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(54) **Title:** METHOD OF PATH PLANNING FOR AUTOGUIDANCE

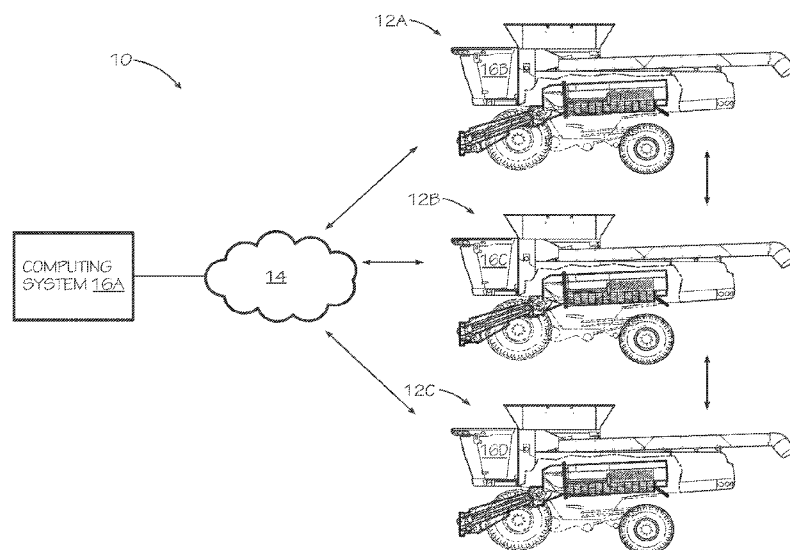


FIG. 1

(57) **Abstract:** In one embodiment, a system comprising a machine having a drive system; a user interface configured to receive operator input; an auto-steer system configured to control the drive system to cause autonomous traversal of a field by the machine; and one or more processors configured to: receive three-dimensional terrain data for the field and the operator input; determine and generate first and second path information for traversing the field based on the three-dimensional terrain data and the operator input, the first and second path information comprising first and second paths used to traverse the field and different travel speed constraints; and provide the first and second path information to the auto-steer system.



METHOD OF PATH PLANNING FOR AUTOGUIDANCE

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 62/093,502 filed December 18, 2014, which is hereby incorporated by reference in its entirety.

TECHNICAL FIELD

[0002] The present disclosure is generally related to agriculture technology, and, more particularly, computer-assisted farming.

BACKGROUND

[0003] Recent efforts have been made to automate or semi-automate farming operations. Such efforts serve not only to reduce operating costs but also improve working conditions on operators and reduce operator error, enabling gains in operational efficiency and yield. For instance, agricultural machines may employ a guidance system to reduce operator fatigue and costs.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] Many aspects of the disclosure can be better understood with reference to the following drawings. The components in the drawings are not necessarily to scale, emphasis instead being placed upon clearly illustrating the principles of the present disclosure. Moreover, in the drawings, like reference numerals designate corresponding parts throughout the several views.

[0005] FIG. 1 is a schematic diagram that illustrates an example environment in which an embodiment of an auto-guidance system may be implemented.

[0006] FIG. 2 is a screen diagram that illustrates an example display screen showing aerial imagery of plural fields and field boundaries and a prompt invoked by an embodiment of an auto-guidance system to enable an operator to choose path determinations that are time-optimized.

[0007] FIG. 3 is a schematic diagram that illustrates parallel waylines for flat ground as determined by an embodiment of an auto-guidance system, the waylines comprising a single travel speed constraint.

[0008] FIG. 4 is a schematic diagram that illustrates parallel waylines for flat and undulating ground as determined by an embodiment of an auto-guidance system, the waylines comprising different travel speed constraints.

[0009] FIG. 5 is a schematic diagram that illustrates parallel waylines with different segments of each wayline for flat and undulating ground as determined by an embodiment of an auto-guidance system, the segments comprising different travel speed constraints.

[0010] FIG. 6 is a schematic diagram that illustrates parallel waylines of different wayline types as determined by an embodiment of an auto-guidance system, the different wayline types comprising different travel speed constraints.

[0011] FIG. 7 is a screen diagram that illustrates an example display screen showing aerial imagery of plural fields and field boundaries and an alert invoked by an embodiment of an auto-guidance system to warn an operator that a wayline or segment is being approached that has a different travel speed constraint than the current travel speed.

[0012] FIG. 8A is a block diagram that illustrates an embodiment of an example auto-guidance system.

[0013] FIG. 8B is a block diagram that illustrates an embodiment of a computing system implemented in an embodiment of the example auto-guidance system of FIG. 8A.

[0014] FIG. 9 is a flow diagram that illustrates an embodiment of an auto-guidance method.

DESCRIPTION OF EXAMPLE EMBODIMENTS

Overview

[0015] In one embodiment, a system comprising a machine having a drive system; a user interface configured to receive operator input; an auto-steer system configured to control the drive system to cause autonomous traversal of a field by the machine; and one or more processors configured to: receive three-dimensional terrain data for the field and the operator input; determine and generate first and second path information for traversing the field based on the three-dimensional terrain data and the operator input, the first and second path information comprising first and second paths used to traverse the field and different travel speed constraints; and provide the first and second path information to the auto-steer system.

Detailed Description

[0016] Certain embodiments of an auto-guidance system and method are disclosed that automatically determine and generate parallel waylines in a field corresponding to paths for a machine to autonomously follow based on a desired, respective speed limit and/or time-optimized plan. In one embodiment, the auto-guidance system receives input corresponding to a field, such as three-dimensional field data acquired from a prior field traversal operation, and operator input corresponding to a desired travel speed and/or an indication of a time-optimized travel plan, and determines and generates one or more waylines with respective travel speed constraints (e.g., maximum speed limits) based on the three-dimensional data and operator input. In some embodiments, the operator input is not needed.

[0017] Digressing briefly, in the field of auto-guidance, conventional systems typically include speed limits for which it is safe to auto-steer the machine. These speed limits are usually less than the maximum speed limit permissible by the machine under manual operation. In early implementations of guidance systems, the operator defined the waylines, and the upper speed limit was a fixed value (sometimes different per machine type) that the machine manufacturer designed to, and was a value that was determined independently of field considerations such as the slope of the terrain, the speed and rate of change of turning the machine, and/or the change in center of gravity of the machine. Further, there is increased pressure for auto-guidance systems to be able to take advantage of more of the machine speed capacity and operate at speeds a manual operator may prefer to run at.

[0018] When an operator wishes to use an auto-guidance feature today, the typical procedure is for the operator to navigate the machine over an initial path (whether it is a straight A-B wayline, a contour, etc.) and then the system generates successive waylines based on the width of a coupled implement. When an operator engages the auto-steer functionality, the operator may keep increasing the speed of the machine until a maximum permissible speed is reached. Increasing the speed past this maximum speed typically disengages the system, such that the operator needs to resume manual control. In other words, the waylines that were created did not consider the speed that the operator wanted to run the machine, which can lead to dissatisfaction in performance. In contrast, certain embodiments of an auto-guidance system enable an operator to omit the step of driving an initial path by using prior knowledge about the machine and the field and a desired speed to calculate waylines that fulfill the operator's needs. Once the waylines are generated, the machine merely follows the paths on the field corresponding to the waylines, automatically adjusting the speed of travel based on the associated wayline travel speed constraints that consider the undulating portions of

the field and/or changes in direction. In other words, in some embodiments, the operator inputs the desired speed, and certain embodiments of auto-guidance systems determine and generate waylines that best achieve the desired speed over the course of traversing the field.

[0019] Having summarized certain features of auto-guidance systems of the present disclosure, reference will now be made in detail to the description of the disclosure as illustrated in the drawings. While the disclosure will be described in connection with these drawings, there is no intent to limit it to the embodiment or embodiments disclosed herein. For instance, in the description that follows, one focus is on an agricultural machine embodied as a combine harvester, though it should be appreciated that some embodiments of auto-guidance systems may use other machines, towed or self-propelled, from the same or different industries, and hence are contemplated to be within the scope of the disclosure. Further, although the description identifies or describes specifics of one or more embodiments, such specifics are not necessarily part of every embodiment, nor are all various stated advantages necessarily associated with a single embodiment or all embodiments. On the contrary, the intent is to cover all alternatives, modifications and equivalents included within the spirit and scope of the disclosure as defined by the appended claims. Further, it should be appreciated in the context of the present disclosure that the claims are not necessarily limited to the particular embodiments set out in the description.

[0020] Referring now to FIG. 1, shown is a schematic diagram that illustrates an example environment 10 in which an embodiment of an auto-guidance system may be implemented. The environment 10 comprises an agricultural environment, and includes one or more agricultural machines 12 (e.g., three (3) shown in FIG. 1, including 12A, 12B, and 12C, though other quantities may be used in some embodiments), a network

14, which may include plural networks, and one or more computing systems 16. It should be appreciated within the context of the present disclosure that, though shown using agricultural machines 12 embodied as combine harvesters, some embodiments may utilize other agricultural machines (e.g., planters, sprayers, etc.) in the same or different quantities, and hence are contemplated to be within the scope of the disclosure. Further, it is noted that the agricultural machines 12 are shown in FIG. 1 without the attached header for purposes of brevity, with the understanding that one of a plurality of different types of headers or other implements may be used with each of the agricultural machines 12. In one embodiment, an auto-guidance system may comprise all of the components shown in FIG. 1, or a portion of the same. For instance, one embodiment of an auto-guidance system may consist of the agricultural machine 12A and the computing system 16A, or some embodiments may consist of the computing system 16B (or portions thereof). The computing systems 16B-16C comprise on-board computers and optionally associated peripherals, and are generally located in the cab of each machine, though not limited to that location.

