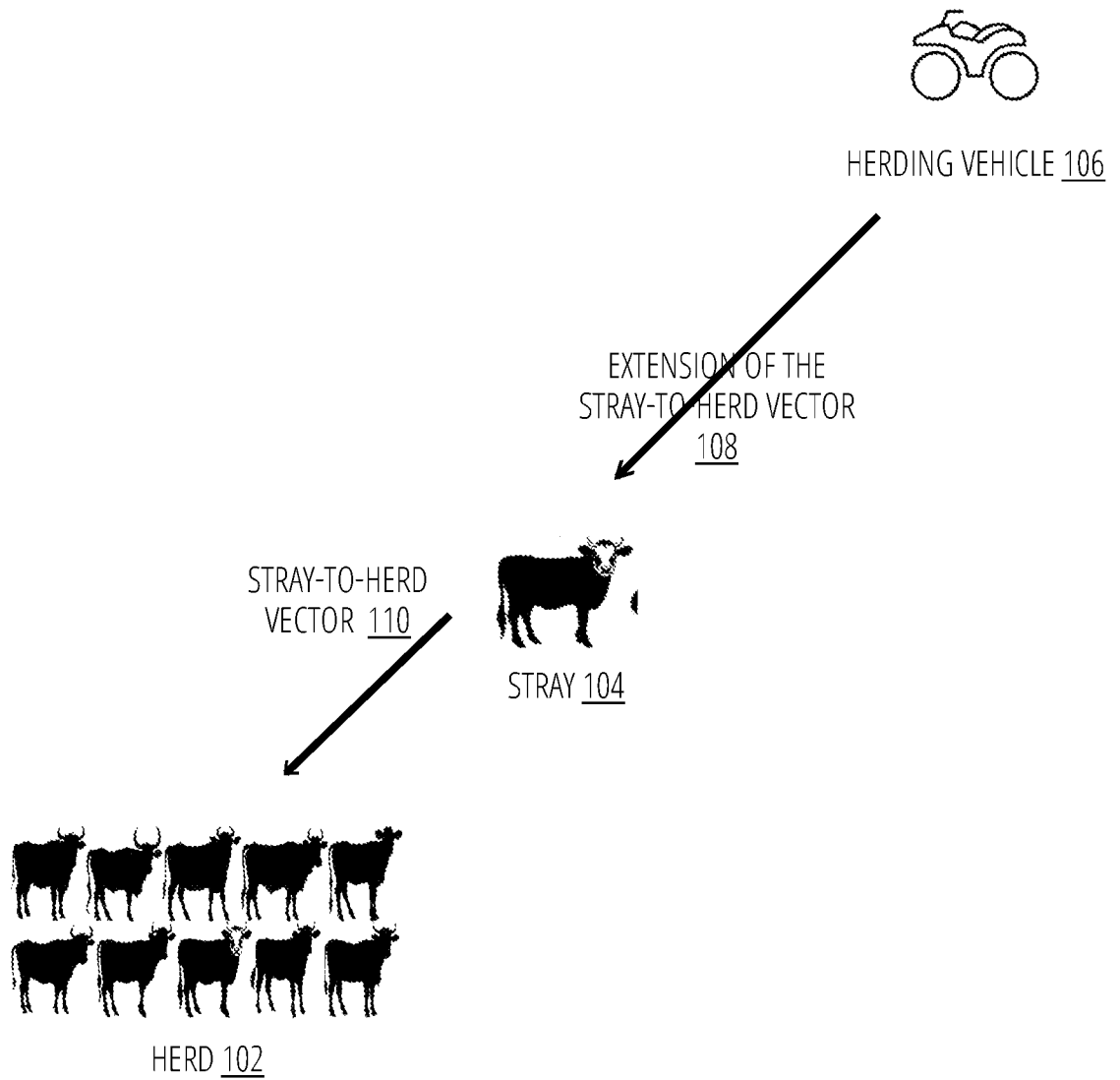
ABSTRACT

An autonomous herding system using a fleet of vehicles to manage and retrieve stray animals, combining technologies from U.S. Patents US 12102060 and US 12153451. The system employs autonomous vehicles equipped with optical-LiDAR sensors, GPS, and machine-learning image recognition to detect and guide strays back to the herd. Vehicles operate in two modes: roundup, for gathering scattered animals, and herding, for maintaining cohesion and directing movement. Positioned in traditional formations (point, swing, flank, drag), they use strategic movements, visual cues, and audio signals to influence herd behavior based on flight zone and point-of-balance principles. A trail boss module coordinates vehicle actions, ensuring efficient herd control. The system includes a battery replacement station for continuous operation, automatically swapping depleted batteries. This integration streamlines livestock management, reducing labor costs while improving animal and handler safety.

ABSTRACT

An autonomous herding system using a fleet of vehicles to manage and retrieve stray animals, combining technologies from U.S. Patents US 12102060 and US 12153451. The system employs autonomous vehicles equipped with optical-LiDAR sensors, GPS, and machine-learning image recognition to detect and guide strays back to the herd. Vehicles operate in two modes: roundup, for gathering scattered animals, and herding, for maintaining cohesion and directing movement. Positioned in traditional formations (point, swing, flank, drag), they use strategic movements, visual cues, and audio signals to influence herd behavior based on flight zone and point-of-balance principles. A trail boss module coordinates vehicle actions, ensuring efficient herd control. The system includes a battery replacement station for continuous operation, automatically swapping depleted batteries. This integration streamlines livestock management, reducing labor costs while improving animal and handler safety.

