

(12) STANDARD PATENT APPLICATION (11) Application No. AU 2025208482 A1
(19) AUSTRALIAN PATENT OFFICE

(54) Title
Method for interfacing machine control system with attachment for automation

(51) International Patent Classification(s)
E02F 3/43 (2006.01) **E02F 9/22** (2006.01)
E02F 3/34 (2006.01) **E02F 9/26** (2006.01)

(21) Application No: **2025208482** (22) Date of Filing: **2025.07.24**

(30) Priority Data

| | | |
|-------------------|-------------------|--------------|
| (31) Number | (32) Date | (33) Country |
| 18/815,966 | 2024.08.27 | US |

(43) Publication Date: **2026.03.19**

(43) Publication Journal Date: **2026.03.19**

(71) Applicant(s)
Deere & Company

(72) Inventor(s)
Kenkel, Aaron R.;Dobchuk, Jeffery W.;Stickssel, Justin A.

(74) Agent / Attorney
Davies Collison Cave Pty Ltd, Level 28 500 Bourke Street, MELBOURNE, VIC, 3000, AU

ABSTRACT OF THE DISCLOSURE

A system and method control the movements of a working tool attached to a work implement of a self-propelled work vehicle via a complex attachment, wherein the complex attachment provides at least one additional freedom of movement for the working tool. A machine control system within the work vehicle determines a trajectory for a point-of-interest for the working tool. The machine control system generates a set of first velocities to enable the machine control system to control the movements of components of the work implement and generates a set of second velocities for the movements of the working tool. The set of second velocities are sent to the complex attachment to cause the complex attachment to control the movements of the working tool with respect to the work implement. The at least one additional freedom of movement can include rotation and tilting of the working tool.

2025208482 24 Jul 2025

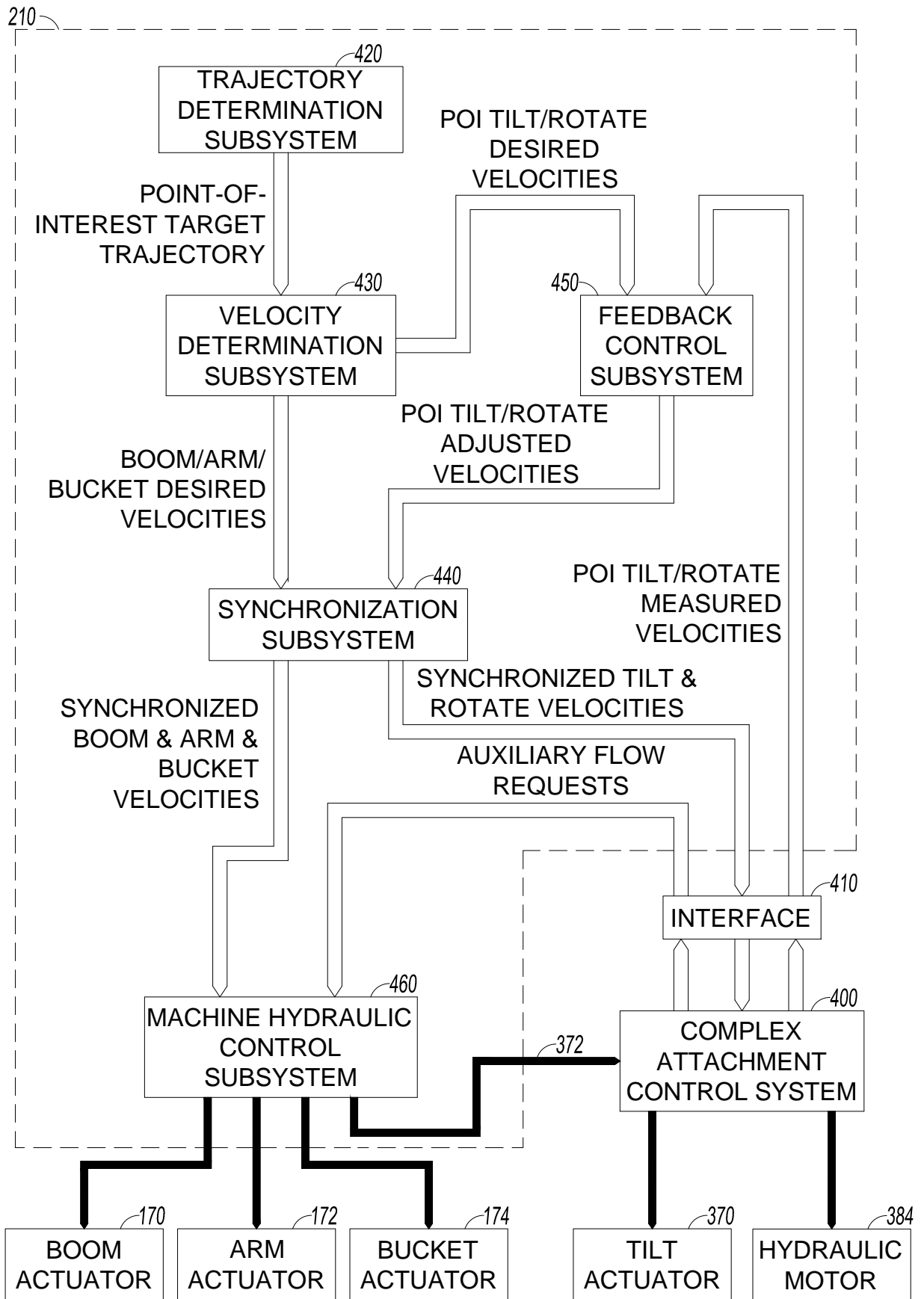


FIG. 7

**METHOD FOR INTERFACING MACHINE CONTROL SYSTEM
WITH ATTACHMENT FOR AUTOMATION**

FIELD OF THE DISCLOSURE

[0001] The present disclosure relates generally to self-propelled work vehicles such as construction and forestry machines, and more particularly to systems and methods for controlling complex attachments to such machines wherein the complex attachments have controllable movements with respect to one or more additional axes not found on the machines to which the complex attachments are attached.

BACKGROUND

[0002] Self-propelled work vehicles of this type may for example include excavators, loaders, crawlers, motor graders, backhoes, forestry machines, front shovel machines, and others. Such work vehicles can typically have tracked ground engaging units supporting the undercarriage from the ground surface. Such work vehicles can further include a work implement, which includes one or more components, that is used to modify the terrain in coordination with movement of the work vehicle. The following discussion refers to the structure and operation of an excavator; however, the discussion also applies to other work vehicles (e.g., loaders, crawlers, motor graders, backhoes, forestry machines, front shovel machines, and others) having work implements.

[0003] An excavator can have an undercarriage that engages the terrain with ground engagement units (e.g., tracks) that are controllable to move the undercarriage forward and backward with respect to the terrain and to turn the undercarriage with respect to the terrain. A main frame is mounted on the frame via a swing bearing and can be rotated (swiveled) with respect to the undercarriage so that the frame can be positioned in different angular directions while the undercarriage remains in a fixed location. If, for example, the forward/backward

motion and turning motion are considered to be motions in an X-Y plane defined by an X-axis and a Y-axis, the rotation can be considered to be motion about a Z-axis perpendicular to the X-Y plane. As discussed herein, the X-Y plane and the X-axis, Y-axis, and Z-axis are defined with respect to the undercarriage, which can be moving or resting with respect to terrain that may or may not be level.

[0004] The frame of the work vehicle (e.g., excavator) is the base for a work implement, which extends from the frame and is pivotable with respect to the frame. With respect to an excavator, the work implement can include a boom, an arm, and a working tool. The boom, arm, and working tool are linked together to form the work implement. For example, a first end portion of the boom can pivot about a first implement axis (e.g., a boom axis), which is fixed with respect to the frame. The boom has a second end portion that rotates angularly about the boom axis. The arm has a first end portion that can pivot about a second implement axis (e.g., an arm axis), which is fixed with respect to the second end portion of the boom. The arm has a second end portion that rotates angularly with respect to the arm axis. The working tool has a first end portion that can pivot about a third implement axis (e.g., a working tool axis), which is fixed with respect to the second end portion of the arm. The working tool has a “point-of-interest,” which is the portion of the working tool that interacts with the terrain to modify the terrain. For example, in an exemplary excavator having a bucket as the working tool, the point-of-interest can be the tip of the bucket or the teeth extending from the tip of the bucket. In another example, the working tool can be a blade, and the point-of-interest can be the edge of the blade that moves dirt or other material. In another example, the working tool can be a jackhammer, and the point-of-interest can be the tip of the jackhammer.

[0005] The movements of the boom, the arm, and the working tool about the respective pivot axes are controlled by respective actuators. For example, a first (boom) actuator controls the

rotation of the boom with respect to the frame. A second (arm) actuator controls the rotation of the arm with respect to the boom. A third (working tool) actuator controls the rotation of the working tool with respect to the arm. For example, the actuators can be hydraulic motors or hydraulic piston-cylinder units.

[0006] Historically, a skilled equipment operator positioned in a cab or other location in or on the frame manipulated control devices (e.g., levers) that selectively activated the actuators to cause the boom, the arm, and the working tool to be positioned such that the point-of-interest of the working tool is positioned in a desired location with respect to the terrain to be modified. The operator then manipulated the control devices further to cause one or more of the boom, the arm, and the working tool to rotate about the respective axes to cause the point-of-interest to modify the terrain proximate to the point-of-interest. For example, for the example of a bucket as the working tool, the boom and the arm can be caused to move the working tool closer to the frame as the tip (point-of-interest) of the bucket digs into the terrain to remove dirt or other material from the terrain. As the bucket moves closer to the frame, the bucket can also be rotated to control the depth of the tip of the bucket into the terrain. As described, the foregoing basic operation relies on the visual acuity and skill of the operator to control the positioning of tip of the bucket to create a desired modification to the terrain.

[0007] Recognizing the difficulty of manually monitoring and controlling the three-dimensional movement of the point-of-interest of the working tool of an excavator or other work vehicle, equipment manufacturers have automated the control of work vehicles. The work vehicles include control systems that monitor the angular positions of the components (e.g., the boom, the arm, and the working tool) with respect to the frame and also monitor the positions of the undercarriage and the frame with respect to the terrain to determine the location of the point-of-interest of the working tool with respect to a target location on the terrain. The control

systems further include control algorithms that generate commands to the actuators of the boom, the arm, and the working tool to position the point-of-interest of the working tool accurately and to move the point-of-interest with precision to achieve a desired trajectory for the point-of-interest. For example, the point-of-interest can be controlled to accurately cut a surface to create a uniform grade between two locations on the terrain.

