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MOBILE MACHINE CONTROL SYSTEM

Abstract

A mobile machine includes a tool coupled to the mobile machine by one or more controllable linkages. The machine includes a user interface mechanism configured to receive input from an operator. The machine includes one or more controllers configured to implement surface follow logic configured to receive the input from the user interface mechanism and identify a desired movement of the tool relative to a control surface, based on the input. The one or more controllers configured to implement control signal generator logic that generates a control signal to control the one or more controllable linkages, based on the identified movement.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION [0001] The present application is a continuation of and claims priority of U.S. patent application Ser. No. 16/935,501, filed Jul. 22, 2020, the content of which is hereby incorporated by reference in its entirety.

FIELD OF THE DESCRIPTION
[0002] The present description is related to excavators used in heavy construction. M ore particularly, the present description is related to a control mode in such excavators.
BACKGROUND
[0003] Hydraulic excavators are heavy construction equipment generally weighing between 3500 and 200,000 pounds. These excavators have a boom, an arm, a bucket (or attachment), and a cab on a rotating platform that is sometimes called a house. A set of tracks is located under the house and provides movement for the hydraulic excavator.
[0004] Hydraulic excavators are used for a wide array of operations ranging from digging holes or trenches, demolition, placing or lifting large objects, and landscaping. Precise excavator operation is very important in order to provide efficient operation and safety. Providing a system and method that increases excavator operational precision without significantly adding to cost would benefit the art of hydraulic excavators.
[0005] The discussion above is merely provided for general background information and is not intended to be used as an aid in determining the scope of the claimed subject matter. SUMMARY
[0006] A mobile machine includes a tool coupled to the mobile machine by one or more controllable linkages. The machine includes a user interface mechanism configured to receive input from an operator. The machine includes one or more controllers configured to implement surface follow logic configured to receive the input from the user interface mechanism and identify a desired movement of the tool relative to a control surface, based on the input. The one or more controllers are configured to implement control signal generator logic that generates a control signal to control the one or more controllable linkages, based on the identified movement.
[0007] This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter. The claimed subject matter is not limited to implementations that solve any or all disadvantages noted in the background.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0008] FIG. **1** is a diagrammatic view showing an example mobile machine.
[0009] FIG. **2** is a block diagram showing an example mobile machine.
[0010] FIG. **3** is a flow diagram showing an example method of controlling a mobile machine.
[0011] FIGS. **4**A-**4**B are diagrams showing example control models of a mobile machine.
[0012] FIG. **5** is a block diagram showing an example computing system.
DETAILED DESCRIPTION
[0013] FIG. **1** is a diagrammatic view showing an example machine **100** that is an excavator. Excavator or machine **100** includes a house **102** having an operator cab **104** rotatably disposed above tracked portion **106**. House **102** may rotate 360 degrees about tracked portion **106** via rotatable coupling **108**. A boom **110** extends from house **102** and can be raised or lowered in the

direction indicated by arrow **112** based upon actuation of hydraulic cylinder(s) **114**. A stick or arm **116** is pivotably connected to boom **110** via linkage pin **118** and is movable in the direction of arrows **120** based upon actuation of hydraulic cylinder **122**. Bucket or tool **124** is pivotably coupled to arm **116** at linkage pin **126** and is rotatable in the direction of arrows **128** about linkage pin **126** based on actuation of hydraulic cylinder **130**. In some examples, tool **124** can rotate in additional directions as well. For instance, a tiltrotor or other linkage device could be provided for additional rotation of tool **124** (or other linkages of machine **100**).

[0014] A common control mode is the ISO control mode. In the ISO control mode, a left hand joystick controls the rotation of house **102** about rotatable coupling **108** (left & right) and the extension or retraction of arm **116** (e.g., away & close, represented by arrow **120**), and the right hand joystick controls the lift of boom **110** (e.g., up & down, represented by arrow **112**) and curl of bucket **124** (e.g., close & dump, represented by arrow **128**). Inherently, because of the connections of the linkages being pivoted about a linkage pin, the movement of the linkages will be circular about the linkage pin. For bucket **124** to move in a non-circular path, the operator must utilize the joysticks in multiple directions simultaneously.