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**FIG. 1**

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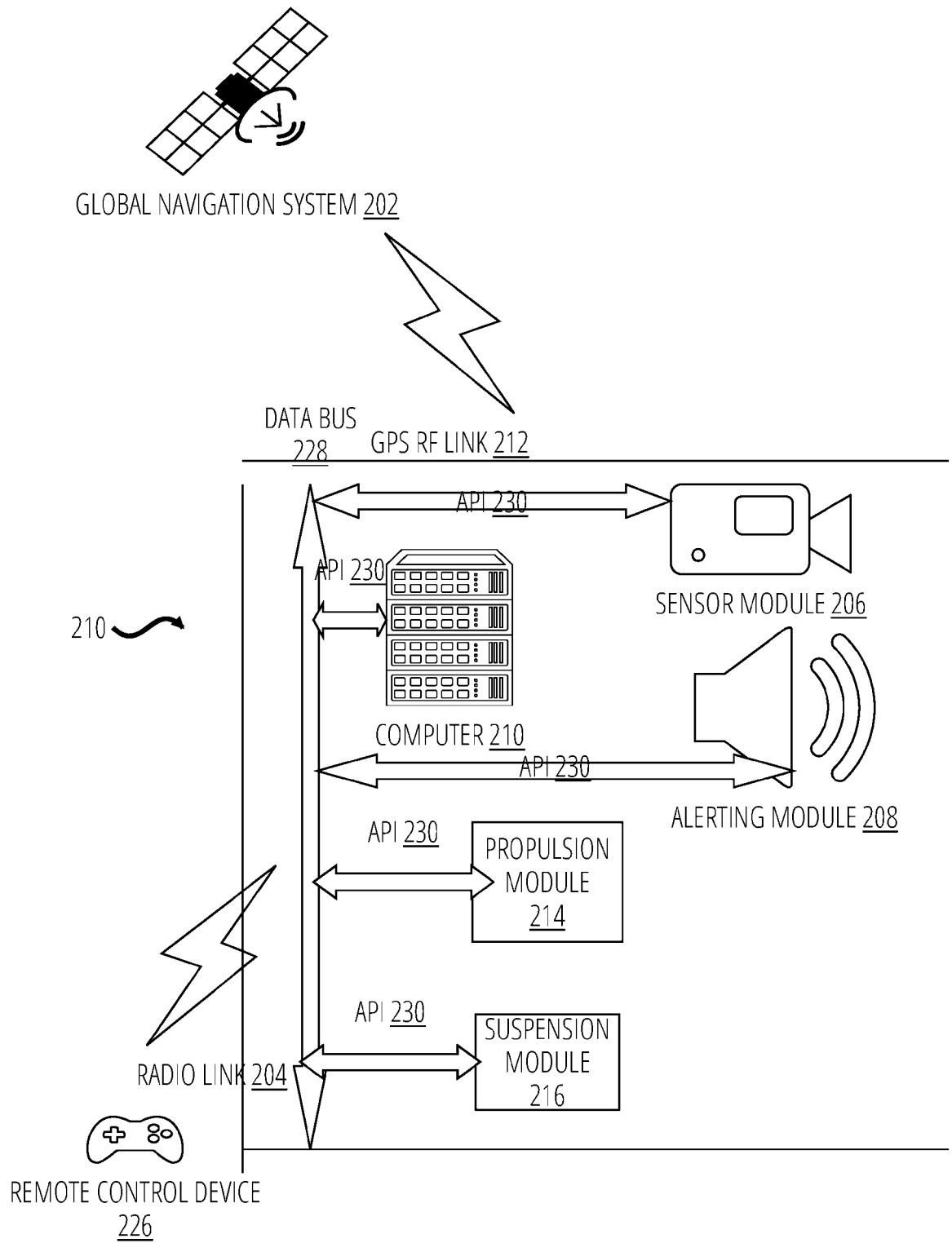
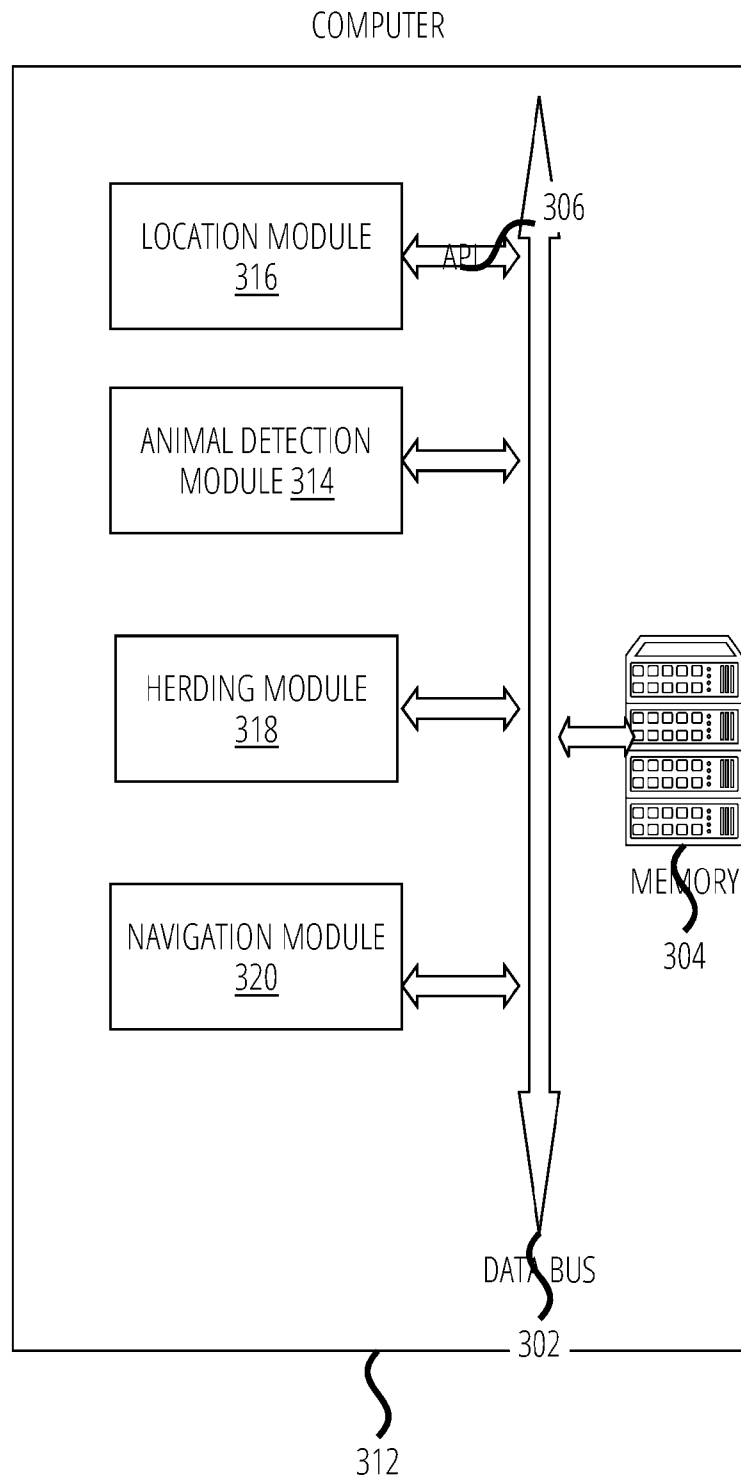


FIG. 2

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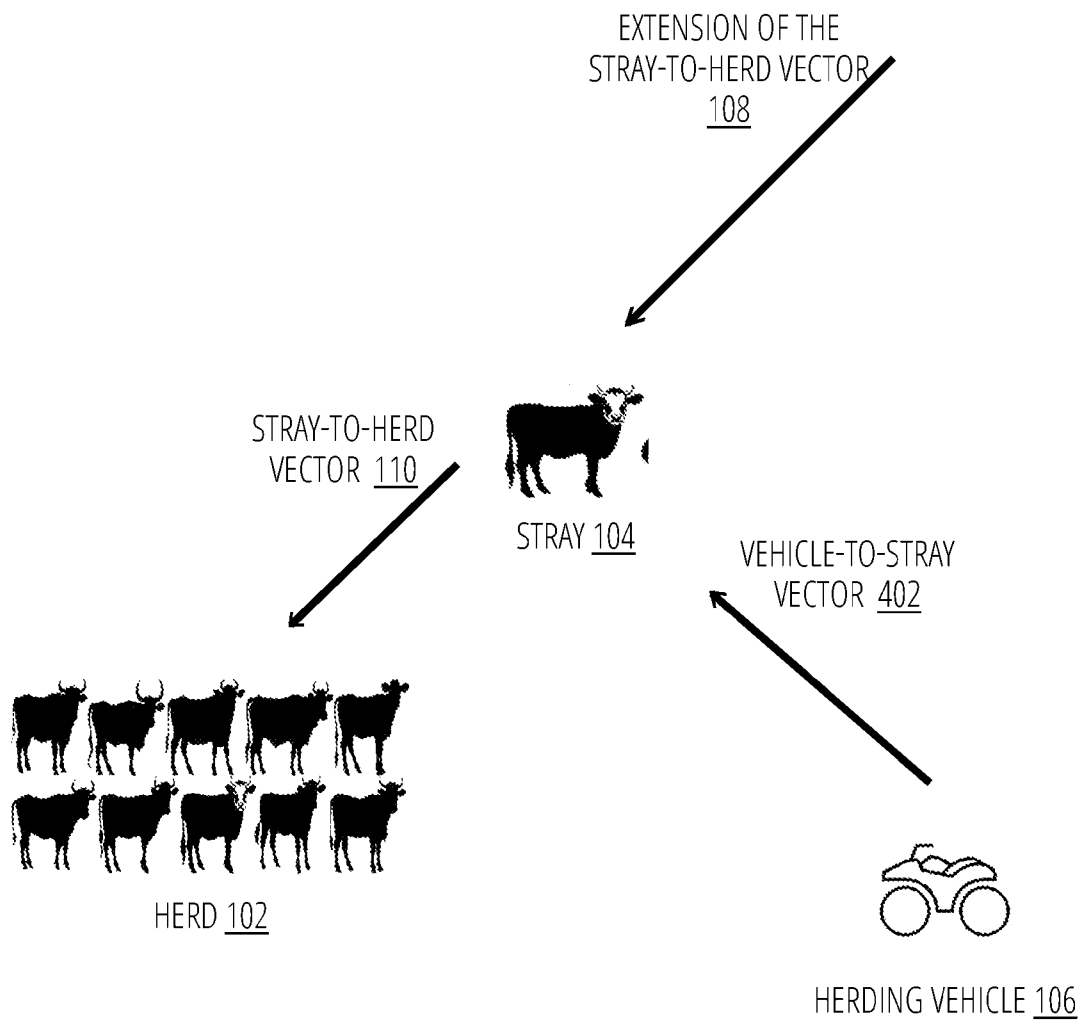