[0008] In addition to accurate information regarding the position and orientation of the undercarriage with respect to the target terrain, the functions of the control algorithms depend on accurate determinations of the relative positions of the boom, the arm, and the working tool with respect to each other and with respect to the frame. U.S. Patent No. 11,873,621 to Kean for “System and Method for Tracking Motion of Linkages for Self-Propelled Work Vehicles in Independent Coordinate Frames” discloses a system and method using inertial measurement units (IMUs) positioned at selected locations on the frame, the boom, the arm, and the working tool to accurately determine the location and orientation of a working tool of an excavator or other work vehicle. U.S. Patent No. 12,006,663 to Kean for “Calibrating Mounting Misalignments of Sensors on an Implement of a Work Machine Using Swing Motion” discloses a system and method for calibrating sensors on a work machine. U.S. Patent No. 11,873,621 and U.S. Patent No. 12,006,663 are incorporated herein by reference.

[0009] The systems and methods disclosed in U.S. Patent No. 11,873,621 and U.S. Patent No. 12,006,663 are effective to accurately determine the position of a point-of-interest of a conventional working tool that is pivotably connected to the arm such that the point-of-interest pivots around the working tool axis as described above. However, the movements of a conventional working tool are limited to the movements about the three pivot axes discussed above. A complex attachment between the arm of the work vehicle and a working tool provides additional pivotal and rotational freedoms of movement of the point-of-interest of the working

tool around additional axes. A complex attachment can also provide linear movement. For example, a complex attachment implemented as a tilt/swivel complex attachment can be interposed between the arm of the work implement of an excavator and the bucket to provide tilting movement of the bucket about a tilt axis at the end of the arm and to provide rotation (swivel) movement. A first end portion of a tilt/swivel assembly can be attached to the working tool axis in place of a conventional bucket. A bucket or other working tool can be attached to a second end portion of the tilt/swivel assembly. The overall tilt/swivel assembly with the attached working tool is pivotable about the working tool pivot axis at the end of the arm such that the point-of-interest of the working tool moves arcuately in a first pivot plane as described above. The attached working tool is pivotable about a tilt/swivel assembly pivot axis such that the point-of-interest of the working tool moves arcuately in a second pivot plane. For example, the tilt/swivel assembly pivot axis can be at an angle to the working tool pivot axis such that the second pivot plane is oriented at an angle to the first pivot plane. The attached working tool is also rotatable about a swivel axis of the tilt/swivel assembly to cause the point-of-interest to move arcuately in a swivel plane. For example, the swivel axis can be at an angle to the working tool pivot axis and the tilt/swivel assembly pivot axis in the manner of a conventional three-axis coordinate system. The movements of the tilt/swivel assembly about the working tool pivot axis and the movements of the working tool about the tilt/swivel assembly pivot axis and about the swivel axis are combinable to move the point-of-interest of the working tool to multiple selectable locations in three dimensions. The respective rates of movement (e.g., angular velocities) of the point-of-interest are controllable so that the point-of-interest can follow a desired trajectory between any two locations.

[0010] As discussed above, the control system of a conventional work vehicle such as an excavator generates commands to various actuators to cause the undercarriage to move with

respect to the terrain, to cause the frame to move (e.g., swivel) with respect to the undercarriage, and to cause the components of the work implement (e.g., the boom, the arm, and the working tool) to move with respect to the frame and with respect to each other. The control system can be programmed to respond to commands from an operator to optimize the movements requested by the operator. For some work vehicles, the control system may be programmed to perform autonomous operations. The control system receives feedback information from the sensors (e.g., the IMUs) to accurately control the trajectory of the point-of-interest of the working tool.

[0011] When a complex attachment is mounted in place of a conventional working tool, the control system of the conventional work vehicle no longer has sufficient control functions and feedback information to control the trajectory of a working tool attached to the complex attachment. Although the control system of a work vehicle could be modified to include additional outputs to control actuators and additional inputs to sense the positions of the components of the complex attachment, such modifications would have to be made on each work vehicle that may receive the complex attachment.

BRIEF SUMMARY

[0012] In view of the foregoing, a need exists for a system and method adding a complex attachment to an existing work vehicle without modifying the control system of the work vehicle to include specific control and feedback functions to control the movements along the additional degrees of freedom provided by the complex attachment.

[0013] The current disclosure describes a modification to a work vehicle to include minimal additional features to the work vehicle and the control system within the work vehicle to enable the operation of a complex attachment coupled to the work vehicle.

[0014] Aspects of the embodiments disclosed herein include a system and method control the movements of a working tool attached to a work implement of a self-propelled work vehicle via a complex attachment, wherein the complex attachment provides at least one additional freedom of movement for the working tool. A machine control system within the work vehicle determines a trajectory for a point-of-interest for the working tool. The machine control system generates a set of first velocities to enable the machine control system to control the movements of components of the work implement and generates a set of second velocities for the movements of the working tool. The set of second velocities are sent to the complex attachment to cause the complex attachment to control the movements of the working tool with respect to the work implement. The at least one additional freedom of movement can include tilting and rotation of the working tool.

[0015] One aspect of the embodiments disclosed herein is a computer-implemented method of controlling movement of a point-of-interest of a working tool mounted to a complex attachment. The complex attachment is mounted to the work implement of a work vehicle. The work implement comprises components movable with respect to the work vehicle and with respect to each other. The complex attachment is operable to move the point-of-interest of the working tool with respect to the work implement. As described herein, the method comprises defining a desired trajectory for the point-of-interest of the working tool. The desired trajectory is used to determine desired first velocities for the movements of the components of the work implement and to determine desired second velocities for the movements of the point-of-interest of the working tool with respect to the work implement. The method applies the desired first velocities to a control system that controls actuators of the work implement. The method sends velocities responsive to the desired second velocities to the complex attachment. The complex

attachment applies the velocities responsive to the desired second velocities to control the movement of the point-of-interest of the working tool with respect to the work implement.

[0016] In certain aspects of the disclosed method, the method receives measured second velocities from the complex attachment, and generates adjusted second velocities in response to differences between the measured second velocities and the desired second velocities. The velocities responsive to the desired second velocities are the adjusted second velocities. In certain aspects of the disclosed method, the adjusted second velocities are the same as the desired second velocities when the measured second velocities are the same as the desired second velocities.

[0017] In certain aspects of the disclosed method, the method includes coupling a source of hydraulic flow to the complex attachment; receiving hydraulic flow requests from the complex attachment; and adjusting hydraulic flow to the complex attachment in response to the hydraulic flow requests.

[0018] In certain aspects of the disclosed method, the work implement comprises a first component having a first end coupled to the main frame at a first linkage joint; a second component a first end coupled to a second end of the first component at a second linkage joint; and a third linkage joint located at a second end of the second component. In certain aspects of the disclosed method, the first component is a boom, the second component is an arm, and the third linkage joint is configured to enable attachment the complex attachment.

[0019] In certain aspects of the disclosed method, the desired first velocities and the velocities responsive to the desired second velocities are synchronized before sending the desired first velocities to the control system and before sending the velocities responsive to the desired second velocities to the complex attachment.

[0020] In certain aspects of the disclosed method, the desired first and second velocities are determined by applying inverse kinematics to the desired trajectory.

[0021] Another aspect of the embodiments disclosed herein is a self-propelled work vehicle that comprises a main frame moveable with respect to terrain. A work implement has a first end moveably coupled to the main frame and has a second end moveable with respect to the main frame. The second end of the work implement includes a first working tool mounting system. The work vehicle further includes a complex attachment. The complex attachment includes a first portion coupled to the first working tool mounting system of the work implement and includes a second portion that includes a working tool mounting system of the complex attachment. A working tool is mounted to the working tool mounting system of the complex attachment. The complex attachment includes at least one actuator configured to selectively tilt the second portion and the working tool mounting system of the complex attachment with respect to the first portion of the complex attachment and to selectively rotate the working tool with respect to the second portion of the complex attachment. A complex attachment control system is configured to receive tilt and rotate commands and to control the at least one actuator to selectively tilt the second portion with respect to the first portion and to selectively rotate the working tool in response to the tilt and rotate commands. A work vehicle control system is configured to monitor and control a position of the first working tool mounting system at the second end of the work implement, to generate the tilt and rotate commands, and to send the tilt and rotate commands to the complex attachment.

[0022] In certain aspects of the disclosed work vehicle, the work vehicle control system comprises a trajectory determination subsystem to determine a desired trajectory of a point-of-interest of the working tool. A velocity determination subsystem is responsive to the desired trajectory to determine desired first velocities and desired second velocities to achieve the

desired trajectory. The desired first velocities control the movements of components of the work implement and the first working tool mounting system. The tilt and rotate commands sent to the complex attachment are responsive to the desired second velocities. A hydraulic control subsystem receives the desired first velocities and controls movements of the components of the work implement and controls the first working tool mounting system of the work implement.

[0023] In certain aspects of the disclosed work vehicle, the work vehicle control system includes a synchronization subsystem that synchronizes the desired first velocities and the velocities responsive to the desired second velocities to generate synchronized first velocities and synchronized second velocities. The complex attachment receives the synchronized second velocities and tilts and rotates the working tool in response to the synchronized second velocities.

[0024] In certain aspects of the disclosed work vehicle, the work vehicle control system includes a feedback control subsystem configured to receive feedback from the complex attachment system. The feedback represents measured second velocities. The feedback control subsystem generates the velocities responsive to the desired second velocities responsive to differences between the measured second velocities and the desired second velocities.

[0025] In certain aspects of the disclosed work vehicle, the velocity determination subsystem generates the desired first velocities and the desired second velocities using inverse kinematics.

[0026] Numerous objects, features, and advantages of the embodiments set forth herein will be readily apparent to those skilled in the art upon reading of the following disclosure when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] FIG. 1 is a side elevation view representing an excavator as an exemplary self-propelled work vehicle according to an embodiment of the present disclosure.

[0028] FIG. 2 is a schematic representation of the components of the work implement of the work vehicle of FIG. 1 showing the pivoting movements of components with respect to each other.

[0029] FIG. 3 is a schematic representation of a machine control system for the work vehicle of FIG. 1.

[0030] FIG. 4 illustrates a flowchart of an exemplary embodiment of a method for tracking motion of linkage joints for the self-propelled work vehicle of FIG. 1 to achieve a desired trajectory for the point-of-interest of a working tool.