[0015] In an alternative control mode, actuation of a joystick along one axis moves bucket **124** (via control of bucket **124** and the other linkages) in a first direction parallel to surface **131** (e.g., an X-axis relative to surface **131** and away from house **102**). Another actuation of a joystick along another axis moves bucket **124** (via control of bucket **124** and the other linkages) in a second direction parallel to surface **131** and perpendicular to the first direction (e.g., the Y-axis relative to surface **131** and perpendicular to boom **110**). Examples of parallel movements are represented by arrows **132-1**, **132-2**, **132-3** and **132-4**. This movement of bucket **124** parallel or substantially parallel to surface **131** can be referred to as the feed rate. Actuation of one of the joysticks in another axis actuates bucket **124** in a direction perpendicular or substantially perpendicular to surface **131** (e.g., a normal of the surface **131**). Examples of perpendicular movement to surface **131** are represented by arrows **133-1**, **133-2** and **133-2**. As can be seen, perpendicular movement is dependent on the location of bucket **124** along control surface **131** or along a path parallel to control surface **131**. Lastly, actuation a joystick in another axis controls the angle at which bucket **124** is oriented relative to surface **131**. For instance, bucket **124** may be curled such that it is cutting into surface **131** or extended such that the cutting edge of bucket **124** scrapes or grades surface **131**. As shown, machine **100** is an excavator, however, the systems and methods described herein can be used on other types of machines as well.

[0016] FIG. **2** is a block diagram showing example machine **100** in an example environment **200**. Environment **200** includes machine **100**, remote systems **201**, operator **203** and can include other items as well, as indicated by block **205**. Remote systems **201** can include a wide variety of systems such as other mobile machines, servers, computers, mobile electronic devices, etc. Remote systems **201** can communicate with machine **100** and other components via various network protocols e.g., Bluetooth, Wi-Fi, cellular data, LAN, WAN, etc. Some blocks representing subcomponents of other components can be disposed, in their entirety or partially, at other locations in environment **200**.

[0017] Machine **100** includes controllers and/or processors **202**, user interface devices **210**, data store **212**, sensors **220**, controllable subsystems **240** and control system **250** and can include other items as well, as indicated by block **234**. Controllers and processors **202** can include processors, servers and other hardware, software and combinations thereof. Controller and processors **202** implement the logic components of control system **250**.

[0018] User interface devices **210** include devices that operator **203** uses to interact with machine **100**. For example, interface devices **210** can include joysticks. Of course, user interface devices **210** can include other items as well, such as touch screens, pedals, steering wheels, handheld controllers, etc. In some examples, user interface devices **210** are disposed on a remote system **201** that is a mobile device.