[0021] The computing system 16A may be a server, computer (e.g., personal computer), or other type of computing device (e.g., electronic control unit or ECU) and/or software that is located at a business (e.g., farm, an Internet Service Provider (ISP) facility, regional or local agricultural machine manufacturer's representative facility, manufacturer's facility, among others), residence, or other locations remote from the agricultural machine 12 or field. The computing system 16A may be communicatively coupled to the computing systems 16B-16D over the network 14 in a master-slave arrangement, peer-to-peer arrangement, or a combination of both.

[0022] The network 14 may include a wide area network, such as the Internet, and local area networks, such as a radio frequency (RF) network, cellular network, POTS, WiFi,

WiMax, satellite, terrestrial, among others. For instance, the computing system 16A may host a web-service, or serve as a gateway to one or more other servers in the Internet, and be coupled to the computing systems 16B-16D of the agricultural machines 12A-12C, respectively, over a wireless, cellular connection. In some embodiments, a cellular connection or otherwise wireless (e.g., RF) connection may be implemented between the computing system 16B, 16C and 16D of the respective agricultural machines 12A, 12B and 12C. These and/or other mechanisms for achieving communications may be used, as should be appreciated by one having ordinary skill in the art in the context of the disclosure, and hence are contemplated to be within the scope of the disclosure. Note that in some embodiments, all or a portion of the agricultural machines 12A-12C may omit network connectivity.

[0023] The agricultural machines 12 are depicted as combine harvesters for illustrative purposes. As is known, the agricultural machine 12 comprises a chassis coupled to rotating elements (e.g., wheels and/or tracks) and a drive system (e.g., engine, transmission, hydraulic pump, etc.) of known components that comprise coupled actuators to enable signals (e.g., over a wired and/or wireless medium) from a computing system 16. The signals enable actuation of steering and/or navigation components associated with the drive system, causing in conjunction with auto-steer software, autonomous and/or semi-autonomous traversal of a field in known manner. Since operations of a combine harvester, and drive systems in general, are known to those having ordinary skill in the art, further description of their operations are omitted here for brevity.

[0024] In one example operation of an auto-guidance system, and referring to an implementation initially where there is a single agricultural machine involved, such as agricultural machine 12A, an operator of the agricultural machine 12A may navigate the

agricultural machine 12A down a road to reach a field. Note that reference to an operator may refer to an operator that is residing in the cab of the agricultural machine and manipulating on-board navigational controls. In some embodiments, reference to an operator may refer to an operator that is navigating the agricultural machine 12A from a remote location. Note that reference to autonomous systems or autonomous control refers to sustained periods of time where there is no direct operator influence on machine navigation.

[0025] With continued reference to FIG. 1, attention is directed to FIG. 2, which is a screen diagram that illustrates a user interface, embodied as an example display screen 18, showing aerial (including satellite) imagery 20 of plural fields and field boundaries. The image 20 may be at least partially interactive such as typical with navigation systems today, with the progress of a machine (or graphic of the same) as it traverses the field presented in an updated manner. The display screen 18 may be proximal to an operator located in a cab of the agricultural machine 12, or in some embodiments, the content presented on the display screen 18 may be presented to a remote operator. In some embodiments, the display screen 18 may be disposed on a portable communications device, such as a cell-phone, tablet, laptop, etc.), or be integrated in a virtual headset. The aerial image 20 comprises one or more fields, such as field 22, and associated field boundaries, such as field boundary 24 for the field 22. Reference hereinafter to the fields and field boundaries focuses on the field 22 and associated field boundary 24 as a representative example for purposes of brevity, with an understanding that similar principles apply to analysis of the other fields. The field boundary 24 may be used by an embodiment of an auto-guidance system to determine the extent or scope of the wayline(s) required. The aerial image 18 further comprises metadata associated with it that provides three-dimensional (3D) field data associated with the field 22. The 3D

field data may be acquired from a previous field traversal operation by the agricultural machine 12 (or other machine and communicated to the auto-guidance system) using one or more on-board sensors, such as a global navigation satellite system (GNSS) receiver, accelerometers, gyroscopes, radar, laser, etc. The 3D field data is associated with the aerial image 18 in known manner. The 3D field data is used by an embodiment of an auto-guidance system to calculate slopes in the field 22 that the agricultural machine 12 may encounter from different angles of approach. The display screen 18 is depicted in FIG. 2 as presenting a prompt 26, which may be invoked by the operator or automatically upon detection of an event (e.g., detecting that the agricultural machine 12 crosses or approaches the field boundary 24, etc.). The prompt 26 provides a message (“would you like the system to generate path(s) that are optimized for time? Yes or No”) that enables the operator to choose whether to have the system time-optimize wayline generation or not. In some embodiments, the optimization may be done automatically (e.g., without presenting the choice to the operator). In some embodiments, the operator may merely enter a desired speed for traversing the field (or portions thereof), and the auto-guidance system determines and generates waylines based on the desired speed and the terrain and/or other parameters (e.g., machine performance capabilities). In some embodiments, the operator input may comprise a combination of time-optimized traversal and desired travel speeds, such as for portions of the field 22 that experience dictates the desired travel speed as an override or constraint to what time-optimization may achieve. The field boundary 24 and the 3D field data may be used by an embodiment of an auto-guidance system to optimize the time of traversal through the field 22. For instance, different speeds of travel may be enabled based on the angle of approach the machine 12 takes up a slope, or based on a change of direction required at the slope or in other areas of the field 22 or based on wayline types (e.g., contour versus straight-line). Additional data may also be used in the determination of path(s),

including machine center of gravity, machine performance, etc. For instance, the machine center of gravity may present a worst-case scenario that can be used when the agricultural machine 12 is most unstable (e.g., typically when loaded, for an applicator for instance). Note that the aerial image 20, 3D field data, boundary information, and/or machine information (e.g., center of gravity, machine performance, etc.) may be stored locally by the computing system 16 (e.g., 16B for agricultural machine 12A in FIG. 1, or transferred via memory device, such as memory stick, by the operator), or stored remotely (e.g., at computing system 16A) and accessed, such as from a data structure (e.g., database) upon operator request or automatically upon detection of an event (e.g., the agricultural machine 12 crossing or approaching the boundary 24).

[0026] Reference now is made to FIGS. 3-6, which show schematics of different fields, representing the determination and generation, by an embodiment of an auto-guidance system, of the waylines for various terrain conditions. Travel speed constraints are depicted with an encircled "A" or "B" overlapping each field, the different letter signifying a different travel speed constraint (where $B < A$). Wayline determination and generation may occur transparently to an operator, or in some embodiments, at least the generated waylines may be presented to the operator (e.g., via display screen 18). It should be appreciated by one having ordinary skill in the art that the depictions in FIGS. 3-6 are merely illustrative of the basic principles described herein, and that other field examples may be encountered and hence are contemplated to be within the scope of the disclosure. With reference to FIG. 3, shown is a field 28 with parallel waylines 30 overlaid on a representation of flat (or substantially flat) ground. The auto-guidance system, in response to the operator indicating that he or she would like a time-optimized traversal of the field 28, assesses the 3D field data for each wayline 30 (and optionally, boundary data, machine center of gravity, performance, etc.) and assigns a travel speed

constraint for each wayline 30 such that the travel speed constraint (e.g., the speed limit threshold) for auto-steer control matches the calculated value. When the operator engages auto-steering, the agricultural machine 12 (FIG. 1) autonomously traverses the field according to the waylines and the travel speed constraints. In some embodiments, the travel speed constraints may be presented to the operator via a user interface (e.g., display screen 18, FIG. 2). In this example, since the ground is relatively flat, the waylines 30 may have the same travel speed constraint.

[0027] Referring now to FIG. 4, shown is a field 32 comprising parallel waylines 34 and 36 overlaid on representations of what are manifested as substantially flat ground (e.g., waylines 34) and undulating ground (e.g., waylines 36). Contour lines 38 are shown as partially overlapping to some extent with the waylines 34 and with the waylines 36 of the undulating ground. It is noted that the waylines 34 and 36 have associated travel speed constraints A and B, respectively. In other words, the auto-guidance system has made a determination that the contour terrain (e.g., based on assessing the 3D field data) corresponding to the waylines 34 is not significant enough to warrant a “B” travel speed constraint, as this is substantially flat ground. On the other hand, the auto-guidance system has determined that the contoured terrain that overlaps with the waylines 36 merits a different (e.g., B, or slower) travel speed constraint.

[0028] In FIG. 5, a field 40 is depicted with parallel waylines 42 and 44, with portions of some of the waylines 42 and 44 depicted as being divided by a contoured terrain 46. For instance, and referring to the wayline 44 as an illustrative example, the wayline 44 comprises a first segment 48 that is overlaid on a representation of flat ground, and a second segment 50 that is overlaid on a representation of the undulating, contoured terrain 46. In this example, the first segment 48 is associated by the auto-guidance system with travel speed constraint “A” and the second segment 50 is associated travel

speed constraint "B." In other words, even along a single wayline, the auto-guidance system may assign different travel speed constraints based on an assessment of the 3D field data indicating the differences in terrain.

[0029] FIG. 6 illustrates a field 52 comprising parallel waylines of different wayline types. For instance, waylines 54 and 56 comprise contour waylines, whereas waylines 58 and 60 comprise straight or A-B waylines. The contour waylines 54 and 56 overlap contoured terrain 62, and hence the auto-guidance system assigns a different travel speed constraint (B) to waylines 54, 56 than the travel speed constraint assigned to waylines 58, 60 (A) on the flat ground.