FIG. 4

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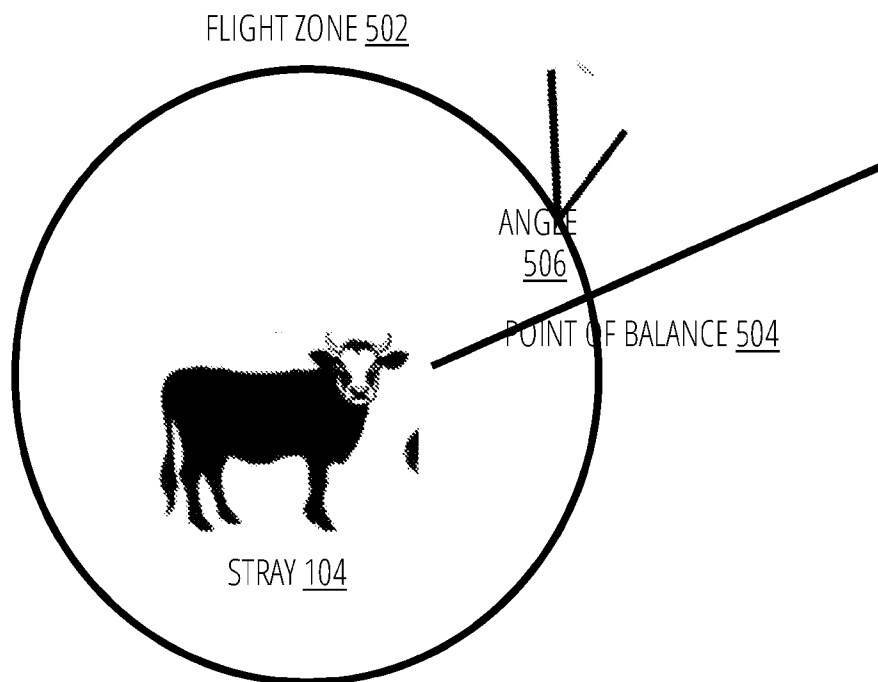
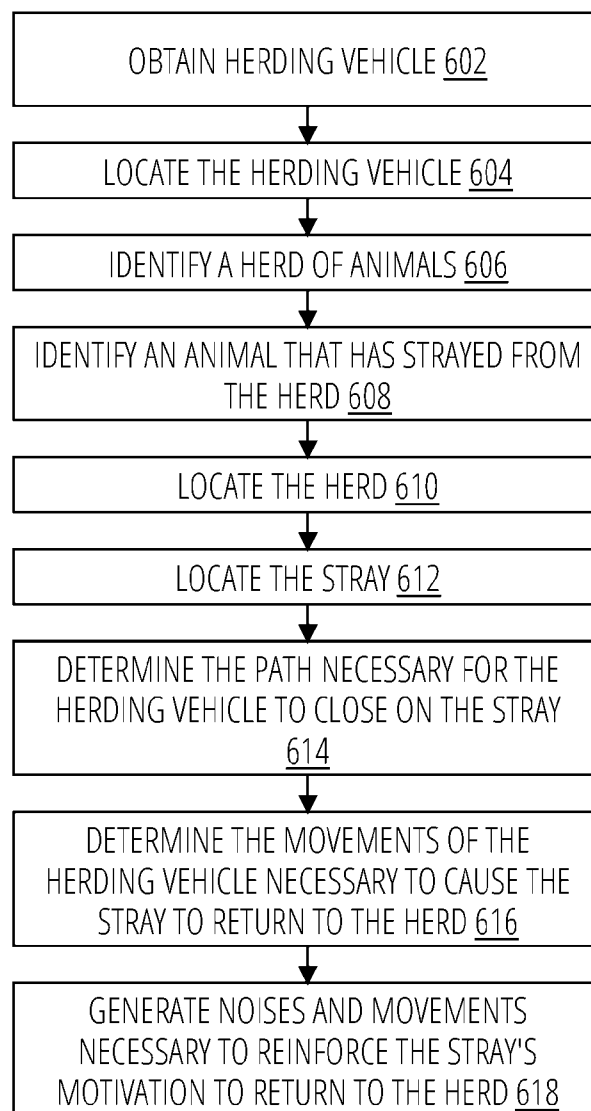