[0031] FIG. 5 illustrates the work vehicle of FIG. 1 equipped with a complex attachment that enables the point-of-interest of the working tool to move in at least one additional degree of freedom.

[0032] FIG. 6 is a schematic representation of the components of the work implement of the work vehicle of FIG. 5 with a complex attachment, which representation is similar to the schematic representation of FIG. 2, and which further shows the pivoting and swiveling (rotation) of the working tool with respect to the end of the work implement.

[0033] FIG. 7 illustrates a block diagram of an overall system that includes a machine control system in communication with a complex attachment control system.

[0034] FIG. 8 illustrates a flowchart of the operation of the overall system of FIG. 7.

DETAILED DESCRIPTION

[0035] FIGS. 1–8 illustrate embodiments of a system and method for controlling the trajectory of a point-of-interest of a working tool attached to the work implement of a self-propelled vehicle via a complex attachment that enables additional degrees of freedom of movement of the point-of-interest.

[0036] FIG. 1 depicts a representative self-propelled work vehicle 120 in the form of, for example, a tracked excavator machine. The work vehicle includes an undercarriage 122, which includes first and second ground engaging units 124 (e.g., tracks). Only one of the ground engaging units is shown in FIG. 1. The other ground engaging unit is parallel to the illustrated ground engaging unit. The undercarriage includes respective first and second travel motors (not shown) for driving the first and second ground engaging units. The ground engaging units can be driven at the same velocity to move the undercarriage forward (e.g., in a forward direction indicated by an arrow 126) or backward (e.g., in a direction opposite the arrow 126) with respect to underlying terrain 128 (e.g., ground or other material supporting the undercarriage). The ground engagement units can also be driven at different velocities to enable the undercarriage to turn with respect to the terrain at an angle with respect to the forward direction represented by the arrow 126.

[0037] A main frame 130 is supported from the undercarriage 122 by a swing bearing 132 such that the main frame is pivotable about a main frame pivot axis 134 relative to the undercarriage. The pivot axis is substantially vertical when the underlying ground terrain 128 engaged by the ground engaging units 124 is substantially horizontal. (In the discussion herein, “horizontal” and “vertical” are referenced to a plane defined by the ground engaging units.) A swing motor (not shown) is configured to pivot the main frame on the swing bearing about the pivot axis relative to the undercarriage.

[0038] In the illustrated embodiment wherein the work vehicle 120 is an excavator, a work implement 140 extends from the main frame 130. In FIG. 1, the work implement is configured as a boom assembly. The work implement includes conventional components in the form of a boom 142, an arm 144, and a working tool 146. The working tool includes a point-of-interest (POI) 148, which engages portions of terrain (or other materials) to be moved or removed.

[0039] The boom 142 is pivotally connected to the main frame by a boom-to-frame linkage joint 150, which provides a horizontal pivot axis for the boom. The arm is pivotally connected to the boom at an arm-to-boom linkage joint 152. In the illustrated embodiment, the working tool 146 is an excavator shovel, which is pivotally connected to the arm 144 at a working tool-to-arm linkage joint 154, which is positioned near a free end 156 of the arm. In the illustrated embodiment, a first end of a dogbone connector 160 is pivotally connected to the arm at a dogbone-to-arm linkage joint 162, which is displaced from the free end of the arm. A second end of the dogbone connector is pivotally connected to a tool link 164. In the context of the illustrated (excavator) work vehicle 120, the tool link is a bucket link.

[0040] The boom 142 is caused to move pivotally with respect to the main frame 130 by a boom actuator 170. The boom actuator can be a hydraulic motor. In the illustrated embodiment, the boom actuator is a hydraulic piston-cylinder unit that is selectively provided with pressurized hydraulic fluid to move the piston within the cylinder to extend or extract the piston. The pressurized hydraulic fluid is provided by a hydraulic system (not shown) and is controlled by manual controls, automatic controls, or a combination of manual and automatic controls. In a similar manner, the arm 144 is caused to pivot with respect to the boom by an arm actuator 172. The working tool (bucket) 146 is caused to pivot with respect to the arm by a working tool actuator 174 acting on the working tool via the dogbone connector 160, the dogbone-to-arm linkage joint 162, and the tool link 164.

[0041] The work implement 140 extends from the main frame 130 along a working direction (represented by an arrow 176) of the work implement. In FIG. 1, the working direction is referenced to the main frame. Although illustrated as parallel to the forward direction (arrow 126) of the undercarriage 122, the working direction can be at an angle to the forward direction depending on the rotational position of the main frame with respect to the undercarriage. The

working direction can also be described as a working direction of the boom 142. As illustrated schematically in FIG. 2, the working direction can be considered to be in an operational plane 180 (represented in phantom lines). The boom-to-frame linkage joint 150 defines a first pivot axis 182. The arm-to-boom linkage joint 152 defines a second pivot axis 184. The working tool-to-arm linkage joint 154 defines a third pivot axis 186. The three pivot axes are perpendicular to the operational plane.

[0042] As described herein, control of the work implement 140 relates to controlling the positioning of any one or more of the associated components (e.g., the boom 142, the arm 144, and the working tool 146) to control the movement of the point-of-interest 148 of the working tool with respect to material to be manipulated (e.g., the material to be moved or removed).

[0043] As illustrated by curved arrows in the schematic representation of FIG. 2, the actuators 170, 172, 174 (FIG. 1) of the work implement 140 can be selectively actuated to pivotally move the boom 142 with respect to the respective boom-to-frame linkage joint 150, to pivotally move the arm 144 with respect to the arm-to-boom linkage joint 152, and to pivotally move the working tool 146 with respect to the working tool-to-arm linkage joint 154. By coordinating the movements of the boom, the arm, and the working tool of the work implement, the point-of-interest of the working tool engages and acts upon the material to be manipulated along a selected trajectory 188 at a target velocity. The selected trajectory can be curved as shown (e.g., by pivoting the working tool about the working tool-to-arm linkage joint or by pivoting the arm about the arm-to-boom linkage joint). The selected trajectory can also be linear by coordinating the pivoting of the boom, the arm, and the working tool using inverse kinematic techniques or other suitable techniques (e.g., open loop modeling) to determine the respective pivotal velocities of the three components of the work implement 140. It should be understood

that the point-of-interest moves within a point-of-interest plane 190, which is encompassed with the operational plane 180 discussed above.

[0044] In the illustrated embodiment, an operator's cab 192 is located on the main frame 130. In the illustrated embodiment, the operator's cab and the work implement 140 are both mounted on the main frame so that the operator's cab faces in the working direction (arrow 176) of the work implement. In the illustrated embodiment, a control station 194 is located in the operator's cab.

[0045] The main frame 130 also supports an engine 196 for powering the work vehicle 120. The engine can be a diesel internal combustion engine or another source of power. In the illustrated embodiment, the engine drives at least one hydraulic pump (not shown) to provide hydraulic power to the various operating systems of the work vehicle.

[0046] In illustrated embodiment, a sensor system 200 (see FIG. 3) is mounted on the work vehicle 120. As illustrated in FIG. 1, the sensor system includes a first sensor 200a mounted to the main frame 130, a second sensor 200b mounted to the boom 142, a third sensor 200c mounted to the arm 144, a fourth sensor 200d mounted to the dogbone connector 160, and a fifth sensor 200e mounted to the working tool 146. In the illustrated embodiment, each of the first through fifth sensors is an inertial measurement unit (IMU). IMUs are tools that capture a variety of motion-based and position-based measurements, including, but not limited to, velocity, acceleration, angular velocity, and angular acceleration.

[0047] An accelerometer is an electro-mechanical device or tool used to measure acceleration (e.g., in meters per seconds squared (m/s^2)), which is defined as the rate of change of velocity (e.g., in meters per second (m/s)) of an object. Accelerometers sense either static forces (e.g., gravity) or dynamic forces of acceleration (e.g., vibration and movement). An accelerometer may receive sense elements measuring the force due to gravity. By measuring

the quantity of static acceleration due to gravity of the Earth, an accelerometer may provide data as to the angle the object is tilted with respect to the Earth, the angle of which may be established in an x-axis, y-axis, and z-axis coordinate frame. However, where the object is accelerating in a particular direction, such that the acceleration is dynamic (as opposed to static), the accelerometer produces data which does not effectively distinguish the dynamic forces of motion from the force due to gravity by the Earth. A gyroscope is a device used to measure changes in orientation, based upon the object's angular velocity (rad/s) or angular acceleration (rad/s²). A gyroscope may constitute a mechanical gyroscope, a micro-electro-mechanical system (MEMS) gyroscope, a ring laser gyroscope, a fiber-optic gyroscope, and/or other gyroscopes as are known in the art. Principally, a gyroscope is employed to measure changes in angular position of an object in motion, the angular position of which may be established in an x-axis, y-axis, and z-axis coordinate frame.

[0048] As schematically illustrated in FIG. 3, the self-propelled work vehicle 120 includes a control system that includes a machine controller 210. The machine controller can be part of the machine control system of the working machine, or it can be a separate machine control module. The machine controller is optionally mounted in the operator's cab 192 at the control station 194. The machine controller can include a user interface 212 such as a control panel. The user interface can include a user interface tool 214 such as an input/output device (e.g., a keyboard, a joystick, or the like.) The user interface can also include a display 216.

[0049] The machine controller 210 is configured to receive input signals from some or all of various sensors 200a ... 200e collectively defining the sensor system 200. The sensors of the sensor system may typically be discrete in nature, but signals representative of more than one input parameter may be provided from the same sensor. The sensor system can also refer to signals provided from the machine control system.

[0050] IMUs include a number of sensors including, but not limited to, accelerometers, which measure (among other things) velocity and acceleration, gyroscopes, which measure (among other things) angular velocity and angular acceleration, and magnetometers, which measure (among other things) strength and direction of a magnetic field. Generally, as discussed above, an accelerometer provides measurements, with respect to (among other things) force due to gravity, while a gyroscope provides measurements, with respect to (among other things) rigid body motion. The magnetometer provides measurements of the strength and the direction of the magnetic field, with respect to (among other things) known internal constants, or with respect to a known, accurately measured magnetic field. The magnetometer provides measurements of a magnetic field to yield information on positional, or angular, orientation of the IMU; similarly to that of the magnetometer, the gyroscope yields information on a positional, or angular, orientation of the IMU. Accordingly, the magnetometer may be used in lieu of the gyroscope, or in combination with the gyroscope, and complementary to the accelerometer, in order to produce local information and coordinates on the position, motion, and orientation of the IMU.