[0019] Controllable subsystems **240** include actuators **242**, rotatable house **102**, tracked portion **106**, linkages **109** and can include other items as well, as indicated by block **214**. Rotatable house **102** rotates about tracked portion **106**. Rotatable house **102** includes operator cab **104** where an operator **203** sits while controlling machine **100**. Rotatable house **102** can include other items as well, as indicated by block **105**. For instance, rotatable house **102** includes an engine that powers machine **100**. Tracked portion **106** includes the tracks that propel machine **100** about a worksite. Linkages **109** include boom **110**, arm **116**, tool **124** and can include other items as well, as indicated by block **125**. Linkages **109** allow machine **100** a wide variety of control of a working environment. As shown, tool **124** is a bucket. However, tool **124** can include a variety of different attachments as well, for example, a packer.
[0020] Machine **100** includes controller **202**, user interface devices **210**, data store **212**, sensors **220**, sensor position determination logic **230**, controllable subsystems **240**, control system and can include other items as well, as indicated by block **234**. Illustratively, the components are part of machine **100**, however, some of the shown blocks may be located remotely from machine **100** (e.g., on a remote server, on a different machine, etc.).
[0021] Controller **202** is configured to receive one or more inputs and perform a sequence of programmatic steps to generate one or more suitable machine outputs for controlling the operation of machine **100** (e.g., implementing the various logic components). Controller **202** may include one or more microprocessors, or even one or more suitable general computing environments as described below in greater detail. Controller **202** is coupled to user interface devices **210** in order to receive machine control inputs from an operator within cab. Examples of operator inputs include joystick movements, pedal movements, machine control settings, touch screen inputs, etc. Additionally, user interface devices **210** also include one or more operator displays in order to provide information regarding excavator operation to the operator.
[0022] Data store **212** stores various information for the operation of machine **100**. As shown, data store **212** includes actuator data **213**, machine geometry **214** and bindings **215**, but can include other items as well, as indicated by block **216**. Actuator data **213** includes various information on actuators **242** that actuate controllable subsystems **240**. For instance, actuator data **213** includes data indicative of the max torque, acceleration, speed, etc. that actuators **242** actuate controllable subsystem **240**. Since the characteristics of actuators **242** can be different based on the pose of machine **100**, actuator data **213** can include pose-specific or other specific data as well. For example, maximum vertical acceleration of bucket **124** is less when boom **110** is lowered and arm **116** is extended than when boom **110** is raised and arm **116** is half retracted.
[0023] Geometry data **214** includes the dimensions and pivot points of the various controllable subsystems **240** of machine **100**. For example, machine geometry **214** includes data indicative of the distance between the first linkage pin of boom **110** to the second linkage pin of boom **110**. In some examples, geometry data **214** includes a three-dimensional model of various subcomponents of machine **100**.
[0024] Bindings **215** include data indicative of controls commands that correspond to operator inputs on various interface devices **210**. For instance, in a standard control mode, joystick movement in one axis raises and lowers boom **110**. In an alternative control mode, joystick movement in one axis actuates various linkages **109** to move tool **124** parallel to a control path.
[0025] Sensors **220** include inertial measurement units (IMU), linkage sensors and can include a variety of other sensors as well. IMU sensors can be disposed on machine **100** at a variety of different places. For instance, IMU sensors can be placed on the rotatable house **102**, boom **110**, arm **116**, and tool **124**. IMU sensors are able to sense acceleration, orientation, rotation, displacement, etc. They are disposed on these and other components of machine **100** for precise control of machine **100**. Sensors **220** also include linkage sensors which can include strain gauges, linear displacement transducers, potentiometers, etc. Linkage sensors can sense the force applied on the controllable subsystems **240** and/or the orientation of the controllable subsystems via the

displacement of its actuator. For instance, boom **110** is often actuated by a hydraulic cylinder and the displacement of the piston in the cylinder will correlate to a location of boom **110** relative to rotatable house **102**. In another example, a potentiometer can be located proximate a linkage pin between boom **110** and arm **116**, this potentiometer will output a signal indicative of the angle between boom **110** and arm **116**.

[0026] Control system **250** includes mode selection logic **252**, control surface generation logic **254**, control binding generator logic **255**, control signal generator logic **256**, surface follow logic **258**, and can include other items as well, as indicated by block **260**.

[0027] Mode selection logic **252** allows the operator to put machine **100** into various different control modes. Control modes enable user interface devices **210** to be bound to different control protocols. For instance, in the standard ISO or SAE control modes disclosed above, the joystick user interface devices **210** control the actuators coupled to boom **110**, arm **116** and bucket **124**. In a surface follow control mode, control of machine **100** via user interface devices **210** is relative to a control surface. For instance, actuating a joystick causes control system **250** to control machine **100** such that a portion of bucket **124** follows a control path along a control surface. Or for instance, actuating a user interface device **210** causes control system **250** to control machine **100** such that a portion of bucket **124** moves away from a control surface.

[0028] Control surface generation logic **254** generates a control surface. A control surface is typically the target or desired surface, however, examples a control surface may be a different type of surface. Control binding generator logic **256** binds user interface devices **210** into the control signals and stores the bindings as bindings **215** in data store **212**.

[0029] Control signal generator logic **256** generates and sends a control signal to an actuator **242** to actuate a component of machine **100**.