FIG. 5

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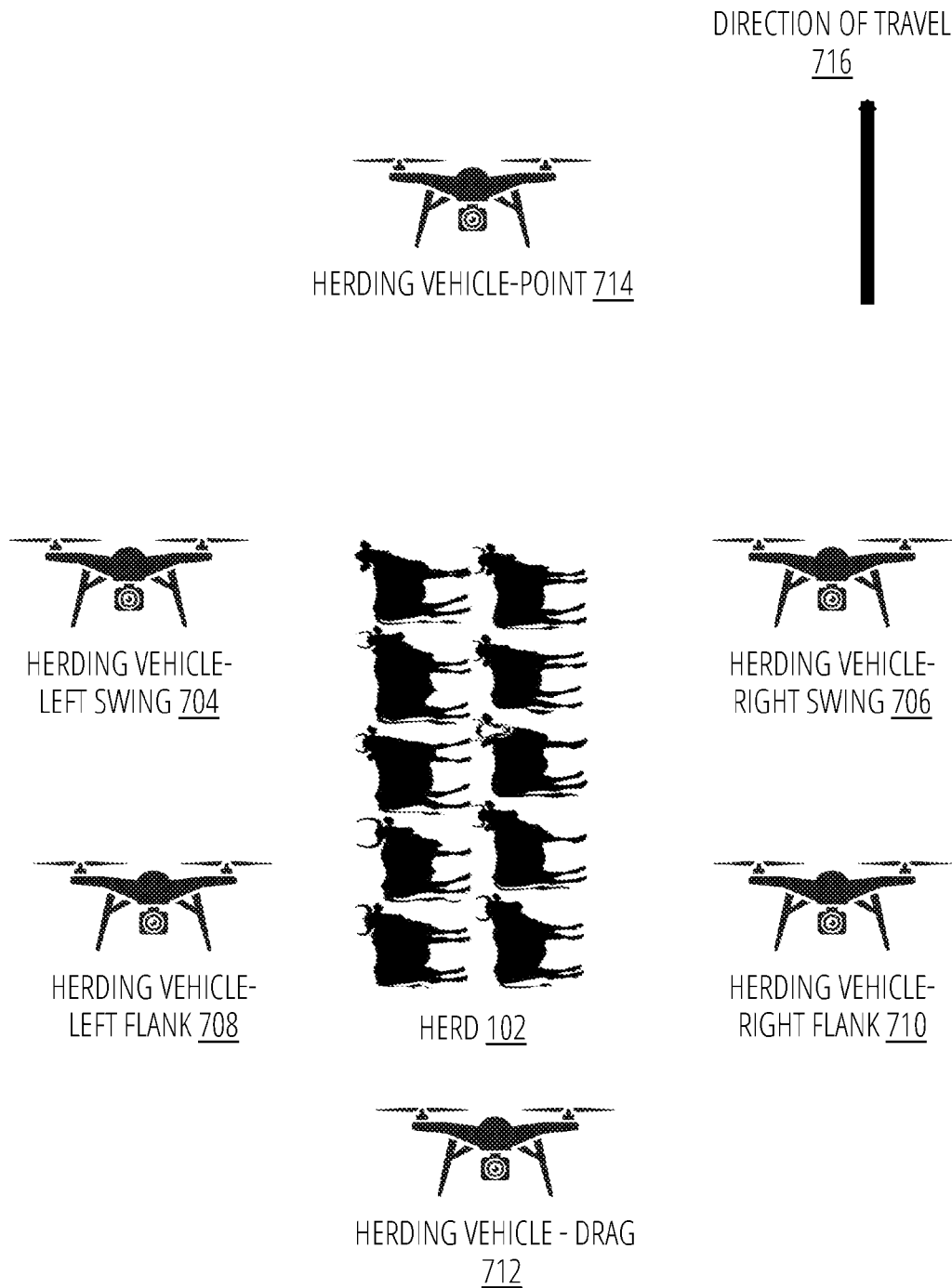
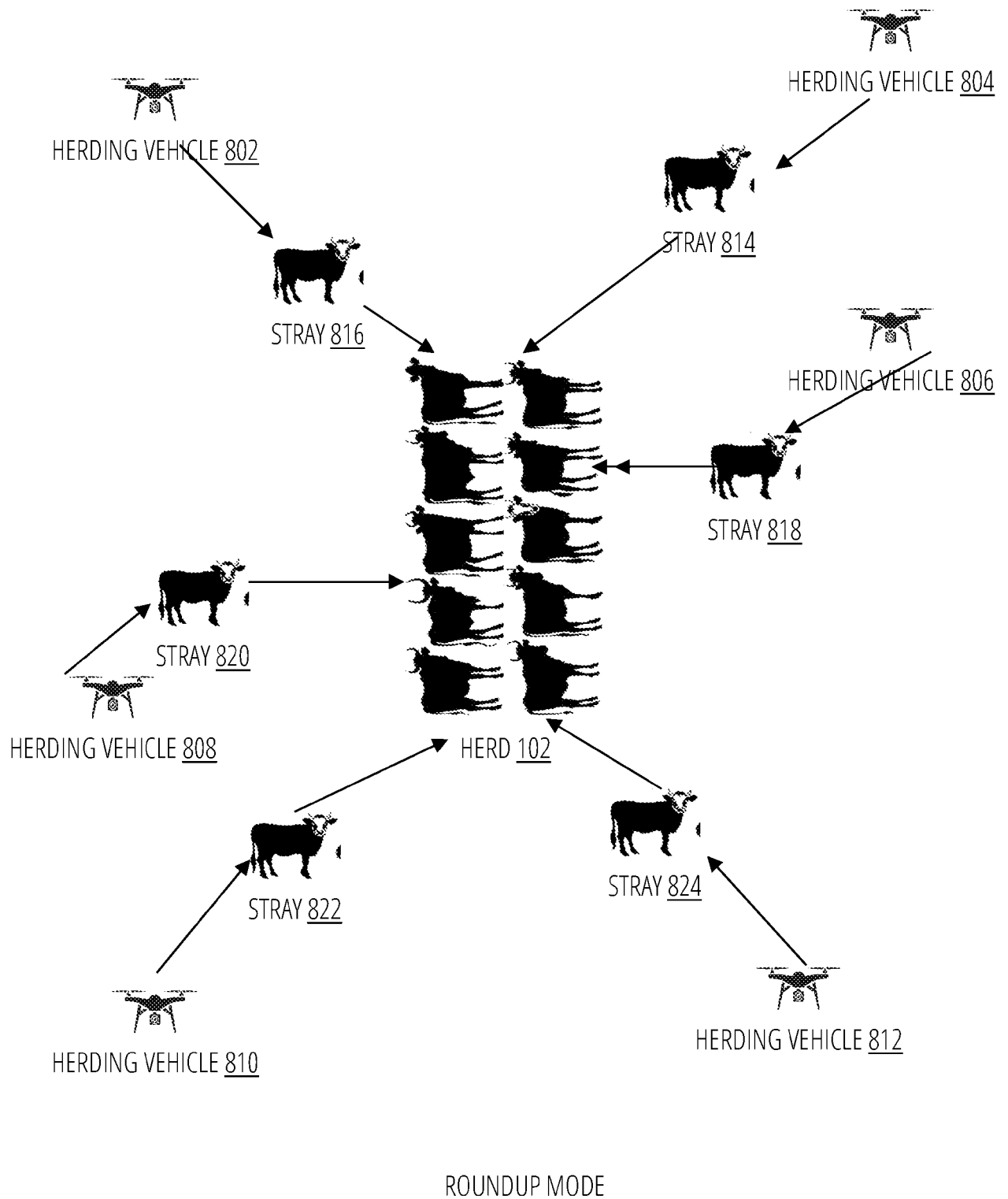


FIG. 7

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**FIG. 8**

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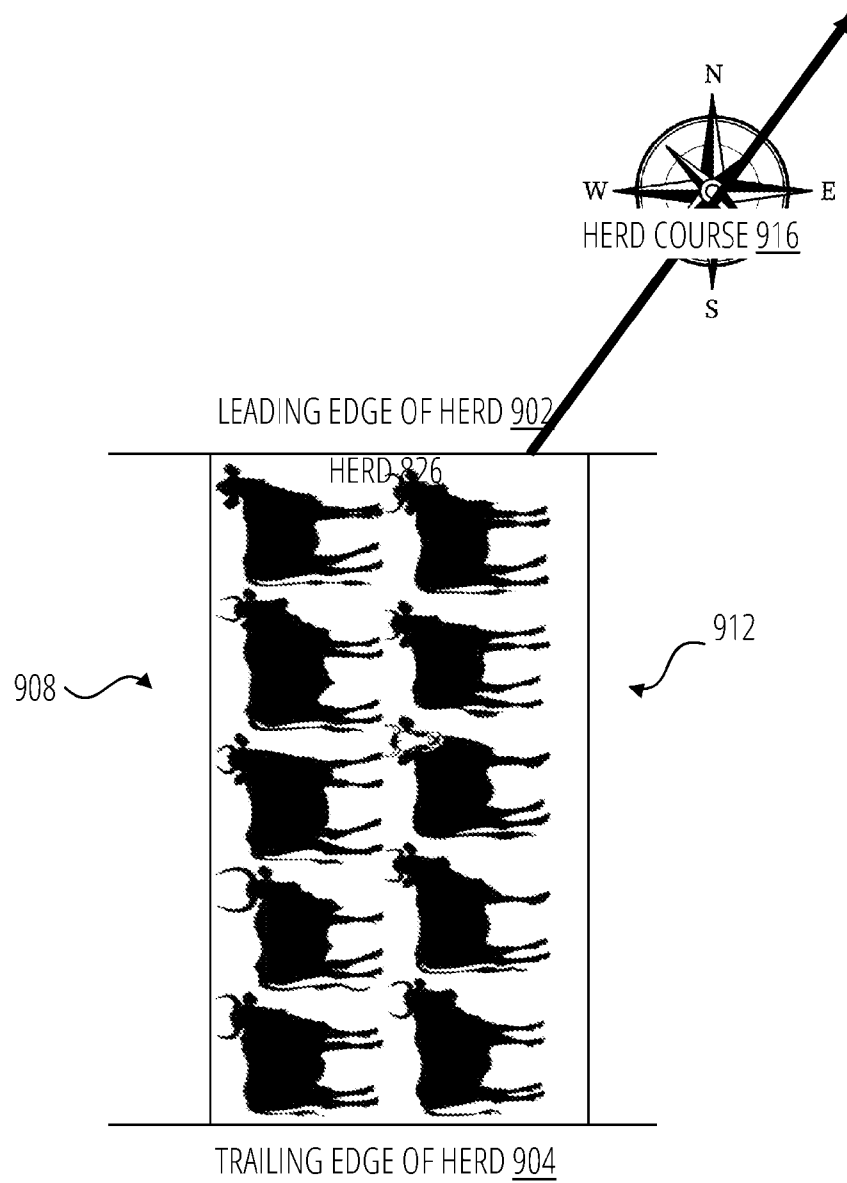