[0051] The machine controller 210 can be configured to produce outputs to the user interface 212 for displaying information to the human operator. In addition, or in the alternative, the machine controller can be configured to generate control signals for controlling the operation of respective actuators, or generate signals for indirect control via intermediate control units, associated with a machine steering control system 226, a machine implement control system 228, and an engine speed control system 230. The machine controller can generate control signals for controlling the operation of various actuators, such as hydraulic motors or hydraulic piston-cylinder units of the boom actuator 170, the arm actuator 172, and the working tool actuator 174. The control signals from the controller can be received by electro-hydraulic

control valves associated with the actuators such that the electro-hydraulic control valves control the flow of hydraulic fluid to and from the respective hydraulic actuators to control the actuation thereof in response to the control signal from the controller.

[0052] In the illustrated embodiment, the machine controller 210 includes, or is associated with, a processor 250, a computer readable medium 252, a communication unit 254, data storage 256 such as for example a database network, and the aforementioned user interface (control panel) 212 having the display 216 and the user interface tool (e.g., input/output device) 214 by which a human operator may input instructions to the controller. The machine controller described herein may be a single controller having all of the described functionality, or it may include multiple machine controllers wherein the described functionality is distributed among the multiple controllers. The data storage may generally encompass hardware such as volatile or non-volatile storage devices, drives, memory, or other storage media, as well as one or more databases residing thereon.

[0053] Various “computer-implemented” operations, steps or algorithms as described in connection with the controller 210 or in connection with alternative but equivalent computing devices or systems can be embodied directly in hardware, in a computer program product such as a software module executed by the processor 250, or in a combination of the two. The computer program product can reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, hard disk, a removable disk, or any other form of computer-readable medium 252 known in the art. An exemplary computer-readable medium 252 can be coupled to the processor 250 such that the processor 250 can read information from, and write information to, the memory/storage medium 252. In the alternative, the computer-readable medium 252 can be integral to the processor 250. The processor 250 and the computer-readable medium 252 can reside in an application specific integrated circuit

(ASIC). The ASIC can reside in a user terminal. In the alternative, the processor 250 and the medium 252 can reside as discrete components in a user terminal.

[0054] The term “processor” as used herein may refer to at least general-purpose or specific-purpose processing devices and/or logic as may be understood by one of skill in the art, including but not limited to a microprocessor, a microcontroller, a state machine, and the like. A processor can also be implemented as a combination of computing devices (e.g., a combination of a digital signal processor (DSP) and a microprocessor), a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

[0055] The communication unit 254 can support or provide communications between the machine controller 210 and external systems or devices, and/or support or provide communication interface with respect to internal components of the self-propelled work vehicle 120. The communications unit 254 can include wireless communication system components (e.g., via cellular modem, Wi-Fi® systems, Bluetooth® systems, or the like) and/or may include one or more wired communications terminals such as universal serial bus ports.

[0056] FIG. 4 illustrates a flowchart of an exemplary embodiment of a method 300 for tracking motion of linkage joints for the self-propelled work vehicle 120 to achieve a desired trajectory (e.g., the selected trajectory 188 in FIG. 2) for the point-of-interest 148. In a first step 310, the method receives the target trajectory for moving the point-of-interest. For example, the target trajectory can be a predetermined target trajectory that forms a portion of an overall terrain forming (e.g., excavation) plan. In a second step 312, the method receives inputs from the above-described IMUs 200a, 200b, 200c, 200d, 200e, and the method determines a current location of the point-of-interest. In a third step 314, the method uses inverse kinematics or other suitable techniques to determine various angles and pivoting velocities of the components of the work implement 140 to achieve the target velocity of the point-of-interest. In

a fourth step 316, the method applies controlled hydraulic pressures to the actuators 170, 172, 174 to move the boom 142, the arm 144, and the working tool 146 to achieve the determined angles and pivoting velocities. In the fourth step 316, the method receives feedback from the IMUs, which enables the method to adjust the hydraulic pressures as needed to maintain the desired trajectory.

[0057] As described above, the work vehicle 120 and the method 300 enable the point-of-interest 148 of the working tool 146 to be moved along a desired trajectory (e.g., the selected trajectory 188 of FIG. 2). Because of the positions of the disclosed pivot axes 150, 152, 154, the point-of-interest is only able to move in the point-of-interest plane 190 perpendicular to the pivoting axes and parallel to the working direction (arrow 176). Thus, the trajectory of the point-of-interest is in the point-of-interest plane as shown in FIG. 2.

[0058] FIG. 5 illustrates the work vehicle 120 of FIG. 1 equipped with a complex attachment 350 that enables a point-of-interest 354 of a working tool 352 to move in at least one additional degree of freedom. In the illustrated example of the work vehicle as an excavator, the working tool is an excavator bucket as previously described. A first (upper) end portion 360 of the complex attachment is pivotally mounted to the arm 144 at the working tool-to-arm linkage joint 154 in place of the conventional bucket working tool 146. Accordingly, the overall complex attachment is pivotally movable about the third pivot axis 186 (shown as an end dot in FIG. 5) of the working tool-to-arm linkage joint using the working tool actuator 174. The fifth sensor 200e is mounted to the first end portion of the complex attachment to enable the machine controller 210 to monitor the movement of the complex attachment about the third pivot axis.

[0059] As further shown in FIG. 5, a second (lower) end portion 362 of the complex attachment 350 is pivotally attached to the first end portion 360 of the complex attachment via an integral complex attachment linkage joint 364, which comprises two pivot brackets in the

illustrated embodiment. The integral complex attachment linkage joint enables the second end portion to pivot (e.g., tilt) with respect to the first end portion about a tilt axis 366, which is perpendicular to the third pivot axis 186, thus providing a first additional degree of freedom (tilting).

[0060] The first end portion 360 of the complex attachment 350 supports at least one hydraulic actuator 370, which is coupled to the second end portion 362. The hydraulic actuator is selectively activated by an internal control system (not shown in FIG. 5) of the complex attachment to tilt the second end portion with respect to the first end portion about the tilt axis 366. The complex attachment receives hydraulic fluid from the work vehicle 120 via at least one hydraulic supply line 372. The complex attachment selectively directs the volume and pressure of the hydraulic fluid to the actuator.

[0061] The second end portion 362 of the complex attachment 350 includes a tool support structure 380 that is rotatable with respect to the first end portion about a rotation axis 382. The tool support structure is rotated by an internal hydraulic motor 384 (FIG. 7) within the second end portion of the complex attachment. The working tool 352 is attached to the tool support structure and rotates with the tool support structure. Thus, the rotation of the tool support structure provides a second additional degree of freedom of movement of the working tool. Although the working tool is illustrated as being an integral part of the complex attachment, the working tool can be removed and replaced with a replacement working tool such as a different-sized excavator bucket. The replacement working tool can be different type of working tool such as a blade.

[0062] The effect of the complex attachment 350 is illustrated schematically in FIG. 6, which is similar to the schematic illustration of FIG. 4, wherein the operational plane 180 and the three pivot axes 182, 184, 186 of the work implement 140 are represented and numbered

accordingly. FIG. 6 further illustrates a representation of the first (upper) end portion 360, the second (lower) end portion 362 of the complex attachment 350 and the tool support structure 380. As illustrated, the second end portion can tilt about the tilt axis 366 of the integral complex attachment linkage joint 364 to cause the point-of-interest 354 to have a tilt trajectory (tilt velocity) 386 in a tilt plane 388, which is perpendicular to the tilt axis. As further illustrated, the tool support structure and the attached working tool 352 can rotate with respect to the second end portion about the rotation axis 382 to cause the point-of-interest to have a rotation trajectory (rotation velocity) 390 in a rotation plane 392, which is perpendicular to the rotation axis.

[0063] Each of the tilt trajectory 386 and the rotation trajectory 390 has a respective trajectory path about the respective tilt axis 366 and the respective rotation axis 382 as illustrated in FIG. 6. Each trajectory has a respective angular velocity along the respective trajectory path. Accordingly, as used herein, the “tilt trajectory” and the “rotation trajectory” are used interchangeably with the respective angular velocities about the respective tilt axis and rotation axis.

[0064] In FIG. 6, the pivot trajectory 386 and the rotation trajectory 390 are each illustrated when only one of either pivotal movement or rotational movement occurs from the illustrated location of the point-of-interest. When the complex attachment applies velocities to cause pivotal movement and rotational movement to occur simultaneously, the resulting trajectory (not shown) will not be confined to either of the illustrated planes and will have a complex movement resulting from the selected velocities of the two movements. A more complex trajectory can be produced by applying pivotal movement about one or more of the pivot axes 182, 184, 186 of the work implement 140 in coordination with the tilt and rotation movements of the complex attachment.

[0065] The complex attachment 350 includes an internal control system (attachment controller) 400 (FIG. 7) that controls the at least one hydraulic actuator 370 (FIG. 5) to pivot the second end portion 362 with respect to the first end portion 360 and that controls the internal hydraulic motor 384 (FIG. 7) to rotate the working tool support structure 380 and the attached working tool 352 with respect to the second end portion. The complex attachment receives commands from the machine controller 210 (FIG. 3) of the work vehicle 120. Rather than commanding the rotation of the second end portion and the pivoting of the working tool directly, the desired velocities tilt and rotate velocities are sent from the machine controller of the work vehicle to the internal control system of the complex attachment to instruct the complex attachment to move the point-of-interest 354 of the working tool with respect to the working tool-to-arm linkage joint 154 to which the complex attachment is pivotally attached. The internal control system of the complex attachment determines how to manipulate the actuators (not shown) of the complex attachment to achieve the desired movement. Thus, the machine controller of the work vehicle does not have to generate actuator controls for the complex attachment. The complex attachment provides feedback to the machine controller of the work vehicle so that the machine controller is able to verify that the complex attachment has rotated and tilted the point-of-interest as requested. The complex attachment also sends requests to the machine controller of work vehicle to identify the hydraulic pressure needed to actuate the actuators (not shown) of the complex attachment to achieve the desired movement of the point-of-interest in the point-of-interest plane 190.

[0066] As discussed above, the machine controller 210 of the work vehicle 120 does not control the actuators of the complex attachment directly. Rather, as illustrated in FIG. 7, the machine controller of the work vehicle communicates with internal control system (attachment controller) 400, which is located within the complex attachment 350. Various communications

protocols can be used to communicate between the machine controller and the attachment control system via an interface 410. As described below, the machine controller includes additional algorithms to determine desired positions and movements of the complex attachment; however, the machine controller does not have to include algorithms to directly monitor and control the rotational movement of the complex attachment or the pivoting movement of the working tool 352 with respect to the complex attachment.