[0030] Surface follow logic **258** includes linkage control logic **264**, normal determination logic **265**, linkage scaling logic **266**, tool control logic **268**, tool stabilization logic **269** and can include other items as well, as indicated by block **270**. Linkage control logic **264** calculates the movement of linkages **109** to maintain the parallel or perpendicular/away movement of tool **124** relative to the control surface. For example, to move tool **124** along a flat control path towards house **102** linkage control logic **264** determines boom **110** must be lifted and arm **116** retracted.

[0031] Normal determination logic **265** calculates the normal relative to the control path/control surface at a given time. The normal can be a true normal (e.g., a direction perpendicular to the slope of the control path at the given point along the control path) or can be a non-traditional normal that includes directions that merely intersect with the control path/control surface at some point. In some examples, the axis of gravity or the machine Z-axis (e.g., the axis that house **102** rotates about) can be used as the normal. In this case, if the control path/control surface had a vertical portion or near vertical, the normal could be modified as perpendicular or near perpendicular to the axis of gravity or the machine Z-axis.

[0032] Linkage scaling logic **266** determines the scaling of movement speed of the various linkages **109** relative to one another. For instance, boom **110** does not typically actuate as fast as arm **116** and tool **124**. Therefore, when movement of boom **110** and another linkage **109** are made simultaneously, the movement speed of the smaller linkage must be scaled to an actuation the speed of boom **110**. Linkage scaling logic **266** can scale or ramp back commands as flow and power limits of the actuators are reached. For instance, an operator may be actuating the joystick at full stroke, but the required actuators (across multiple linkages) might not be able to attain full movement speed and maintain the control path, so the maximum speed is scaled to the slowest actuator's maximum speed and the controlled tool follows the control path at its new, scaled, maximum speed. Linkage scaling logic **266** can also scale commands across dimensions. For instance, if both a parallel and a perpendicular command are issued at the same time but only one of these commands cannot be completed at the commanded speed, both dimensions of movement can be scaled (e.g., at a ratio equal to the user commanded speed) to the limited speed.

[0033] Tool control logic **268** controls the orientation of the tool **124** relative to the control surface (or the current control path parallel or substantially parallel to the control surface). The movement of tool **124** is substantially relative to the control surface however the angle of tool **124** can be adjusted relative to the surface. This is useful when tool **124** is a bucket and either a cutting, scraping, or backfilling etc. operation is desired. A II of these operations would require a different angle of tool **124** relative to the control surface. When tool control logic **268** rotates tool **124** linkage control logic **264** adjusts the other linkages **109** such that an operating portion of tool **124** is on the control path (e.g., linkage control logic **264** maintains the cutting edge of a bucket **124** on the control path as bucket **124** is rotated).
[0034] Tool stabilization logic **269** stabilizes tool **124** as other components of machine **100** move. For instance, tool stabilization logic **269** keeps an operating point of bucket on a control path/surface as machine **100** moves. Tool stabilization logic **269** can also maintain an angle of tool **124** relative to the control path/surface as well. In some examples, tool stabilization logic **269** maintains the operating point of tool **124** in space as tool **124** is rotated e.g., by controlling the other linkages **109** and/or rotating house **102**.
[0035] FIG. **3** is a flow diagram showing an example operation **300** of controlling machine **100**. Operation **300** begins at block **310** where the operator puts machine **100** into the surface follow control mode. A s indicated by block **312**, the operator may put machine **100** into the control mode manually. For example, actuating a user interface mechanism on a touch screen that corresponds to the surface follow control mode. A s indicated by block **314**, machine **100** can be put into a surface follow control mode automatically. For example, machine **100** defaults to this control mode when a target surface is loaded by the operator. As indicated by block **315**, machine **100** can enter the surface follow control mode in other ways as well.
[0036] Operation **300** proceeds at block **320** where a desired surface is acquired. The surface can be received from another source or generated. As indicated by block **322**, the desired surface can be received from a worksite specification server or the specifications can be uploaded into machine **100** by an operator. As indicated by block **324**, the desired surface can be automatically generated. For example, a flat, level, surface at a given elevation is entered and a plane is generated. Or, for example, some dimensions of a basement dig are given and the surface is generated as a topless rectangular prism. As indicated by block **326**, the surface can be acquired in other ways as well.
[0037] Operation **300** proceeds at block **330** where a coordinate system is generated based on the surface from block **320**. As indicated by block **332**, sets of axes can be generated as parallel to the surface. As indicated by block **334**, sets of control axes are defined that are perpendicular to the surface. In some examples, perpendicular to the surface includes near perpendicular axes or simply axes away from the surface. For instance, a control surface with a grade (greater than 0 degree or less than 90 degrees incline) the perpendicular axes can correspond to the gravitational or machine Z axis rather than a normal of the surface. The above axes do not necessarily have to be linear like a traditional axis. As indicated by block **336**, the axes may be smoothed. For example, where two planes of a control surface meet a sharp intersection is formed, and technically this intersection does not have a normal. Accordingly, the edge can be smoothed or the normal at the edge can be calculated as an average between the intersecting planes. The coordinate system can be generated in other ways as well, as indicated by block **338**.
[0038] Operation **300** proceeds at block **340** where controls are bound to machine controls. As indicated by block **342**, a set of user interface controls are bound to feed movements (e.g., movements parallel/near-parallel to the control surface). As indicated by block **344**, another set of user interface controls are bound to normal movements (e.g., movements perpendicular to/away from the control surface). As indicated by block **345**, some of the user interface controls can be bound to other movements. For example, a set of user interface controls are bound to one or more rotations of the tool relative to the control surface.
[0039] Operation **300** proceeds at block **350** where user input is received on one or more of the user