[0030] In effect, the auto-guidance system determines and generates waylines based on a desired speed limit and/or time-optimized speed limit as opposed to manually defining waylines that may not optimally conform to the system-defined limits. Current systems typically use fixed upper speed limits that are not tied to environmental factors and/or other variables that consider auto-steering capabilities, and these fixed upper limits are usually lower than the speeds the operators would drive at while operating manually. For instance, the same speed limits would be used on existing systems regardless of whether the ground was flat or undulating. In contrast, certain embodiments of auto-guidance systems analyze the field topology (and optionally other parameters) and determine and generate each wayline or one of its dependent passes or portions or segments thereof and an associated travel speed constraint that may differ along each wayline.

[0031] In some embodiments, the auto-guidance system may optionally recommend a path order for the agricultural machine 12 (FIG. 1) to traverse to further ensure that complete field traversal time is minimized. In some embodiments, the path order determination may be based on an initial location of the machine relative to the field to

be traversed. In some embodiments, the auto-guidance system receives a desired travel speed for the field (e.g., via operator input), and determines wayline information (e.g., plural waylines, including segments thereof, and associated travel speed constraints for the plural waylines) based on the desired travel speed and further based on the 3D terrain data. For instance, the waylines may be determined in a manner that enable machine traversal according to, or in close approximation to, the desired travel speed, such as by determining waylines that take a speedier approach to certain slopes, among other strategies to enable the travel speed to equal the desired travel speed to the extent physically permissible. In some embodiments, the auto-guidance system uses the collective information to determine a path order that minimizes the time of traversal of the field, such as when requested by an operator or as programmed into the machine 12 as part of normal operations.

[0032] In some implementations, the engagement by the operator of auto-steer functionality may be while the agricultural machine 12 (FIG. 1) is on or approaching a path corresponding to the wayline at a speed that differs from the assigned travel speed constraint. For instance, and referring to FIG. 7, shown is the display screen 18 showing the aerial image 20 as shown in FIG. 2, but with an alert 64 invoked by an embodiment of an auto-guidance system to warn an operator that a path corresponding to a wayline or segment is being approached that has a different travel speed constraint than the current travel speed of the agricultural machine 12. In this example, the alert 64 warns the operator with a message ("slow down to XX MPH due to change in terrain in YY Feet") based on conditions. In this example, the agricultural machine 12 is currently traveling at a speed that is higher than the upcoming segment of the wayline and is warned to slow down. On the other hand, if the current travel speed of the agricultural machine 12 is less than the assigned travel speed, the machine may automatically

speed up upon reaching the path corresponding to the wayline, or alert the operator of the difference in travel speeds, or both provide the alert and automatically change the travel speeds.

[0033] In some implementations, if the operator attempts to engage the auto-steer functionality while the agricultural machine 12 is presently traveling on a path corresponding to the wayline with a different travel speed than the travel speed constraint assigned to that wayline, in one embodiment, the auto-guidance system prohibits engagement of the auto-steer functionality. For instance, if the current machine travel speed is greater than the assigned travel speed constraint, engagement of auto-steer functionality is prohibited. In some embodiments, an alert is presented to the operator warning of the prohibition, with optionally a recommendation to slow the travel speed or automatically causing a slowing of the machine travel speed. In instances where the current travel speed is slower than the assigned travel speed, in some embodiments, an alert is presented recommending a speed-up, or in some embodiments, speed-up is automatic (e.g., without alert), or in some embodiments, a combination of an alert advising of the condition and automatic speed up is performed.

[0034] Attention is now directed to FIG. 8A, which illustrates an embodiment of an auto-guidance system 66 that may be used in the environment 10. It should be appreciated within the context of the present disclosure that some embodiments may include additional components or fewer or different components, and that the example depicted in FIG. 8A is merely illustrative of one embodiment among others. The auto-guidance system 66 comprises the computing system 16. Note that the computing system 16, though depicted as a component of the auto-guidance system 66, may be a stand-alone unit, such as when implemented remotely from the field to be farmed (e.g., computing system 16A) or at least external to the machine 12. The auto-guidance system 66 is

described hereinafter as a component of (e.g., hosted by) the agricultural machine 12 (FIG. 1), with the understanding that all or a portion of the computing system functionality may be located remotely or otherwise external to the machine 12 in some embodiments. The computing system 16 is coupled to a network 68, which in one embodiment may comprise a controller area network (CAN) bus, such as implemented according to ISO 11783 (also referred to as “ISOBUS”) standard. The network 68 may be configured according to one or more other industry and/or proprietary communication specification or standards, and is not limited to a single network. Also coupled to the network 68 is a position determining device 70 (e.g., GNSS receiver), a drive system 72, a user interface 74 (which in one embodiment includes the display screen 18), and a network interface 76. In some embodiments, functionality of the network interface 76 may be embedded in (or directly coupled to) the computing system 16, particularly for remote-server systems.

[0035] The drive system 72 collectively comprises the various power drive, gearing (e.g., transmission), actuators, sensors, and/or subsystems residing on the agricultural machine 12, including those used to control machine navigation (e.g., speed, direction (such as a steering system), etc.), implement (e.g., header or trailer) position, and/or control, internal processes, among others.

[0036] The user interface 74 may be a keyboard, mouse, microphone, touch-type display device, joystick, steering wheel, or other devices (e.g., switches) that enable input by an operator and also enable monitoring of machine operations. As noted above, the display screen 18 may be a component of the user interface 74.

[0037] The position determining device 70 (e.g., GNSS receiver), as is known, may enable autonomous or semi-autonomous operation of the agricultural machine 12 in cooperation with the drive system 72 and the computing system 16 (e.g., via auto-guidance software residing in the computing system 16).

[0038] The network interface 76 comprises hardware and software that enables wireless connection among computing systems 16 via the network 14 (FIG. 1) and/or over wireless RF, enabling communication via browser software to remote computing systems (e.g., computing system 16A) through cellular links, among other telephony communication mechanisms and radio frequency communications. The network interface 76 may comprise MAC and PHY components (e.g., radio circuitry, including transceivers, antennas, a cellular and/or radio modem, etc.), as should be appreciated by one having ordinary skill in the art. As indicated above, at least some of the functionality of the network interface 76 (or other components of the auto-guidance system 66) may be integrated into the computing system 16 in some embodiments.

[0039] One or more of the computing systems 16 is configured to receive and process the information from the network interface 76, the position determining device 70, and/or the user interface 74. For instance, the computing system 16 may receive operator input from the display screen 18, such as to enable operator intervention of machine operation, selection of wayline options, access of machine and/or field data, selection of time-optimized travel, desired travel speed, etc.. In some embodiments, the computing system 16 may receive input from the drive system 72 (e.g., such as to enable feedback as to the position or status of certain devices, such as a header height and/or width, and/or speed, direction of the agricultural machine 12, etc.). The computing system 16 may also receive input data corresponding to 3D field data, machine center of gravity, boundaries, image data via the network interface 76, or via the network 68 from a local storage device. For instance, the computing system 16 is configured to cause the transmission of information (and/or enable the reception of information) via the network interface 76 with other computing systems 16.

[0040] FIG. 8B further illustrates an example embodiment of the computing system 16. One having ordinary skill in the art should appreciate in the context of the present

disclosure that the example computing system 16 is merely illustrative, and that some embodiments of computing systems may comprise fewer or additional components, and/or some of the functionality associated with the various components depicted in FIG. 8B may be combined, or further distributed among additional modules, in some embodiments. It should be appreciated that, though described in the context of residing in the agricultural machine 12, in some embodiments, the computing system 16 or its corresponding functionality may be implemented in a computing device or devices located outside of the field. Referring to FIG. 8B, with continued reference to FIG. 8A, the computing system 16 is depicted in this example as a computer system (e.g., an electronic control unit or ECU), but may be embodied as a programmable logic controller (PLC), FPGA, among other devices. It should be appreciated that certain well-known components of computer systems are omitted here to avoid obfuscating relevant features of the computing system 16. In one embodiment, the computing system 16 comprises one or more processors (also referred to herein as processor units or processing units), such as processor 78, input/output (I/O) interface(s) 80, and memory 82, all coupled to one or more data busses, such as data bus 84. The memory 82 may include any one or a combination of volatile memory elements (e.g., random-access memory RAM, such as DRAM, and SRAM, etc.) and nonvolatile memory elements (e.g., ROM, hard drive, tape, CDROM, etc.). The memory 82 may store a native operating system, one or more native applications, emulation systems, or emulated applications for any of a variety of operating systems and/or emulated hardware platforms, emulated operating systems, etc. In the embodiment depicted in FIG. 8B, the memory 82 comprises an operating system 86 and auto-guidance software 88. The auto-guidance software 88 comprises wayline determination/generation software 90, auto-steer software 92, and data module 94 (e.g., data structure, such as a database). It should be appreciated that in some embodiments, additional (e.g., browser, or if located remotely,

web-host network software) or fewer software modules (e.g., combined functionality) may be employed in the memory 82 or additional memory. In some embodiments, a separate storage device may be coupled to the data bus 84 (or network 68), such as a persistent memory (e.g., optical, magnetic, and/or semiconductor memory and associated drives).

[0041] The auto-guidance software 88 enables wayline determination and generation comprising one or more travel speed constraints and auto-steer functionality according to the generated waylines. For instance, the wayline determination/generation software 90 determines waylines (whole and partial) with different travel speed constraints based on the assessment of data (e.g., image data, boundaries, 3D field data, machine center of gravity, etc.) from the data module 94 and operator input (e.g., desired travel speed, indication of whether to use a time-optimized travel mode, etc.), and further comprises functionality (e.g., calculate and compare time traversals for a plurality of travel paths) to order the manner of traversing paths guided by the waylines to provide a time-optimized traversal of the field(s). In some embodiments, the data stored in data module 94 may reside external to the computing system 16, such as in separate storage coupled to the network 68 or remotely (e.g., computing system 16A or an associated database). The determination/generation software 90 generates the waylines and associated travel speed constraints (e.g., collectively, wayline or path or segment information) and provides the same to the auto-steer software 92. The auto-steer software 92 provides for auto-steer functionality of the agricultural machine 12, as auto-steering is commonly known. For instance, the auto-steer software 92 receives the wayline information generated by the wayline determination/generation software 90, and enables autonomous or semi-autonomous traversal of the agricultural machine 12 according to the generated waylines with their respective travel constraints via signaling to the drive system 72 (FIG. 8A).