FIG. 9

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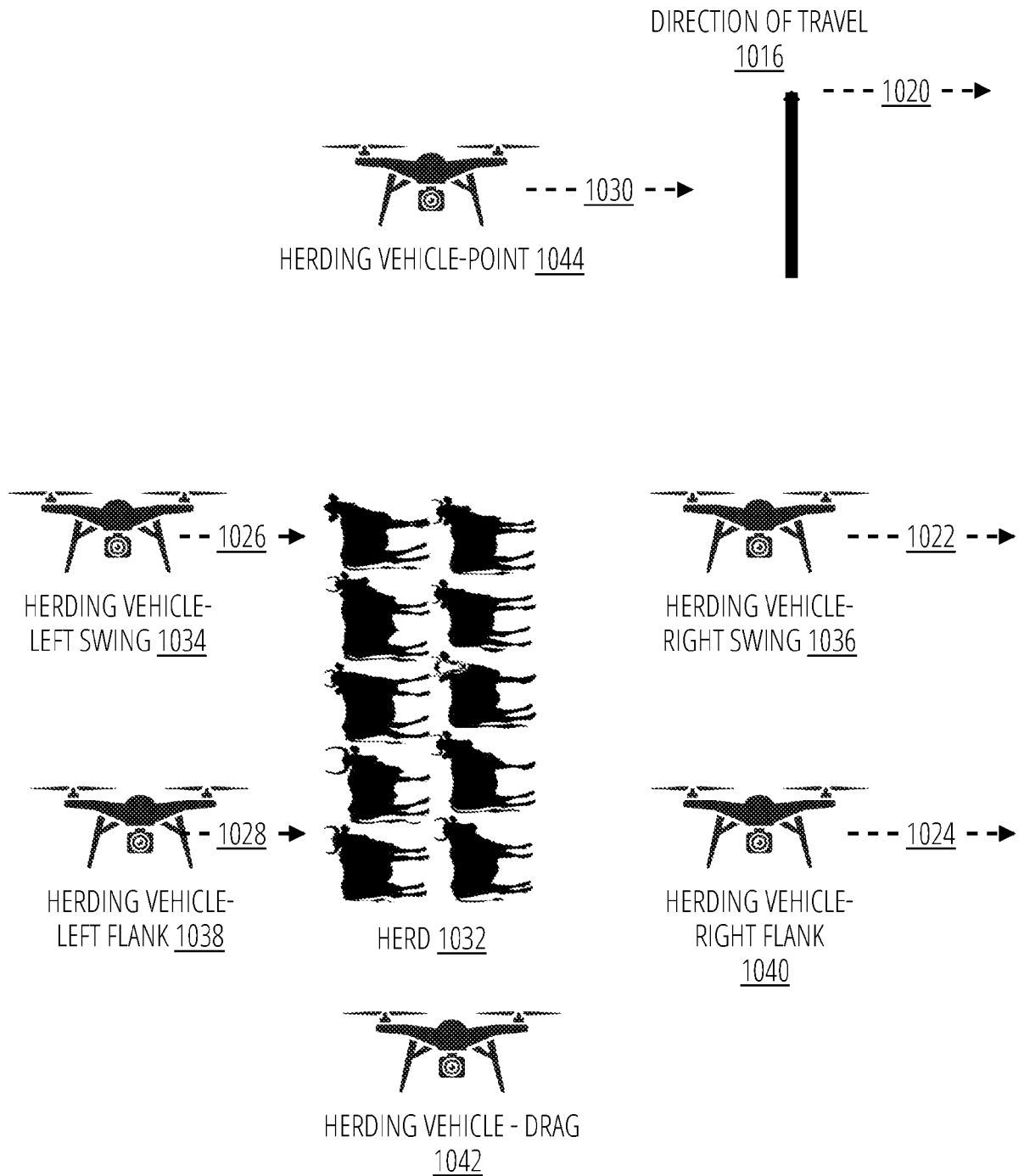
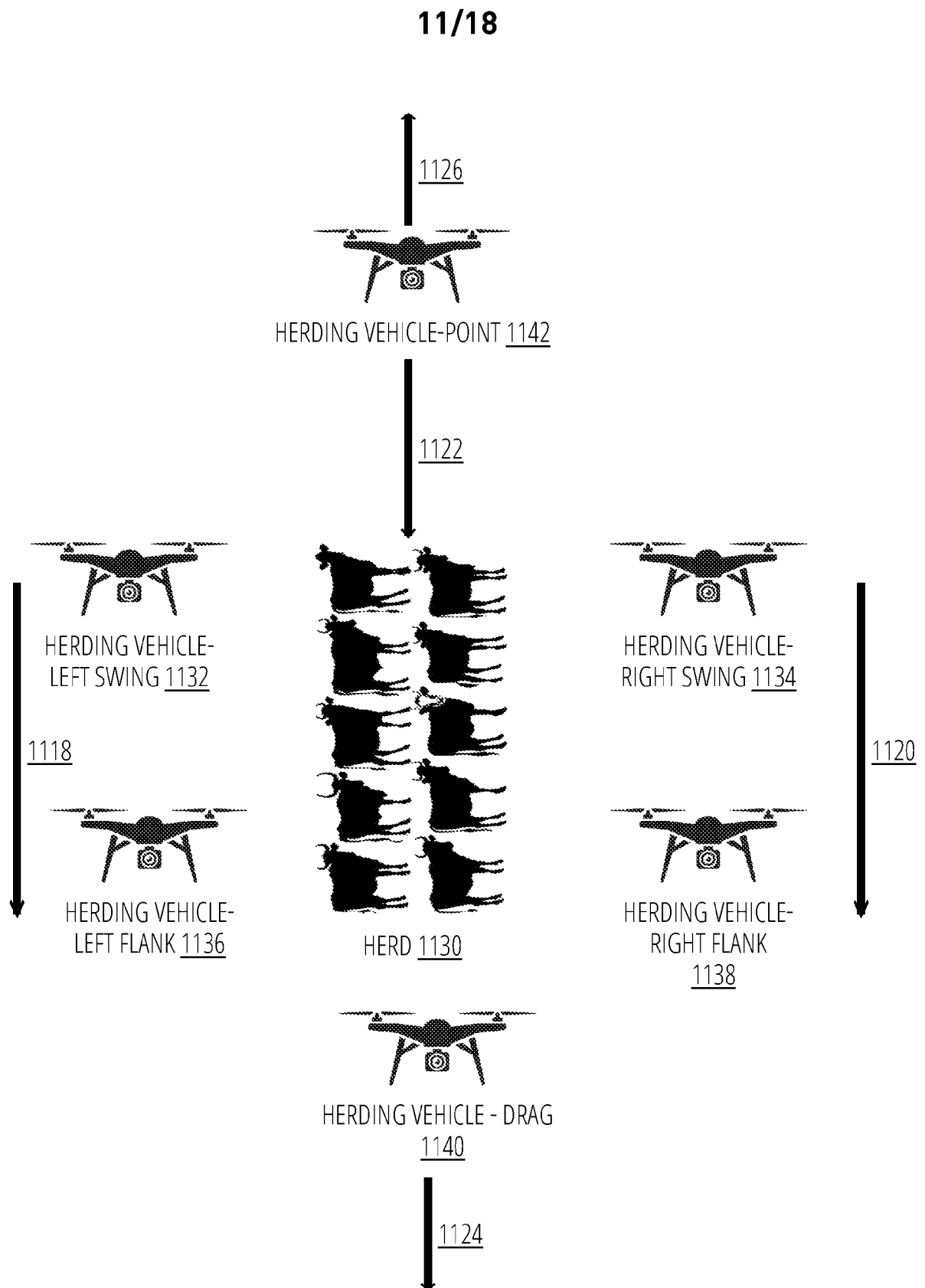