[0067] As further shown in FIG. 7, the subsystems of the machine controller 210 pertinent to this disclosure includes a trajectory determination subsystem 420 that determines a target velocity for the point-of-interest 354 based on the currently known position of the point-of-interest and based on a desired movement of the point-of-interest with respect to the terrain to be manipulated. Because of the complex attachment 350, the desired movement of the point-of-interest is not limited to movement in the operational plane 180. Instead, the movement can include movement in a different plane (e. g., movement in the point-of-interest plane 190 discussed above).

[0068] The target velocity determined by the trajectory determination subsystem 420 is provided as an input to a velocity determination subsystem 430. The velocity determination subsystem performs a modeling technique such as an inverse kinematic determination based on the target velocity to determine a desired boom pivot velocity, a desired arm pivot velocity, and a desired bucket pivot velocity. As described herein, the working tool (bucket) 146 of FIG. 1 is replaced with the complex attachment 350. Accordingly, the desired bucket velocity determines the tilt location and velocity of the first end portion 360 of the complex attachment with respect to the arm 144. The velocity determination subsystem also determines a desired second end portion rotation location and velocity of the second end portion 362 of the complex attachment with respect to the first end portion of the complex attachment. The tilt

determination establishes the orientation and movement of the tilted rotation plane 392 (FIG. 6). The rotation determination establishes the orientation and movement of the tilt plane 388. The velocity determination subsystem also determines velocities of the point-of-interest 354 within the two planes

[0069] The desired boom velocity, the desired arm velocity and desired the bucket velocity determined by the velocity determination subsystem 430. In the illustrated embodiment, the desired boom, arm, and bucket velocities are provided as inputs to a synchronization subsystem 440, which operates as described below. The desired tilt velocity of the second end portion 362 of the complex attachment 350 and the desired rotation velocity of the point-of-interest 354 determined by the second machine control subsystem are provided as inputs to a feedback control subsystem 450.

[0070] The feedback control subsystem 450 receives measured velocities reported by the attachment controller 400. A measured second end portion tilt velocity is compared to the desired second end tilt velocity to determine whether the complex attachment is achieving the desired tilt velocity. If the measured second end tilt velocity is different, a slight adjustment is made to the desired tilt velocity to generate an adjusted second end tilt velocity. Similarly, a measured point-of-interest rotation velocity is compared to the desired point-of-interest rotation velocity to determine whether the complex attachment is achieving the desired point-of-interest rotation velocity. If the measured point-of-interest rotation velocity is different, a slight adjustment is made to the desired point-of-interest rotation velocity to generate an adjusted point-of-interest rotation velocity. No adjustment may be necessary if the complex attachment is achieving the desired velocities, and the adjusted velocities can be the same as the desired velocities.

[0071] The adjusted second end tilt velocity and the adjusted point-of-interest rotation velocity generated by the feedback control subsystem are provided as inputs to the synchronization subsystem 440, which synchronizes the three desired velocities of the work implement (e.g., the desired boom pivot velocity, the desired arm pivot velocity, and the desired bucket pivot velocity (referred to below as the machine desired velocities)) from the velocity determination subsystem 430 with the two adjusted velocities from the feedback control subsystem 450 (referred to below as the working tool desired velocities). The synchronization compensates for any known latencies between the control functions that would cause one of the machine desired velocities or the working tool desired velocities to be achieved before the other of the machine desired velocities or the working tool desired velocities. The latencies are characterized by collecting data on a machine and on a complex attachment and deriving a multi-order transfer function to represent the relationship between the latencies. The synchronization subsystem may not be needed in systems having no latencies or minimal latencies.

[0072] The synchronized velocities for the machine controlled functions (e.g., the boom pivot velocity, the arm pivot velocity, and the bucket pivot velocity) generated by the synchronization subsystem 440 are provided to a machine hydraulic system controller subsystem 460, which controls pumps and valves in a conventional manner to produce the respective synchronized velocities for the boom, the arm, and the bucket, wherein the conventional bucket is replaced by the first end portion 360 of the complex attachment.

[0073] The synchronized working tool desired velocities generated by the synchronization subsystem 440 are provided to the attachment controller 400, which implements control algorithms to selectively apply hydraulic pressure to the at least one hydraulic (tilt) actuator 370 to control the tilting of the second end portion 362 with respect to the first end portion 360 of the complex attachment 350 and to selectively apply hydraulic pressure to the internal hydraulic

motor 384 to control the rotation of the working tool 352. The hydraulic actuator and the hydraulic operate to move the point-of-interest 354 along a selected trajectory as described above. In the illustrated embodiment, the synchronized tilt and rotation velocities from the synchronization subsystem 440 of the machine controller 210 to the attachment controller are provided in real units (e.g., degrees per second) such that the attachment controller is able to generate the requested motions relative to the working tool-to-arm linkage joint 154.

[0074] The complex attachment 350 does not need information regarding the locations and velocities of the components of the work implement 140. The machine controller 210 does not need to know how the attachment controller 400 of the complex attachment achieves the requested tilt of the second end portion and the requested rotation of the working tool support structure 380. Accordingly, when a new complex attachment is attached to the work vehicle 120, the machine controller only needs to receive information about the tilt range of the second end portion 362 and the rotation range of the working tool support structure 380 so that calculated requests are generated within the requested ranges. For example, in certain embodiments of the complex attachment the rotation range of the working tool support structure can be a full circle (e.g., 360 degrees).

[0075] As discussed above, the attachment controller 400 provides feedback to the feedback control subsystem 450 within the machine controller 210 to inform the feedback controller about the actual tilt and rotation velocities. The attachment controller also provides an auxiliary flow request signal to the machine hydraulic system controller 460 that indicates the hydraulic pressure and flow required to achieve the desired rotation and tilt velocities for the complex attachment. The hydraulic fluid is provided to the complex attachment 350 via the at least one hydraulic supply line 372. As discussed above, the complex attachment controls the application

of the hydraulic pressure and flow to the at least one hydraulic actuator 370 and to the internal hydraulic motor 384 within the complex attachment.

[0076] The foregoing operations are illustrated in FIG. 8 as a flowchart of an exemplary embodiment of a method 500 for controlling the point-of-interest 354 of the working tool 352 attached to the second end portion 362 of the complex attachment 350.

[0077] The method 500 begins in a first step 510 in which a desired target trajectory for the point-of-interest 354 of the working tool 352 is defined. Then, in a second step 512, a velocity determination technique (e.g., inverse kinematics) is applied to the desired target trajectory to determine respective desired first velocities for the movements of the components of the work implement 140 (e.g., the boom 142, the arm 144, and the first (upper) end portion 360 of the complex attachment 350). The applied technique also determine respective desired second velocities for the pivotal movement of the second end portion 362 of the complex attachment with respect to the first end portion of the complex attachment and for the rotational movement of the working tool support structure 380 and the attached working tool with respect to the second end portion of the complex attachment.

[0078] In a third step 514, the method 500 receives measured second velocities from the complex attachment 350, and compares the measured second velocities to the desired second velocities. In a fourth step 516, the method generates adjusted second velocities in response to differences in the measured second velocities and the desired second velocities. As discussed above, if the measured second velocities are the same as the desired velocities, the adjusted second velocities are the same as the desired second velocities. If a particular complex attachment is known to accurately generate measured second velocities corresponding to the desired second velocities, the third and fourth steps.

[0079] In a fifth step 518, the method 500 synchronizes the desired first velocities and the adjusted second velocities to generate respective first synchronized velocities and second synchronized velocities.

[0080] In a sixth step 520, the method 500 applies the first synchronized velocities to the machine controller 210 to control the boom actuator 170, the arm actuator 172, and the working tool actuator 174 of the work implement.

[0081] In a seventh step 522, the method 500 applies the second synchronized velocities to the complex attachment 350.

[0082] In an eighth step 524 of the method 500, the complex attachment 350 responds to the second synchronized velocities to control the movement of the point-of-interest 354 of the working tool 352 with respect to the work implement 140 by tilting the second end portion 362 and by rotating the tool support structure 380 and the attached working tool.

[0083] In the illustrated embodiment, the method 500 further includes a ninth step 540 of coupling a source of hydraulic flow to the complex attachment 350, a tenth step 542 of receiving auxiliary hydraulic flow requests from the complex attachment; and an eleventh step 544 of adjusting hydraulic flow to the complex attachment in response to the auxiliary hydraulic flow requests. The ninth, tenth, and eleventh steps operate independently of the other steps of the method and are shown as parallel steps.

[0084] As described herein, the complex attachment 350 can be coupled to the arm 144 of the work implement 140 of a work vehicle 120 in place of a conventional working tool 146, and a working tool 352 can be coupled to the working tool support structure 380 of the complex attachment. The machine controller 210 of the work vehicle does not control the actuators of the complex attachment directly. Rather, the work vehicle provides hydraulic pressure and flow to the complex attachment via the at least one hydraulic supply line 372 and provides

synchronized target velocities to the complex attachment. The complex attachment manipulates the at least one hydraulic actuator 370 to tilt the second end 362 of the complex attachment and manipulates the internal hydraulic motor 384 (FIG. 7) of the complex attachment to rotate the working tool support structure 380 and the attached working tool 352.

[0085] Thus, it is seen that the apparatus and methods of the present disclosure readily achieve the ends and advantages mentioned as well as those inherent therein. While certain preferred embodiments of the disclosure have been illustrated and described for present purposes, numerous changes in the arrangement and construction of parts and steps may be made by those skilled in the art, which changes are encompassed within the scope and spirit of the present disclosure as defined by the appended claims. Each disclosed feature or embodiment may be combined with any of the other disclosed features or embodiments.

CLAIMS

What is claimed is:

1. A computer-implemented method of controlling movement of a point-of-interest of a working tool mounted to a complex attachment, the complex attachment mounted to the work implement of a work vehicle, the work implement comprising components movable with respect to the work vehicle and with respect to each other, the complex attachment operable to move the point-of-interest of the working tool with respect to the work implement, the method comprising:

defining a desired trajectory for the point-of-interest of the working tool;

determining desired first velocities for the movements of the components of the work implement and determining desired second velocities for the movements of the point-of-interest of the working tool with respect to the work implement;

applying the desired first velocities to a control system that controls actuators of the work implement; and

sending velocities responsive to the desired second velocities to the complex attachment, the complex attachment applying the velocities responsive to the desired second velocities to control the movement of the point-of-interest of the working tool with respect to the work implement.