[0042] Execution of the auto-guidance software 88 (and associated software 90-92) may be implemented by the processor 78 under the management and/or control of the operating system 86. In some embodiments, the operating system 86 may be omitted and a more rudimentary manner of control implemented. The processor 78 may be embodied as a custom-made or commercially available processor, a central processing unit (CPU) or an auxiliary processor among several processors, a semiconductor based microprocessor (in the form of a microchip), a macroprocessor, one or more application specific integrated circuits (ASICs), a plurality of suitably configured digital logic gates, and/or other well-known electrical configurations comprising discrete elements both individually and in various combinations to coordinate the overall operation of the computing system 16.

[0043] The I/O interfaces 80 provide one or more interfaces to the network 68 and other networks. In other words, the I/O interfaces 80 may comprise any number of interfaces for the input and output of signals (e.g., analog or digital data) for conveyance of information (e.g., data) over the network 68. The input may comprise input by an operator (local or remote) through the user interface 74 (e.g., a keyboard, joystick, steering wheel, or mouse or other input device (or audible input in some embodiments)), and input from signals carrying information from one or more of the components of the auto-guidance system 66, such as the position determining device 70, the drive system 72, and/or the network interface 76, among other devices.

[0044] When certain embodiments of the computing system 16 are implemented at least in part as software (including firmware), as depicted in FIG. 8B, it should be noted that the software can be stored on a variety of non-transitory computer-readable medium for use by, or in connection with, a variety of computer-related systems or methods. In the context of this document, a computer-readable medium may comprise an electronic, magnetic, optical, or other physical device or apparatus that may contain or store a

computer program (e.g., executable code or instructions) for use by or in connection with a computer-related system or method. The software may be embedded in a variety of computer-readable mediums for use by, or in connection with, an instruction execution system, apparatus, or device, such as a computer-based system, processor-containing system, or other system that can fetch the instructions from the instruction execution system, apparatus, or device and execute the instructions.

[0045] When certain embodiment of the computing system 16 are implemented at least in part as hardware, such functionality may be implemented with any or a combination of the following technologies, which are all well-known in the art: a discrete logic circuit(s) having logic gates for implementing logic functions upon data signals, an application specific integrated circuit (ASIC) having appropriate combinational logic gates, a programmable gate array(s) (PGA), a field programmable gate array (FPGA), etc.

[0046] In effect, certain embodiments of an auto-guidance system 66 enables an operator to specify whether he or she wishes to complete field operations in as short a time as safely possible (and/or to designate a desired travel speed), and the auto-guidance system 66 assesses each wayline for consideration for the 3D terrain and optionally the boundary and/or machine parameters and assigns specific speed limits to each wayline and/or each generated subsequent path from a wayline such that speed limit threshold for control matches the calculated value. An operator may then engage the auto-steering functionality as he or she would normally do and the agricultural machine 12 (FIG. 1) traverses the field according to the generated waylines and travel speed constraints. The operator may be apprised of the speed limit for each wayline/generated path as the agricultural machine 12 traverses the field.

[0047] In view of the above description, it should be appreciated that one embodiment of an auto-guidance method 96, depicted in FIG. 9, comprises receiving input for a field, the input comprising three-dimensional terrain data for the field and operator input (98);

automatically determining and generating first segment information and second segment information of a first path based on the three-dimensional terrain data and the operator input, the first and second segment information comprising first and second segments of the first path having different travel speed constraints (100); and providing the first and second segment information to an auto-steer system (102).

[0048] Any process descriptions or blocks in flow diagrams should be understood as representing modules, segments, or portions of code which include one or more executable instructions for implementing specific logical functions or steps in the process, and alternate implementations are included within the scope of the embodiments in which functions may be executed out of order from that shown or discussed, including substantially concurrently or in reverse order, depending on the functionality involved, as would be understood by those reasonably skilled in the art of the present disclosure.

[0049] It should be emphasized that the above-described embodiments of the present disclosure, particularly, any “preferred” embodiments, are merely possible examples of implementations, merely set forth for a clear understanding of the principles of the disclosure. Many variations and modifications may be made to the above-described embodiment(s) of the disclosure without departing substantially from the spirit and principles of the disclosure. All such modifications and variations are intended to be included herein within the scope of this disclosure and protected by the following claims.

CLAIMS

At least the following is claimed:

1. A method, comprising:
receiving input for a field, the input comprising three-dimensional terrain data for the field and operator input;
automatically determining and generating first segment information and second segment information of a first path based on the three-dimensional terrain data and the operator input, the first and second segment information comprising first and second segments of the first path having different travel speed constraints; and
providing the first and second segment information to an auto-steer system.
2. The method of claim 1, further comprising causing, by the auto-steer system, autonomous traversal of a machine along the field according to the first and second segments and the different travel speed constraints, wherein one of the travel speed constraints equals a first speed of travel based on the operator input and the other travel speed constraint is less than the first speed of travel.
3. The method of claim 1, wherein the first segment corresponds to a substantially flat surface of the field and the second segment corresponds to an undulating surface of the field.
4. The method of claim 1, further comprising determining and generating second path information based on the three-dimensional terrain data and the operator input, the second path information comprising a second path of the field and a travel speed constraint for the second path.

5. The method of claim 4, wherein the travel speed constraint for the second path is different than the travel speed constraints for the first segment and the second segment.
6. The method of claim 1, wherein the input further comprises one or a combination of a boundary for the field and a parameter corresponding to a center of gravity for the machine, wherein the determining and generating are further based on the one or combination of the boundary and the parameter.
7. The method of claim 1, wherein the operator input comprises one or a combination of a desired travel speed and an indication of time-optimized traversal of the field.
8. A system, comprising:
 - a machine having a drive system;
 - a user interface configured to receive operator input;
 - an auto-steer system configured to control the drive system to cause autonomous traversal of a field by the machine; and
 - one or more processors configured to:
 - receive three-dimensional terrain data for the field and the operator input;
 - determine and generate first and second path information used for traversing the field based on the three-dimensional terrain data and the operator input, the first and second path information comprising first and second paths used to traverse the field and different travel speed constraints; and
 - provide the first and second path information to the auto-steer system.

9. The system of claim 8, wherein the first path corresponds to a first wayline type and the second path corresponds to a second wayline type.
10. The system of claim 8, wherein responsive to receiving the operator input corresponding to an indication of time optimized traversal of the field, the one or more processors are configured to determine and generate the first and second paths at the different travel speed constraints that optimize a speed of travel by the machine along the field based on terrain conditions and change of direction of travel.
11. The system of claim 8, wherein responsive to receiving the operator input corresponding to a desired speed of travel, the one or more processors are configured to determine and generate the first and second paths and the different travel speed constraints, wherein one of the travel speed constraints comprises a first speed of travel that equals the desired speed of travel and the other travel speed constraint comprises a travel speed that is less than the first speed of travel.
12. The system of claim 8, wherein the one or more processors are further configured to determine which of the first or second paths to traverse first based on minimizing traversal time of the field.
13. The system of claim 12, wherein the determination of which of the first or second paths to traverse first is based on an initial location of the machine.
14. The system of claim 8, wherein the one or more processors are located within the machine.

15. The system of claim 8, wherein the auto-steer system is engaged based on additional operator input.

16. The system of claim 15, wherein if the current speed of the machine exceeds the travels constraints of the first or second paths when the auto-steer system receives the additional operator input, the auto-steer system does not engage if the machine is located on the first or second paths.

17. The system of claim 15, wherein if the current speed of the machine exceeds the travels constraints of the first or second paths when the auto-steer system is engaged, the one or more processors are configured to provide an alert via the user interface that the machine is closely approaching the first or second paths.