FIG. 10



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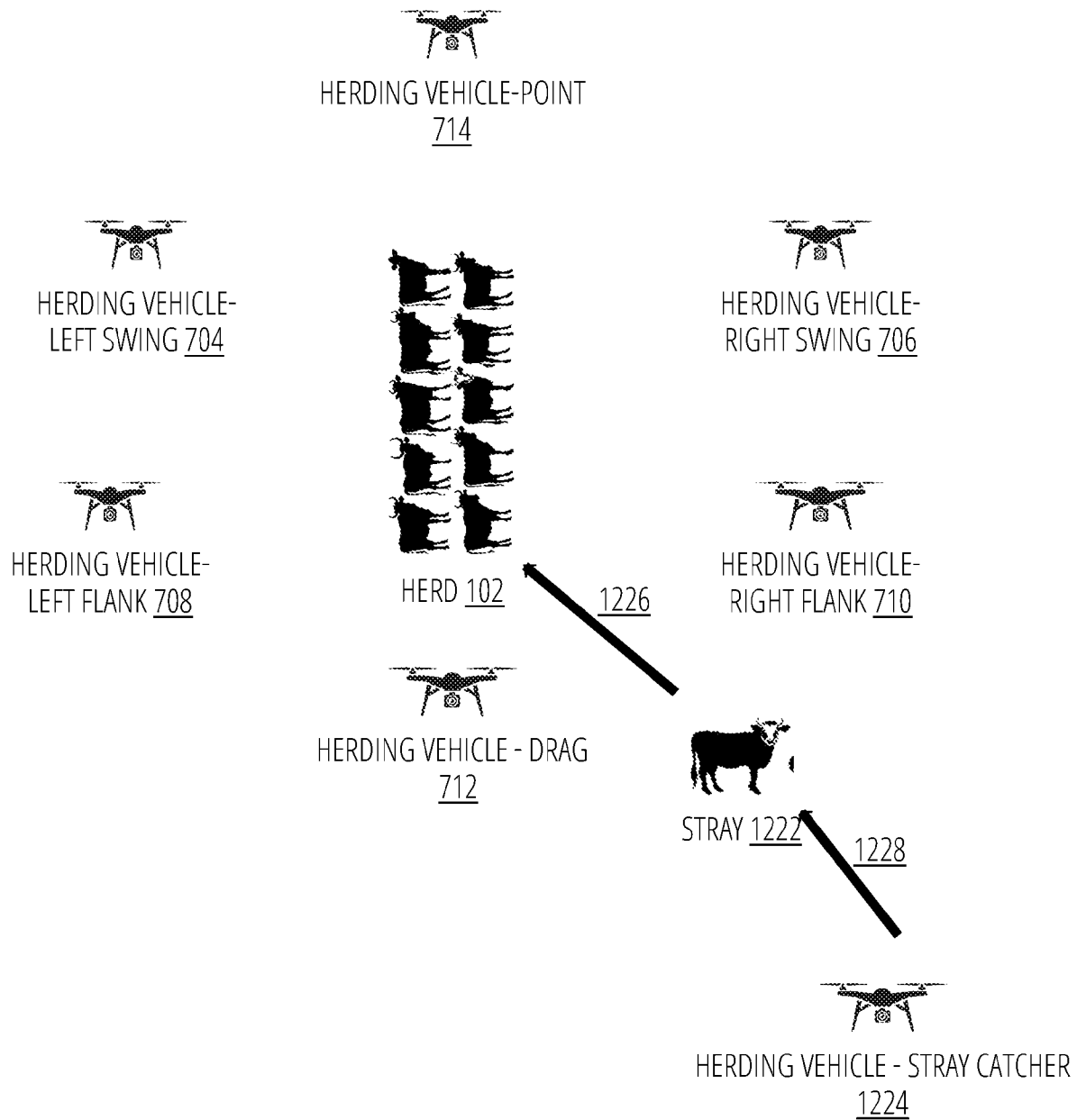