2. The method of claim 1, further comprising:

receiving measured second velocities from the complex attachment; and

generating adjusted second velocities in response to differences between the measured second velocities and the desired second velocities and providing the adjusted second velocities as the velocities responsive to the desired second velocities.

3. The method of claim 2, wherein the adjusted second velocities are the same as the desired second velocities when the measured second velocities are the same as the desired second velocities.
4. The method of claim 1, further comprising:
 - coupling a source of hydraulic flow to the complex attachment;
 - receiving hydraulic flow requests from the complex attachment; and
 - adjusting hydraulic flow to the complex attachment in response to the hydraulic flow requests.
5. The method of claim 1, wherein the work implement comprises :
 - a first component having a first end coupled to the main frame at a first linkage joint;
 - a second component having a first end coupled to a second end of the first component at a second linkage joint; and
 - a third linkage joint located at a second end of the second component.
6. The method of claim 5, wherein the first component is a boom, the second component is an arm, and the third linkage joint is configured to enable attachment of the complex attachment.
7. The method of claim 1, wherein the desired first velocities and the velocities responsive to the desired second velocities are synchronized before sending the desired first velocities to the control system and before sending the velocities responsive to the desired second velocities to the complex attachment.
8. The method of claim 1, wherein the desired first and second velocities are determined by applying inverse kinematics to the desired trajectory.

9. A self-propelled work vehicle comprising:
- a main frame moveable with respect to terrain;
 - a work implement having a first end moveably coupled to the main frame and having a second end moveable with respect to the main frame, the second end including a first working tool mounting system;
 - a complex attachment comprising:
 - a first portion coupled to the first working tool mounting system of the work implement;
 - a second portion including a working tool mounting system of the complex attachment;
 - a working tool mounted to the working tool mounting system of the complex attachment;
 - at least one actuator configured to selectively tilt the second portion and the working tool mounting system of the complex attachment with respect to the first portion of the complex attachment and to selectively rotate the working tool with respect to the second portion of the complex attachment; and
 - a complex attachment control system configured to receive tilt and rotate commands and to control the at least one actuator to selectively tilt the second portion with respect to the first portion and to selectively rotate the working tool in response to the tilt and rotate commands;
- and
- a work vehicle control system configured to monitor and control a position of the first working tool mounting system at the second end of the work implement, to generate the tilt

and rotate commands, and to send the tilt and rotate commands to the complex attachment.

10. The self-propelled work vehicle of claim 9, wherein the work vehicle control system comprises:

a trajectory determination subsystem to determine a desired trajectory of a point-of-interest of the working tool;

a velocity determination subsystem responsive to the desired trajectory to determine desired first velocities and desired second velocities to achieve the desired trajectory, the desired first velocities for components of the work implement and for the first working tool mounting system, the desired second velocities for the complex attachment, wherein the tilt and rotate commands sent to the complex attachment are responsive to the desired second velocities; and

a hydraulic control subsystem that receives the desired first velocities and that controls movements of the components and the first working tool mounting system of the work implement.

11. The self-propelled work vehicle of claim 10, further comprising a synchronization subsystem to synchronize the desired first velocities and velocities responsive to the desired second velocities to generate synchronized first velocities and synchronized second velocities, the complex attachment receiving the synchronized second velocities and tilting and rotating the working tool in response to the synchronized second velocities.

12. The self-propelled work vehicle of claim 11, wherein the work vehicle control system includes a feedback control subsystem configured to receive feedback from the complex attachment system representing measured second velocities and to generate the velocities

responsive to the desired second velocities responsive to differences between the measured second velocities and the desired second velocities.

13. The self-propelled work vehicle of claim 10, wherein the velocity determination subsystem generates the desired first velocities and the desired second velocities using inverse kinematics.