18. A machine, comprising:

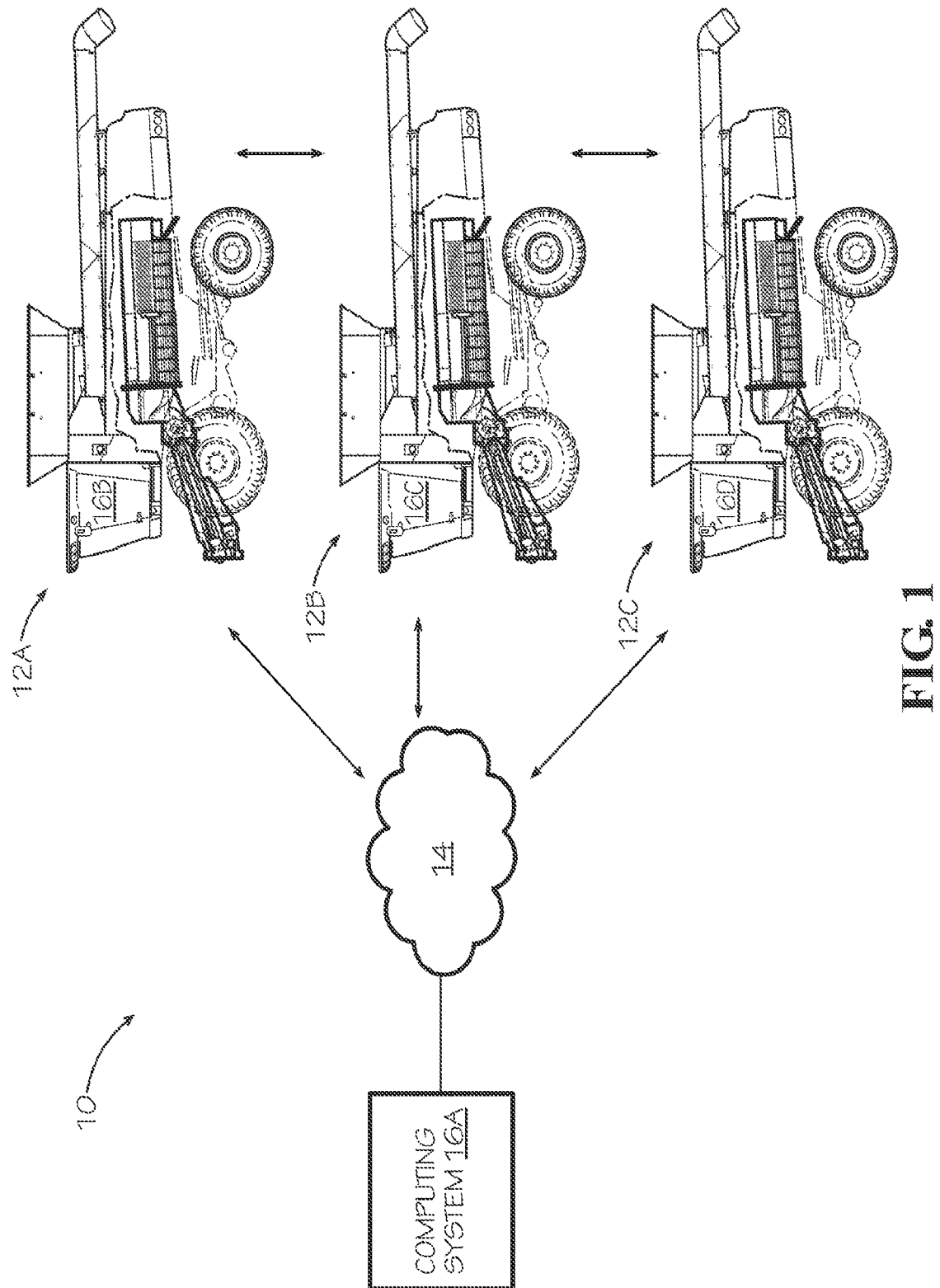
- a chassis coupled to rotating elements;
- a drive system supported by the chassis and configured to cause rotation of the rotating elements;
- an auto-steer system configured to control the drive system to cause autonomous traversal of a field by the machine; and
- a processor configured to:
 - receive three-dimensional terrain data for the field;
 - automatically determine and generate a plurality of waylines having different travel speed constraints based on the three-dimensional terrain data, the plurality of waylines determined in a manner that optimize a time of travel by the machine throughout the field; and

provide the first and second waylines and the associated travel speed constraints to the auto-steer system.

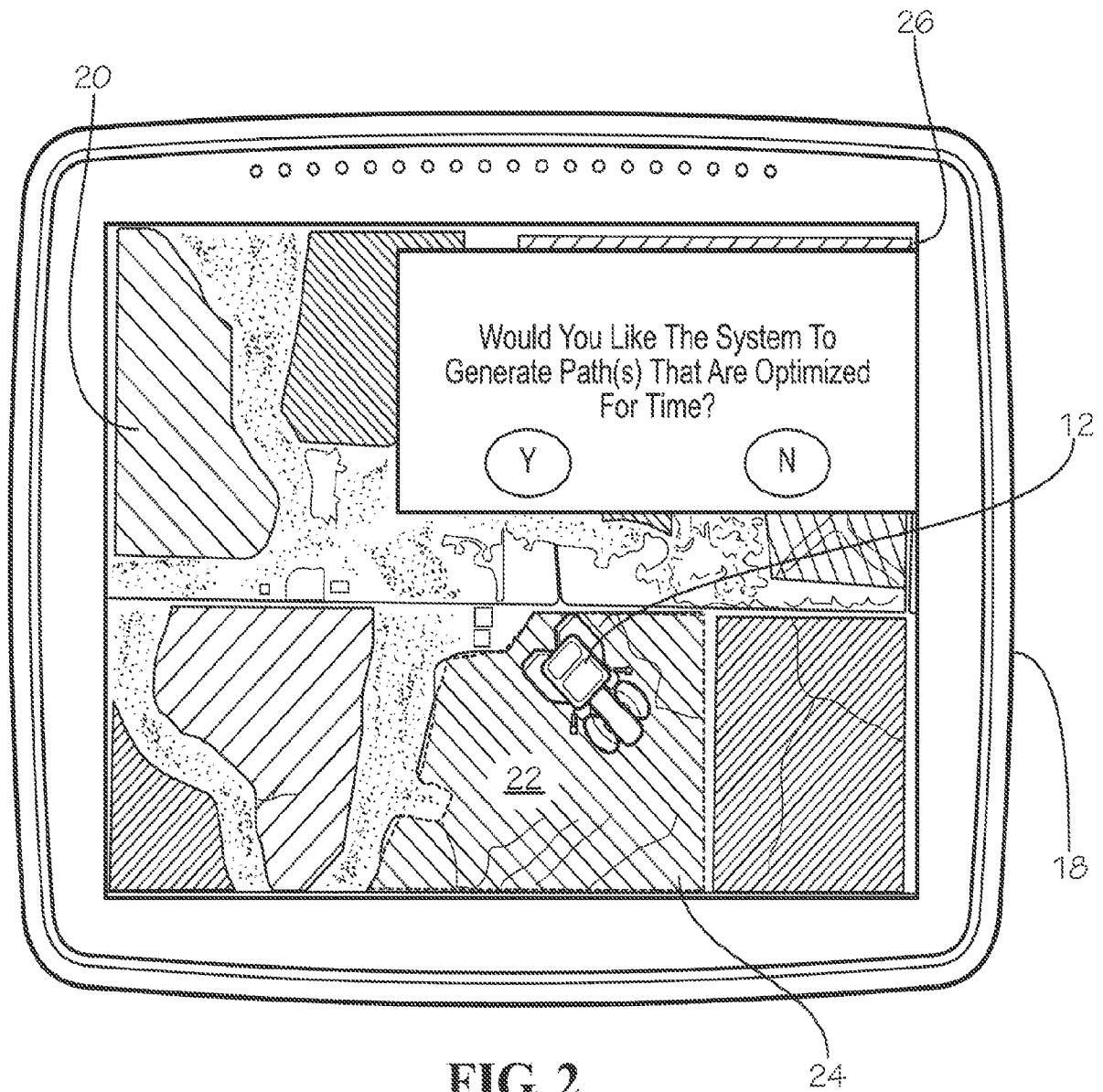
19. The machine of claim 18, wherein the auto-steer system causes autonomous traversal along plural paths in the field corresponding to the plurality of waylines responsive to being engaged.

20. The machine of claim 18, further comprising a user interface, wherein the auto-steer system causes autonomous traversal at a first travel speed corresponding to a desired speed inputted at the user interface and at a second travel speed that is lower than the first travel speed.