FIG. 12

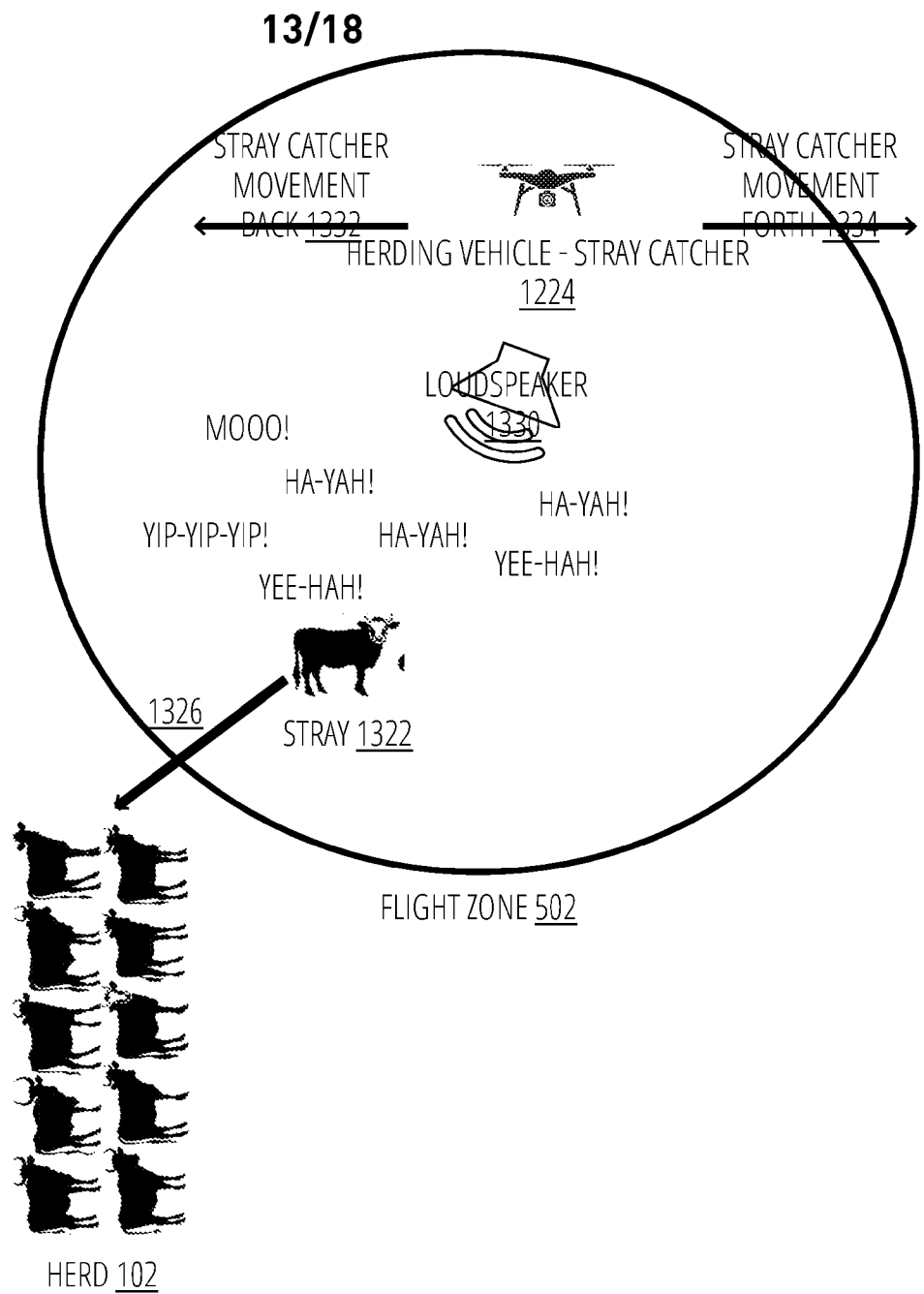


FIG. 13

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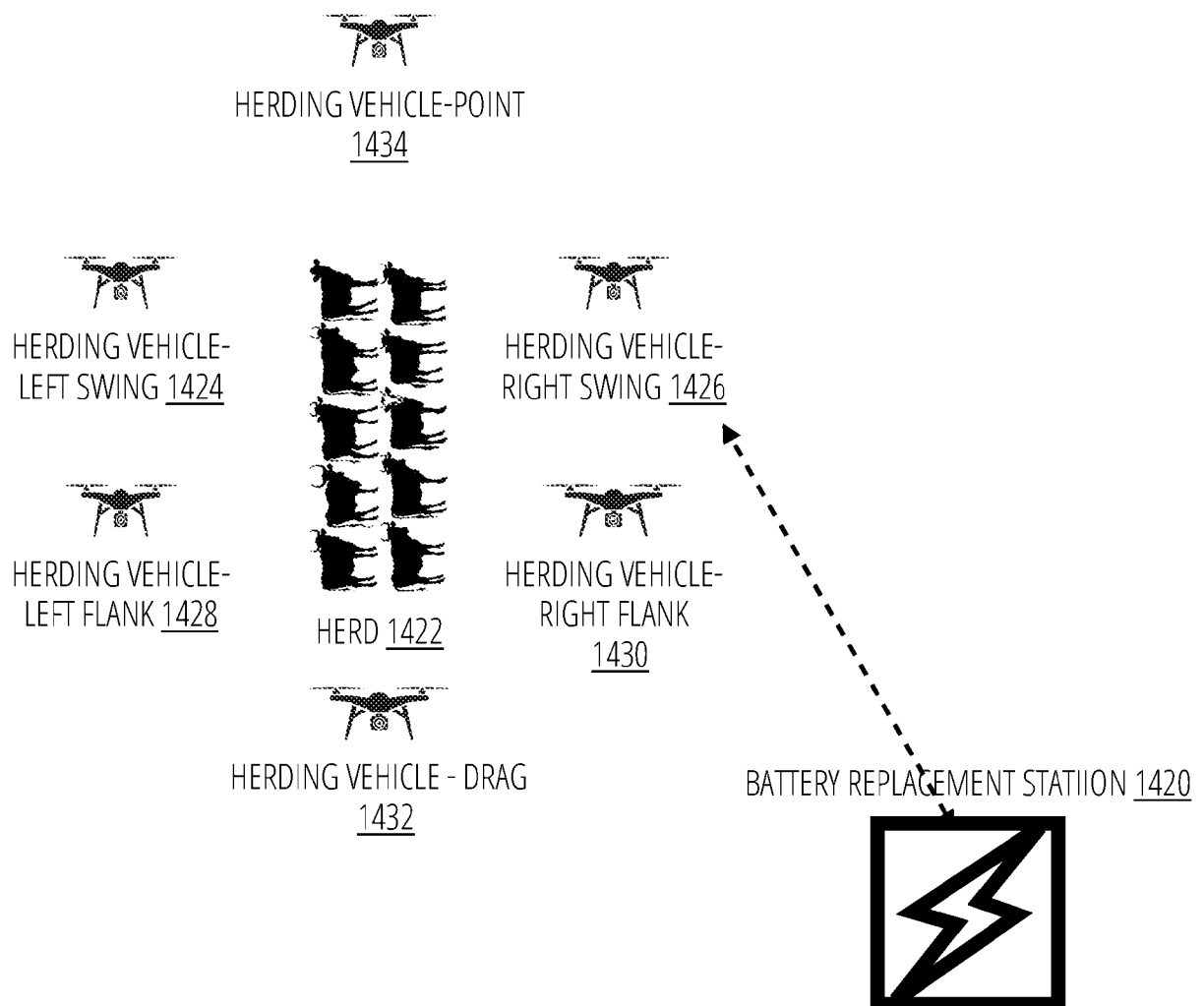
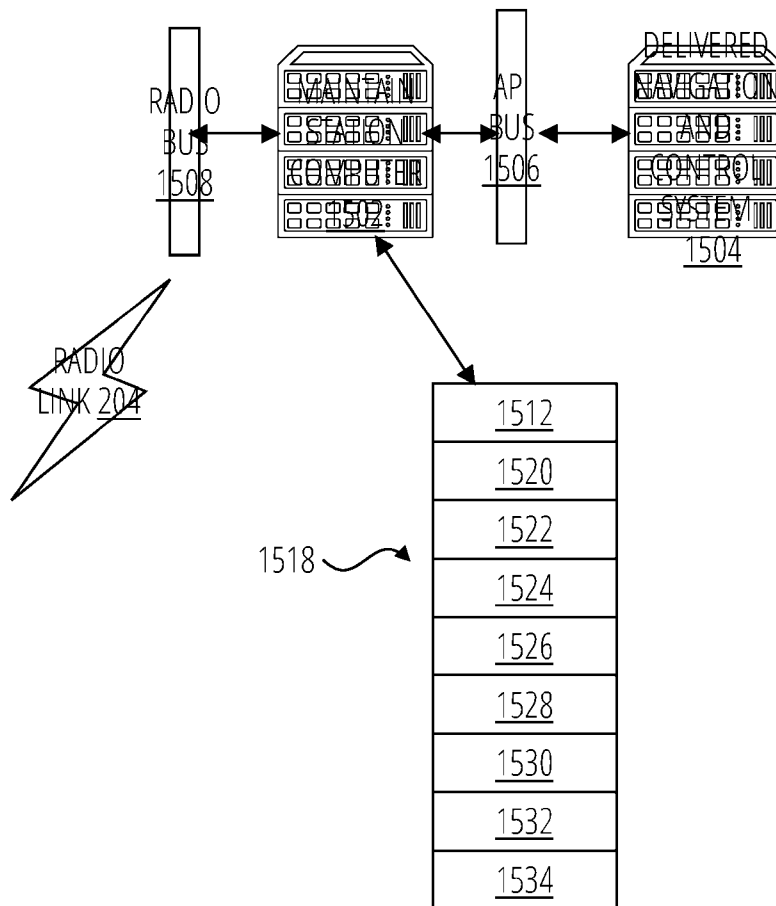