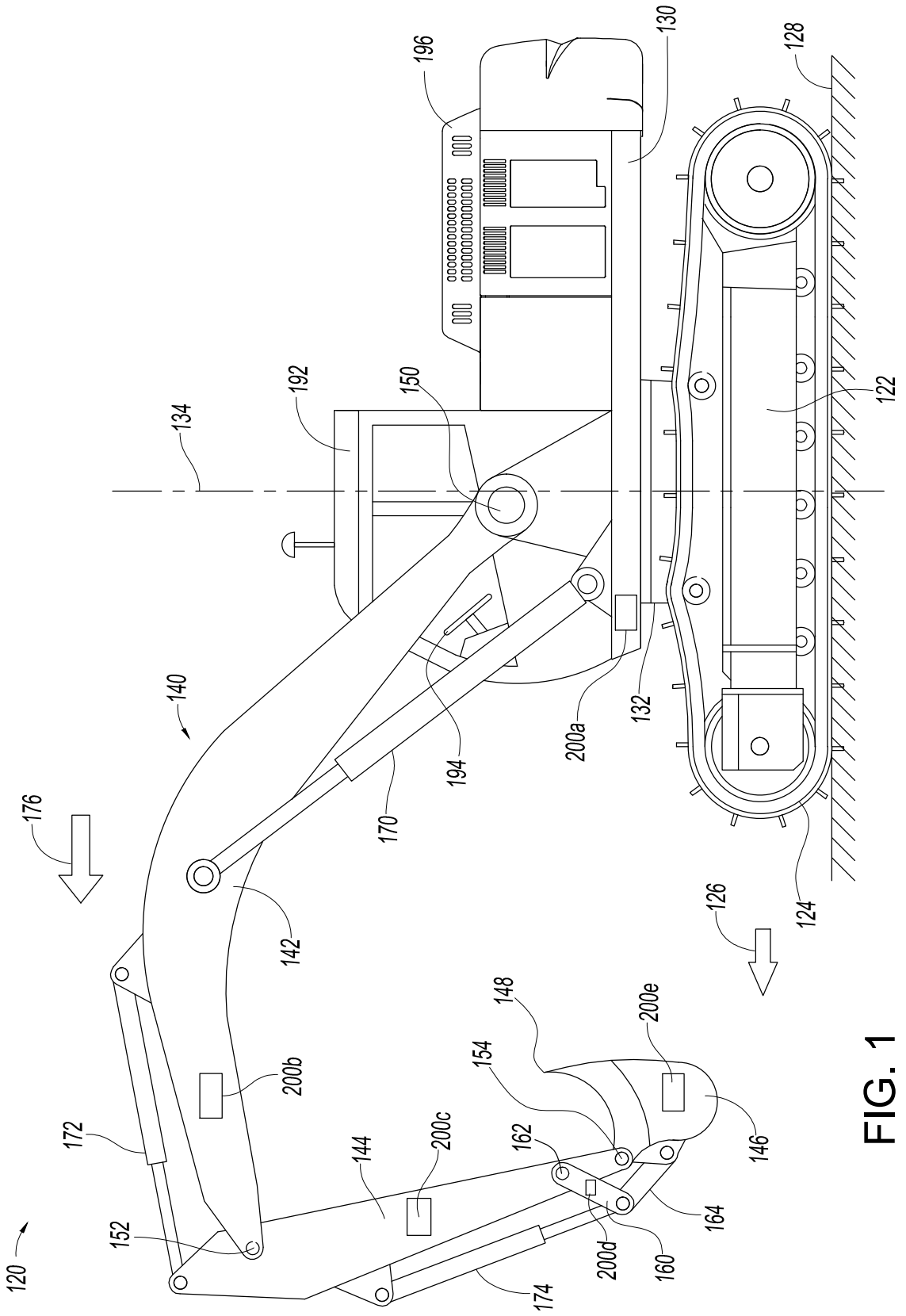


FIG. 1

2025208482 24 Jul 2025

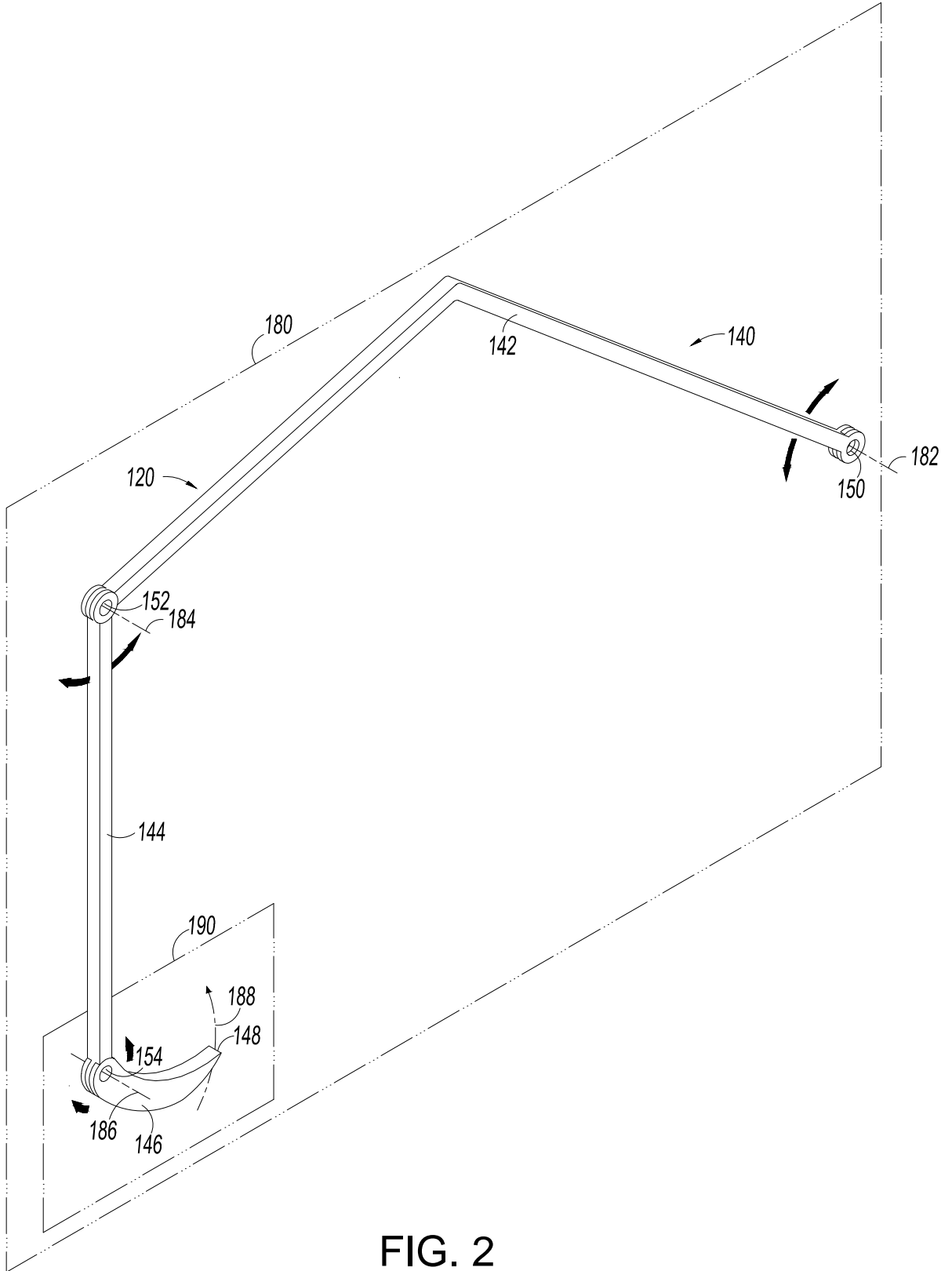


FIG. 2

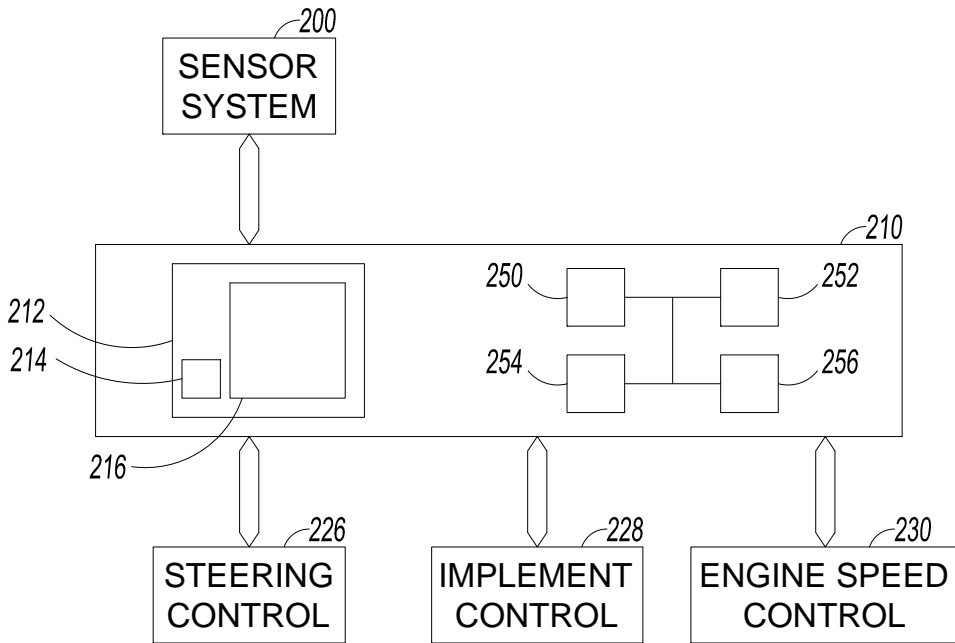


FIG. 3

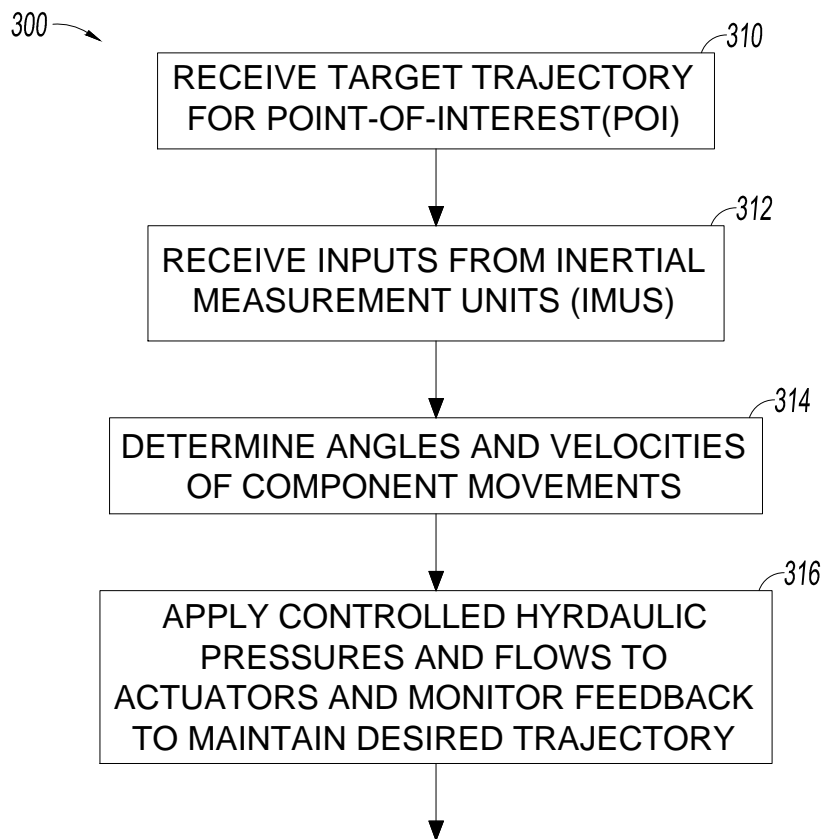


FIG. 4

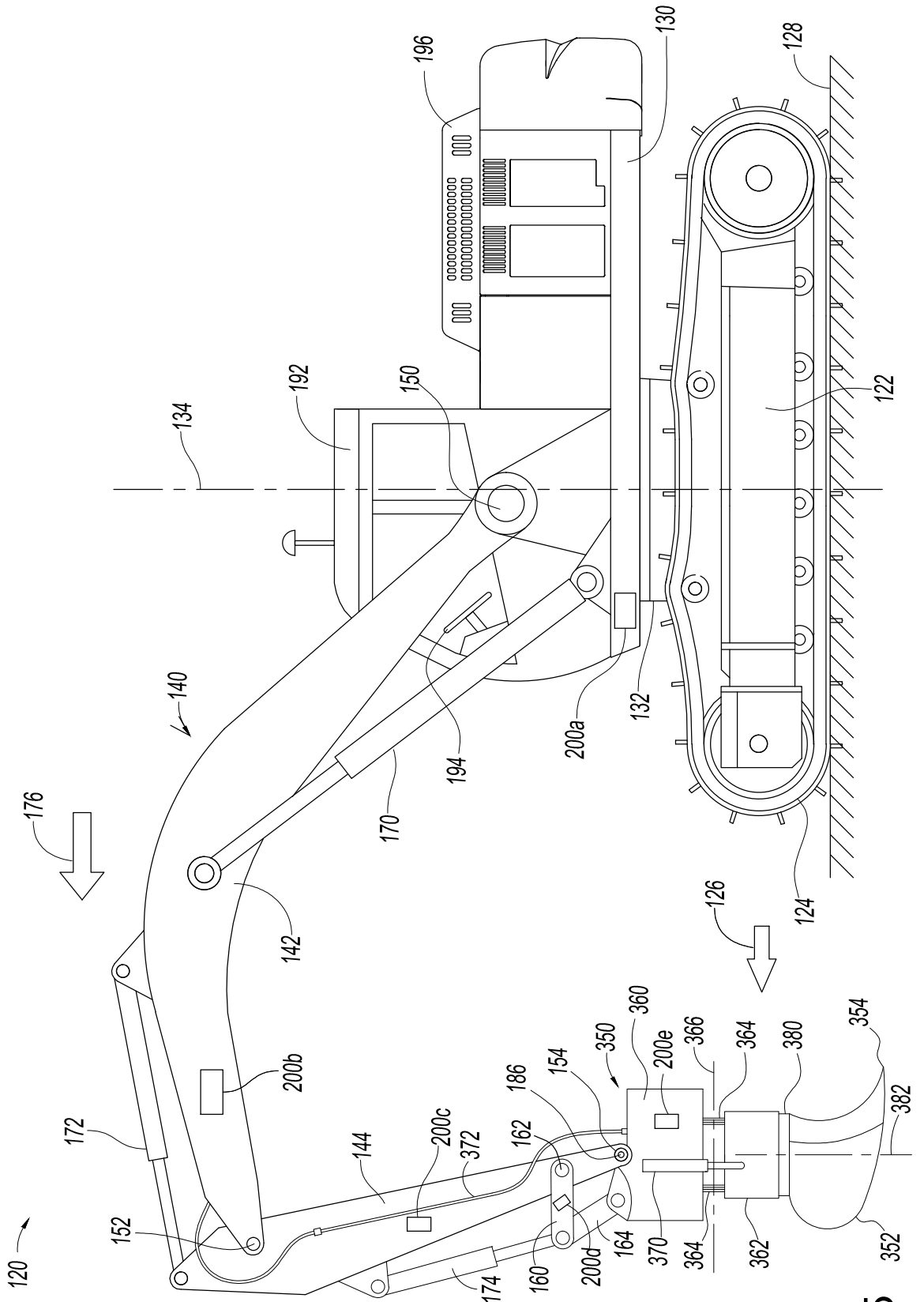