1/10



2/10



3/10

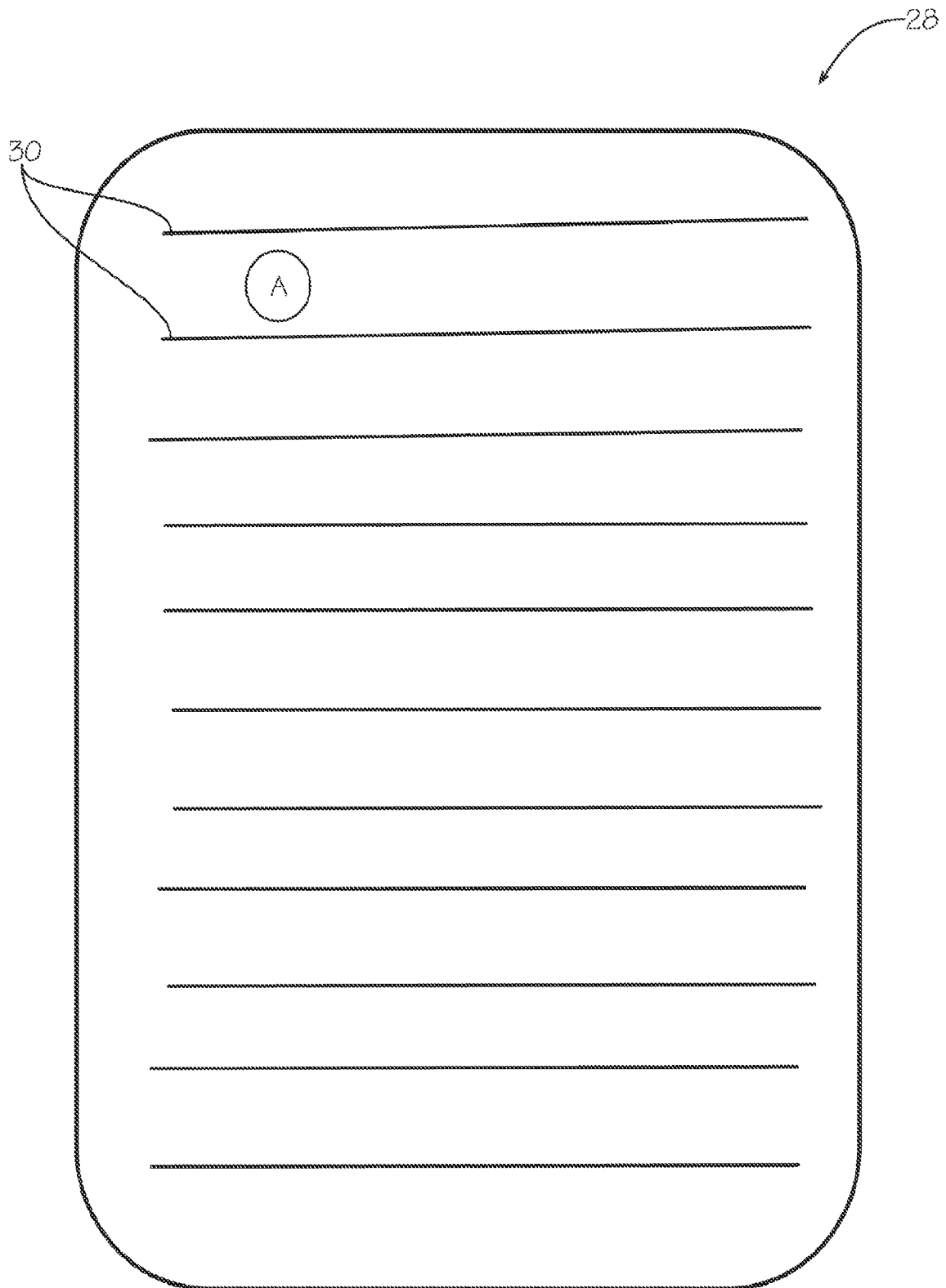


FIG. 3

4/10

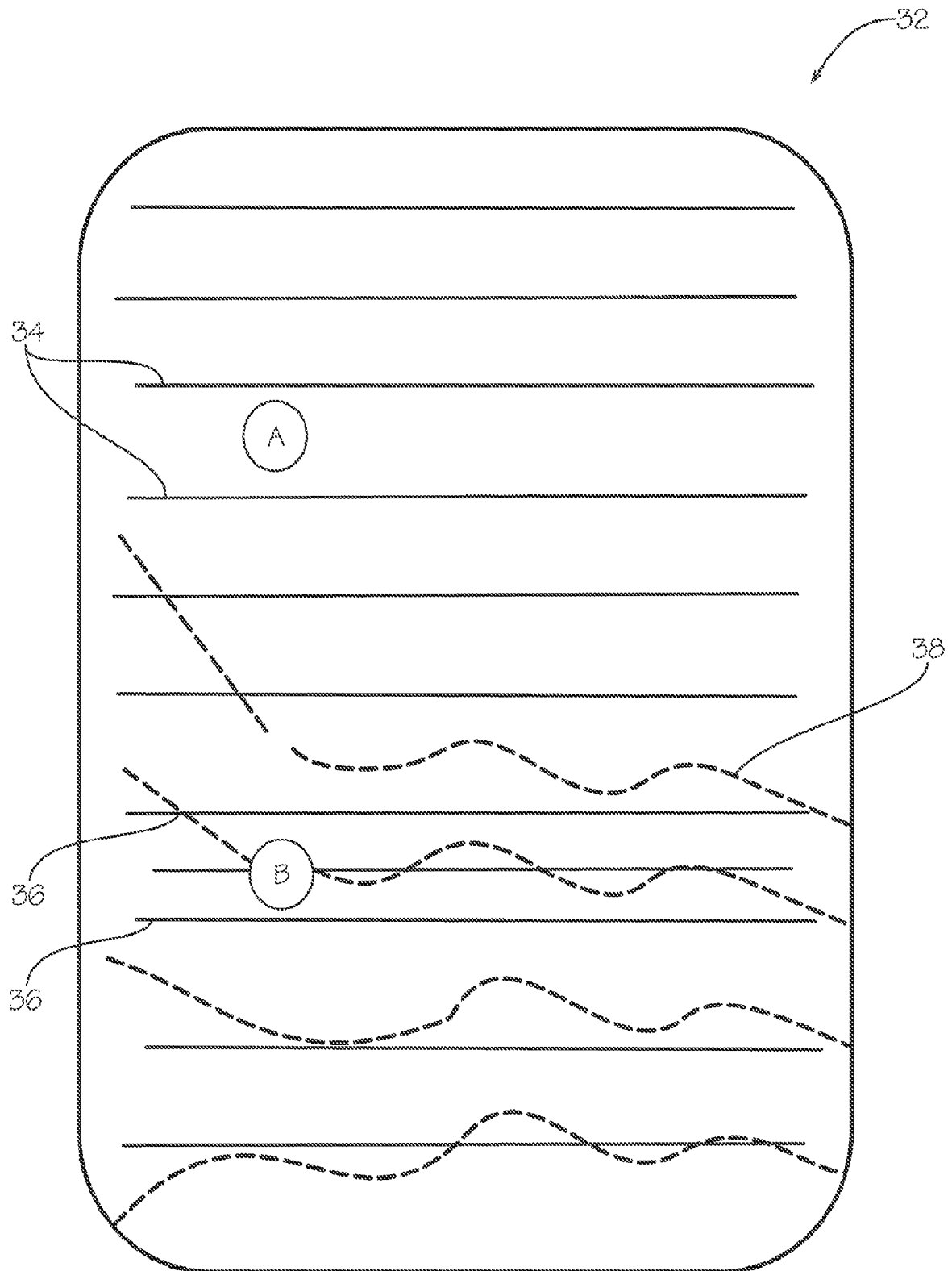


FIG. 4

5/10

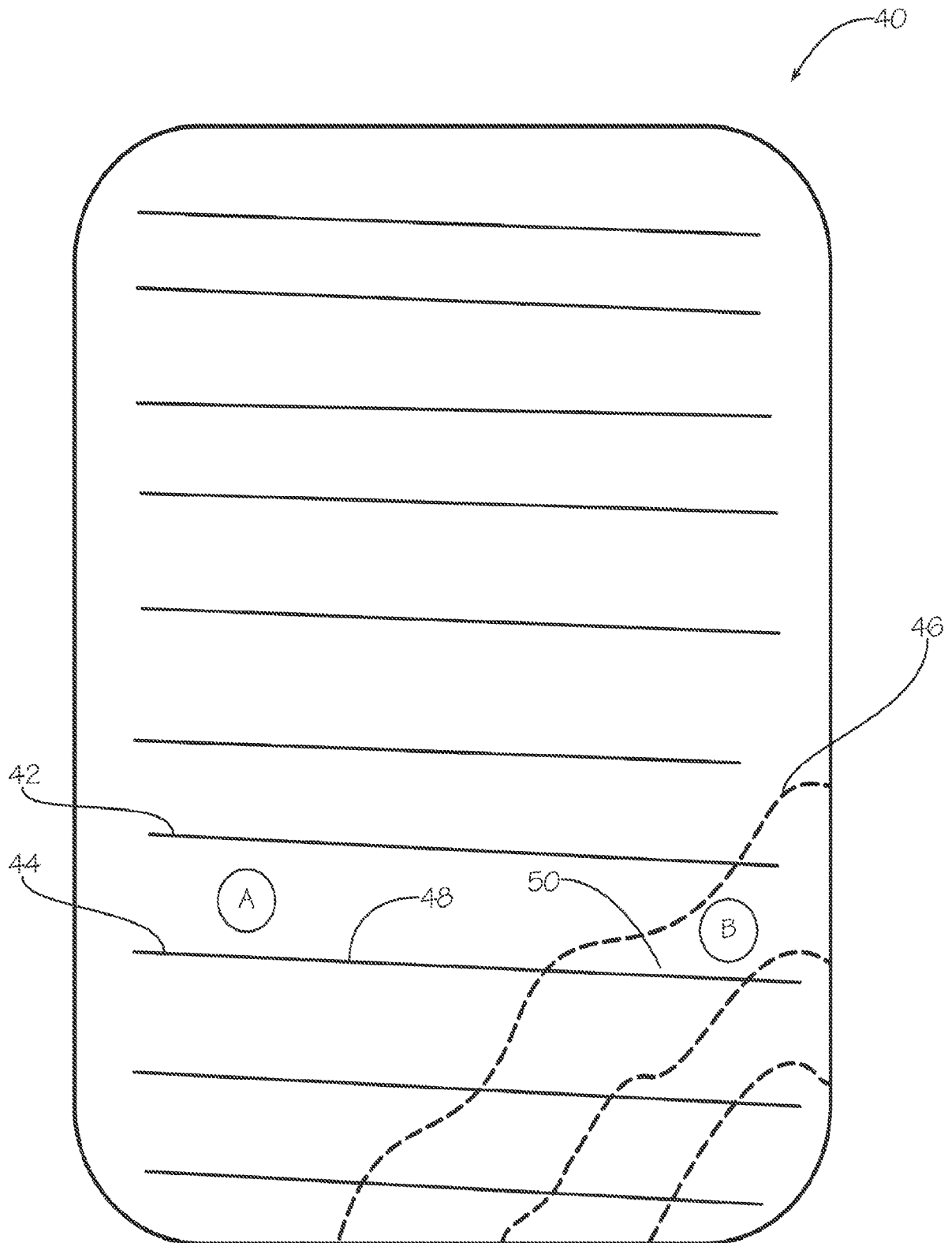