FIG. 14

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HERDING VEHICLE

FIG. 15

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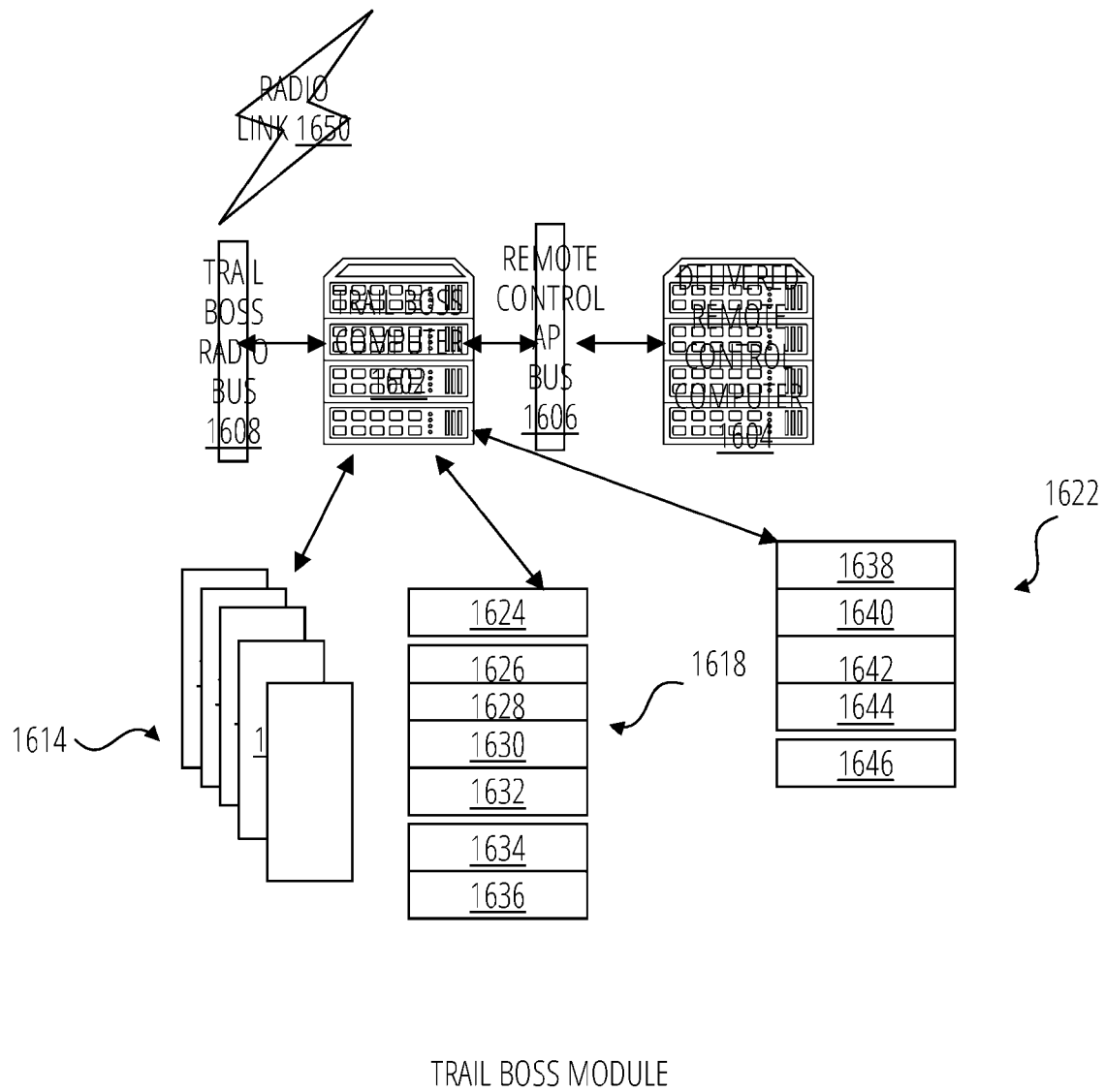
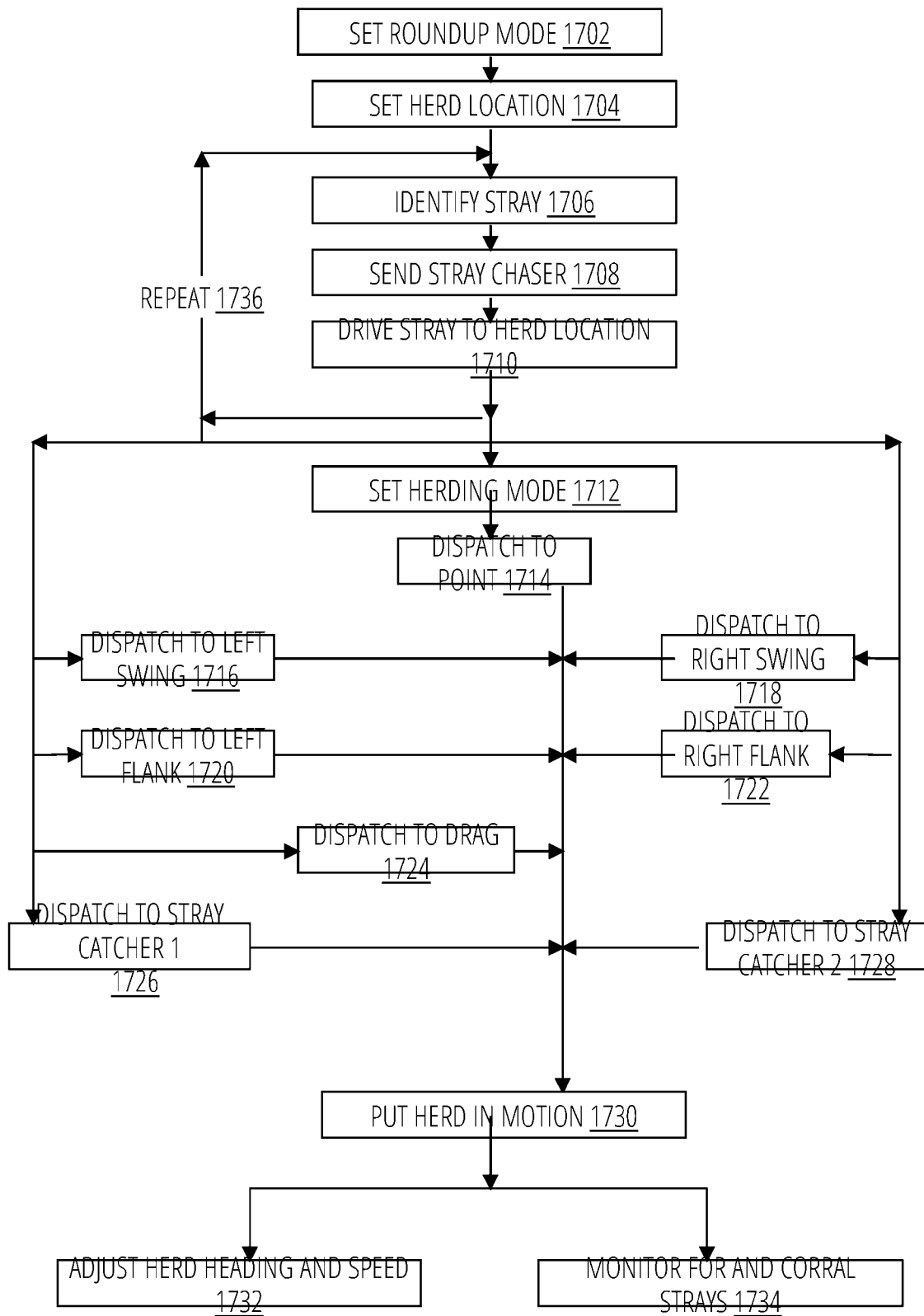
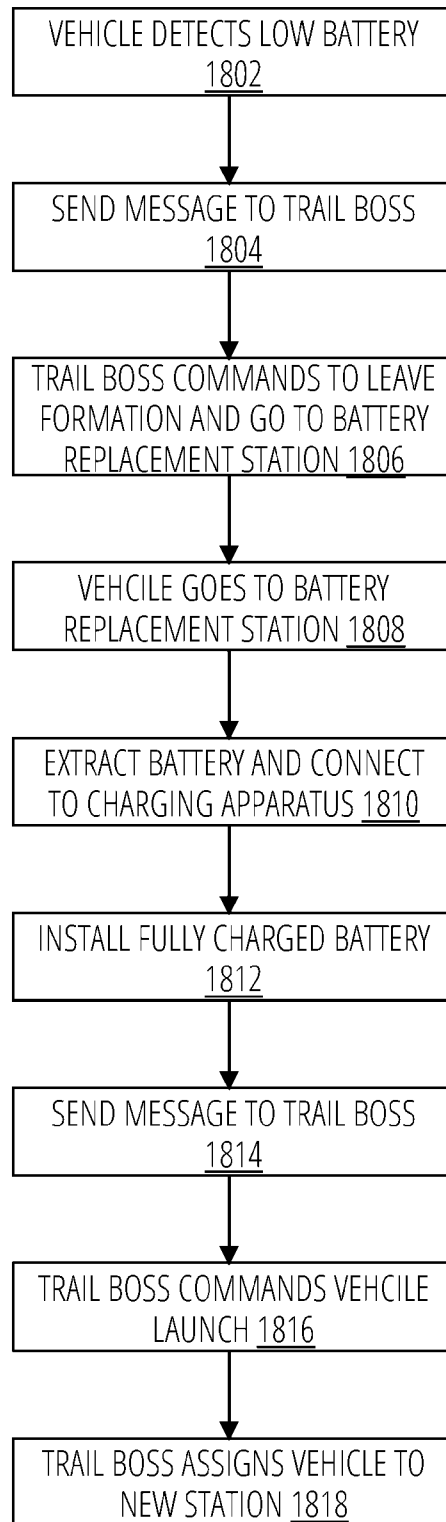


FIG. 16

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