FIG. 5

2025208482 24 Jul 2025

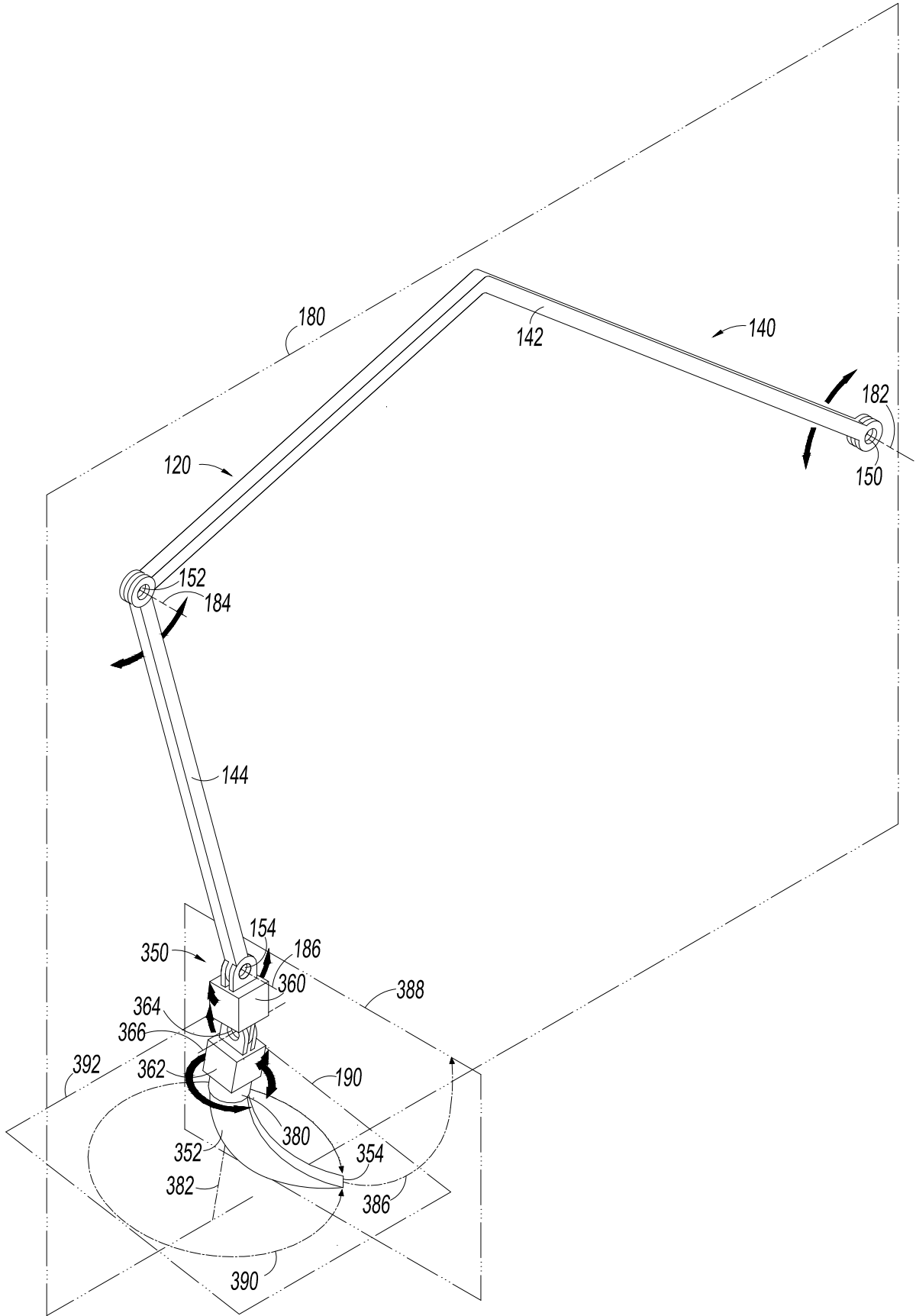


FIG. 6

2025208482 24 Jul 2025

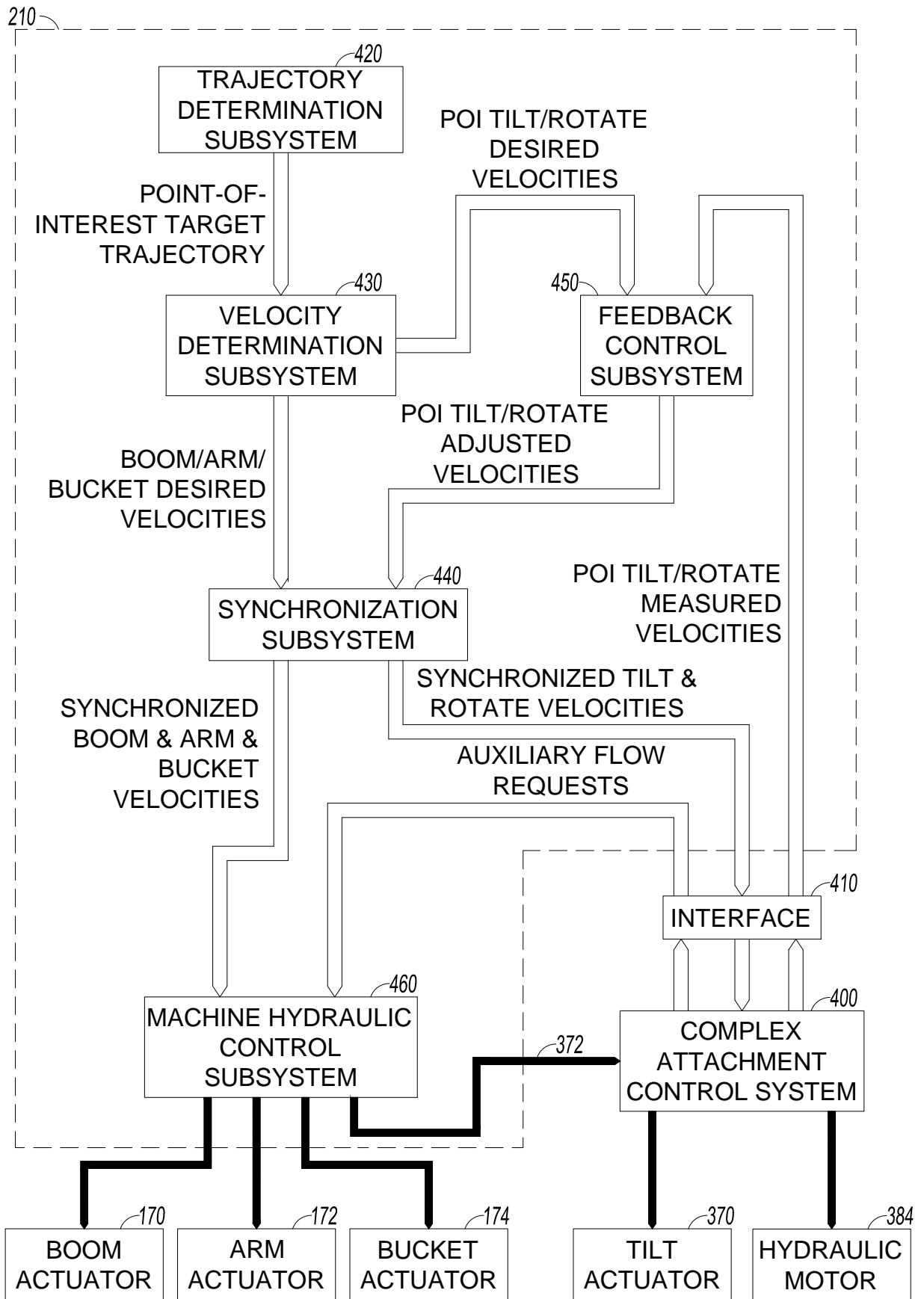


FIG. 7

2025208482 24 Jul 2025

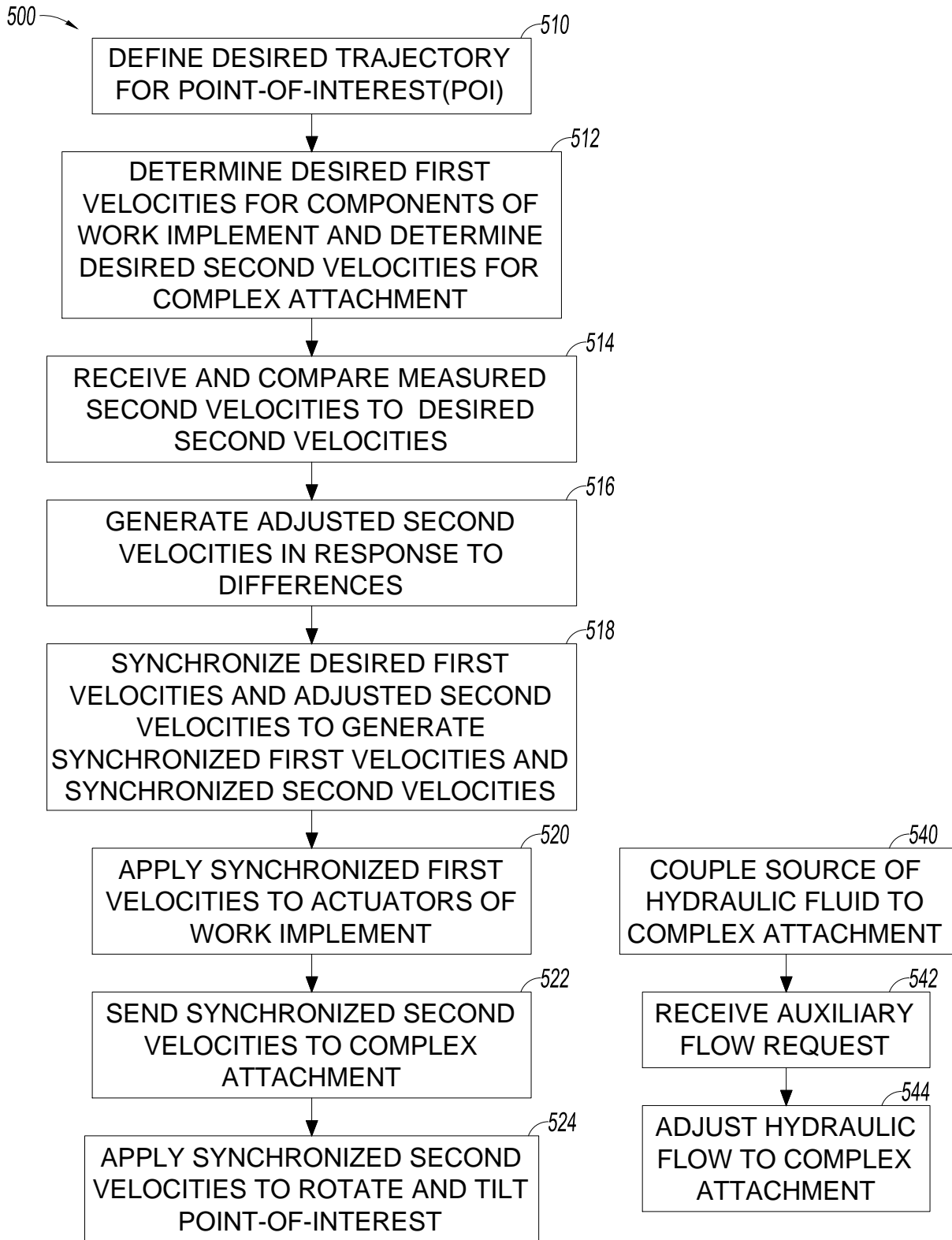


FIG. 8