FIG. 5

6/10

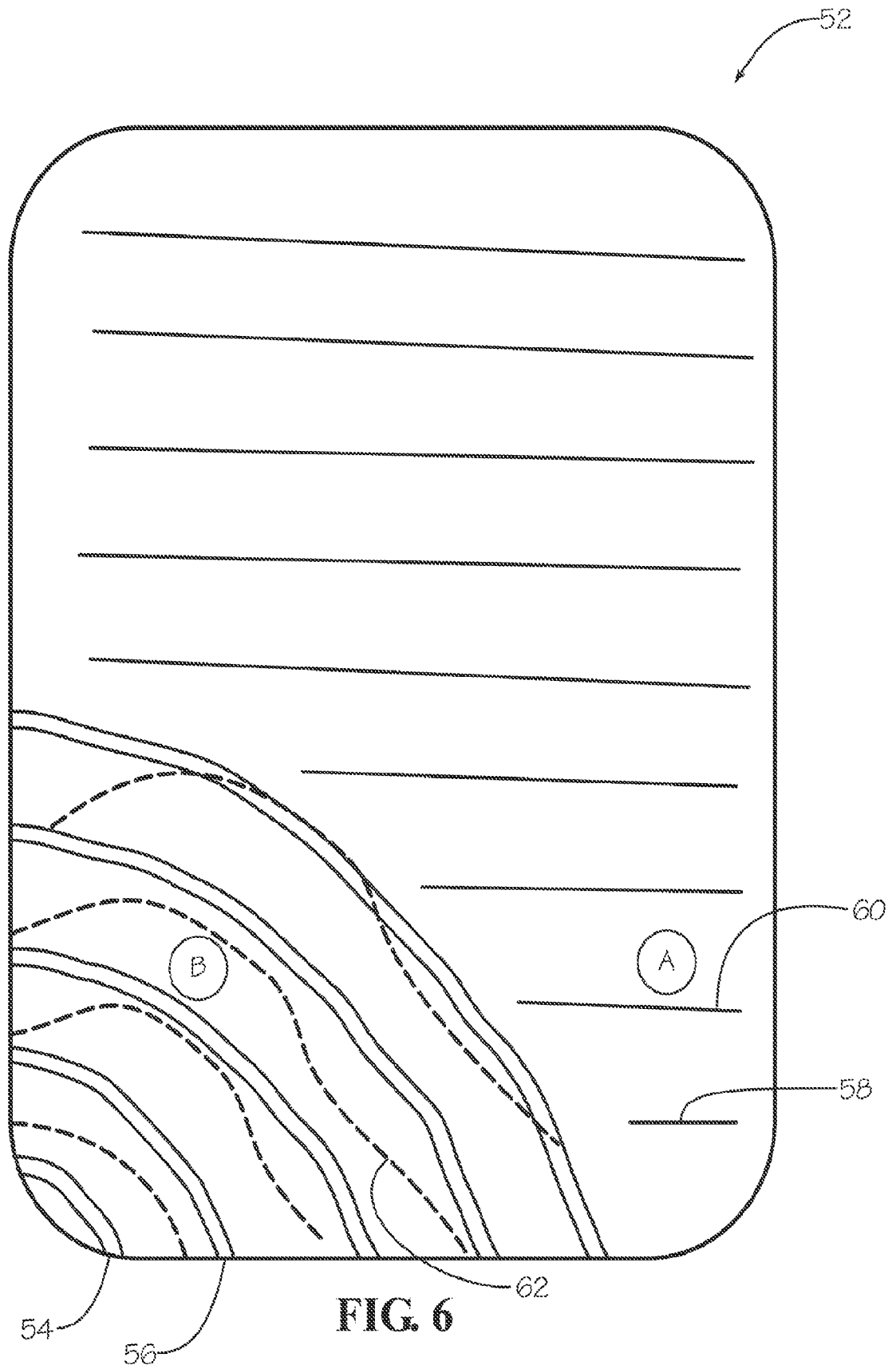
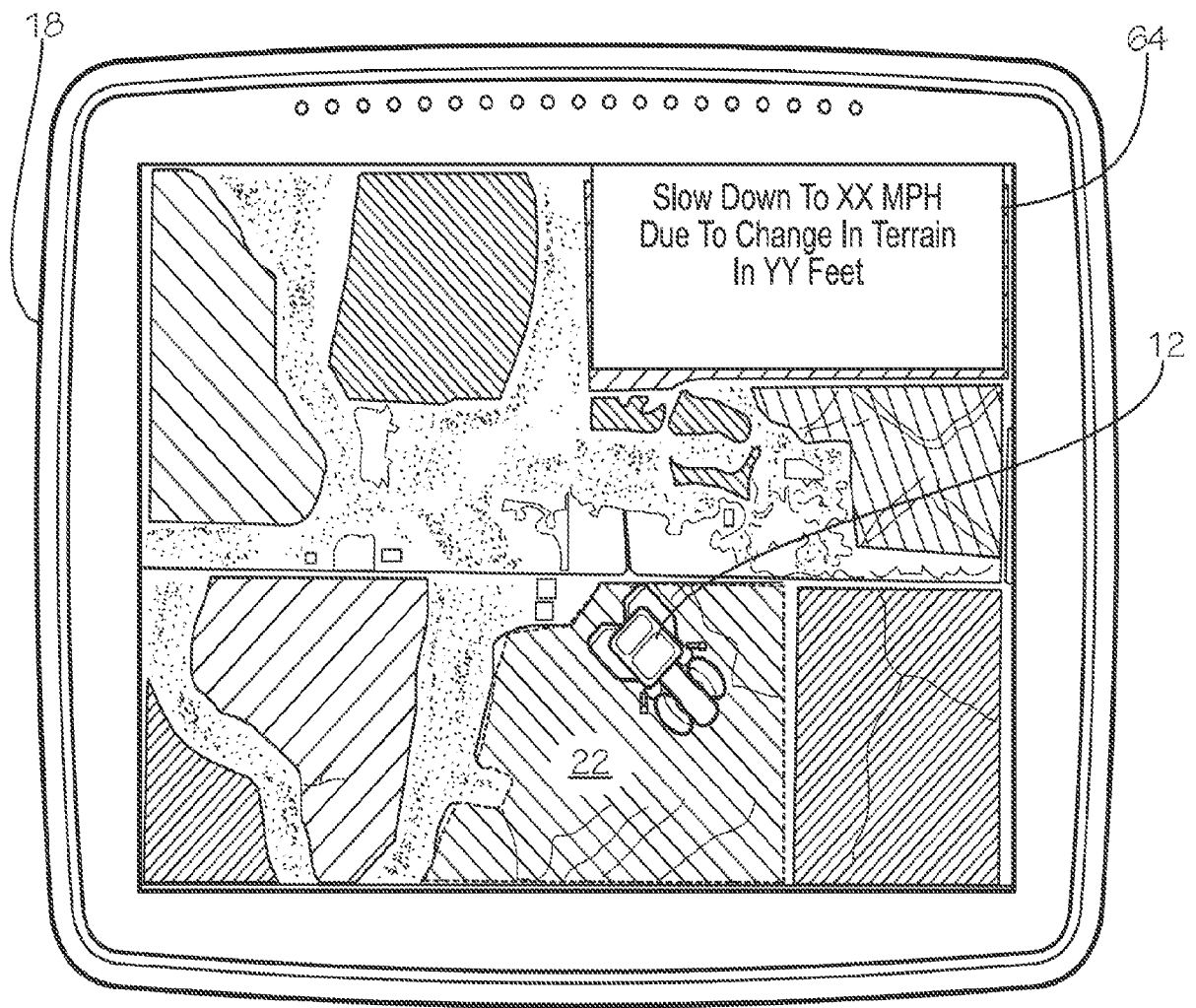
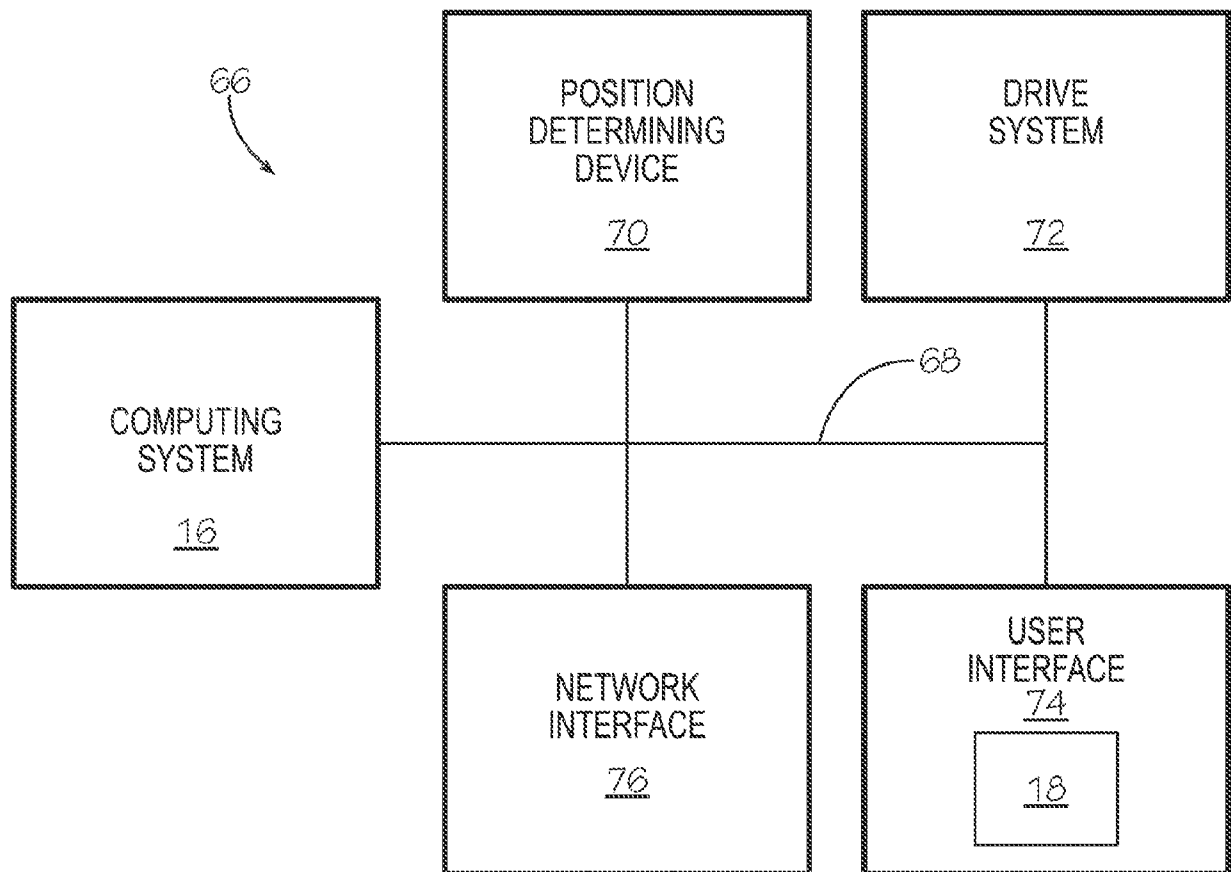


FIG. 6

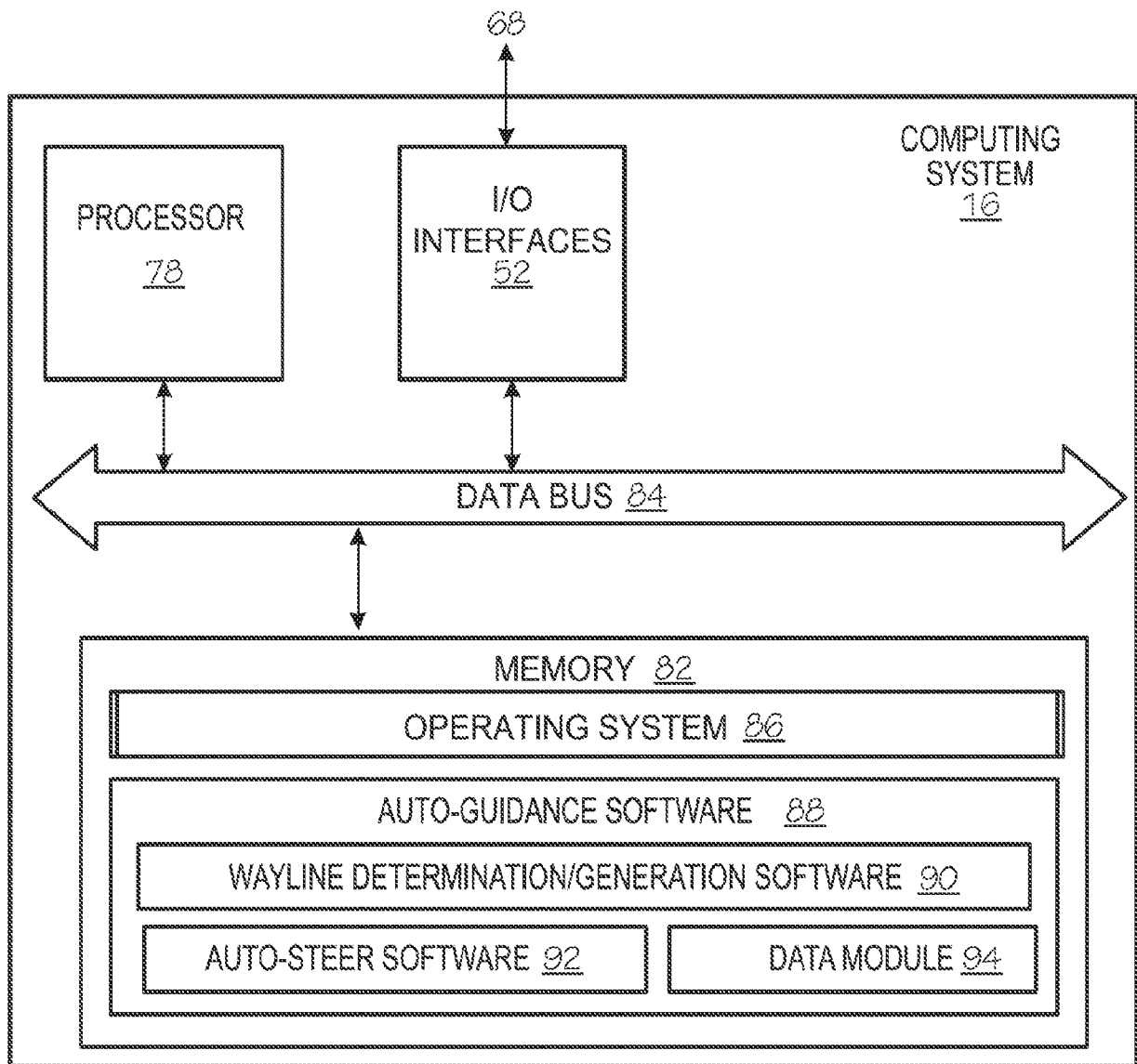
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**FIG. 7**

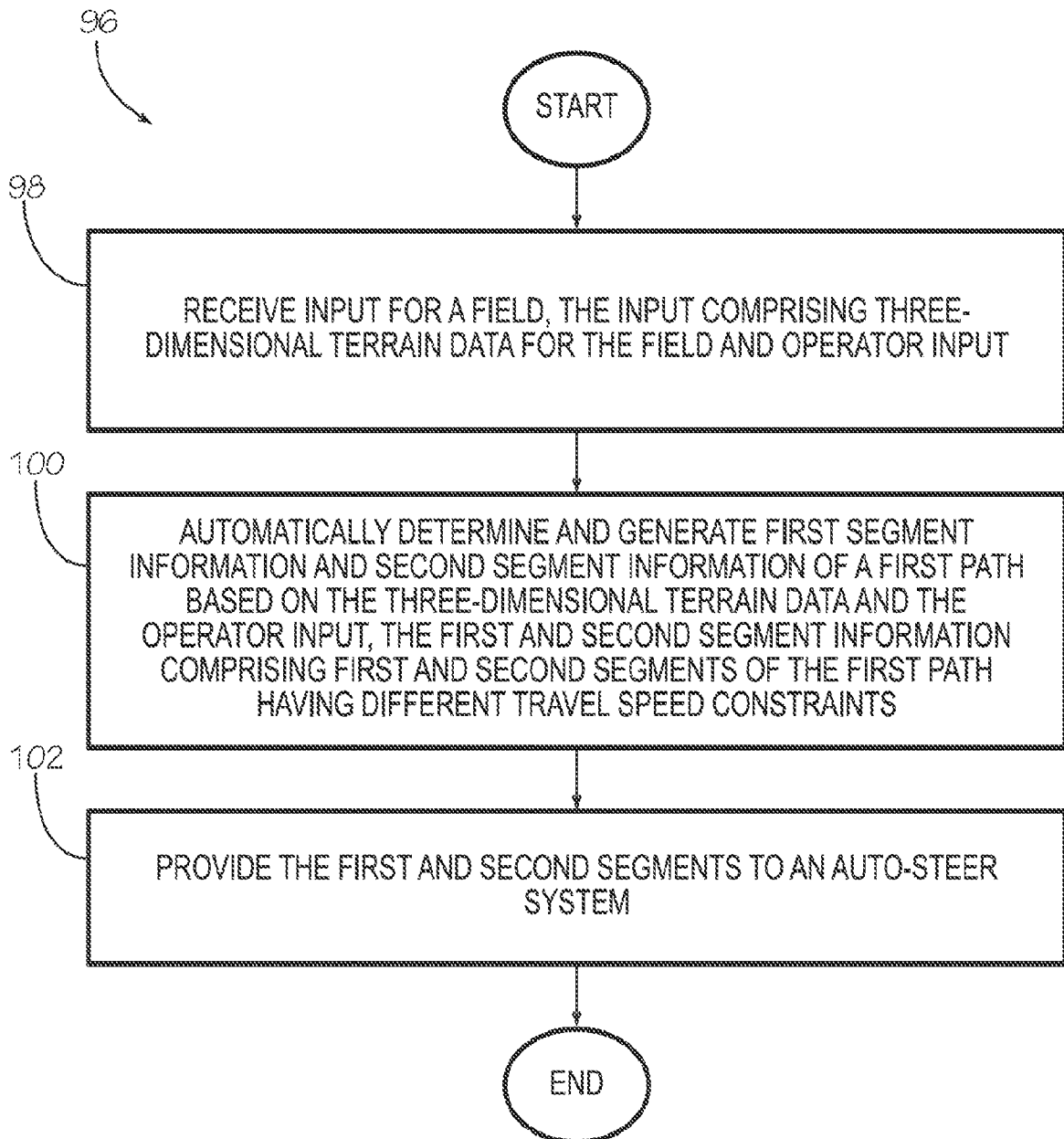
8/10

**FIG. 8A**

9/10

**FIG. 8B**

10/10

**FIG. 9**

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 15/65007

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - G05D 1/00; G01C 22/00 (2016.01)

CPC - A01B69/008

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8): G05D 1/00; G01C 22/00 (2016.01)

CPC: A01B69/008

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
 IPC(8): G05D 1/00; G01C 22/00 (2016.01); CPC: A01B69/008, G05D1/0272, G05D1/027, G05D1/0278, G05D2201/0216, G05D1/0255;
 USPC: 701/23, 701/28, 701/50 (keyword limited; terms below)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PatBase; Google(Web); Search terms used: path planning autoguidance steering segment field three-dimensional terrain operator input travel speed constraint wayline time

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2008/0059015 A1 (Whittaker et al.) 06 March 2008 (06.03.2008), entire document especially Fig. 6, 9; para [0024]-[0054], [0060]-[0073], [0080]-[0084]	1-15, 17-20
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Y		16
Y	US 2013/0274986 A1 (Trepagnier et al.) 17 October 2013 (17.10.2013), entire document especially para [0209], [0211]	16

☐ Further documents are listed in the continuation of Box C.

* Special categories of cited documents:

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

25 January 2016 (25.01.2016)

Date of mailing of the international search report

19 FEB 2016

Name and mailing address of the ISA/US

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