interface mechanisms. The user input can include data indicative of a tool transformation relative to the control surface. As indicated by block **352**, the one or more user interface mechanism(s) include one or more joysticks. For example, there can be a joystick for an operator's left hand and a second joystick for an operator's right hand. As indicated by block **354**, the one or more user interface mechanism(s) include one or more pedals. For example, there can be a pedal for an operator's left foot and a second pedal for an operator's right foot. Of course, other user interface mechanisms can be used as well, as indicated by block **356**.

[0040] Operation **300** proceeds at block **360** where tool transformation commands are converted into linkage actuation commands. As indicated by block **362**, a transformation command corresponding to a feed can be converted into linkage commands. For example, a transformation parallel to the surface towards machine **100** can include lifting boom **110** and retracting arm **116**. As indicated by block **363**, a transformation command corresponding to a normal translation can be converted into linkage commands. For example, a transformation that is up and away from the surface can include lifting boom **110** and extending arm **116**. As indicated by block **366**, a transformation command corresponding to a tool orientation can be converted into linkage commands. For example, a transformation on the orientation of the tool can include curling bucket **124**. As indicated by block **368**, a transformation command can require scaling the speeds of various linkage actuators. For instance, an actuator of arm **116** at full speed may outrun the actuator of boom **110** at full speed and cause the tool to deviate from an intended path. Accordingly, the actuator of arm **116** may be scaled back to match the speed of the actuator of boom **110**. Of course, the commands can be converted into linkage commands in other ways as well, as indicated by block **369**.

[0041] Operation **300** proceeds at block **370** where the linkage commands are sent to the linkage actuators. As indicated by block **372**, the signal can be electric. For example, the signal is an electrical signal sent to a hydraulic valve controller. As indicated by block **374**, the signal can be mechanical. For instance, a rod mechanically opens a hydraulic valve. As indicated by block **376**, the linkage commands are sent in other ways as well. For example, a combination of electrical and mechanical signals can be sent to the linkage actuators.

[0042] Operation **300** proceeds at block **380** where it is determined if there are more controls to complete. If not, then operation **300** ends. If there are additional controls to complete, then operation **300** proceeds again at block **350**.

[0043] FIG. **4**A is a diagram showing an example machine **100** executing a control command. Shown in the bottom left are two joysticks, a left joystick **422** and a right joystick **420**. The operator controls various movements of machine **100** utilizing these joysticks **420**, **422**. As shown, bucket **124** is on a control path **402** that is parallel with, and offset from, a control surface **400**. As shown, an operational point/line/plane **408** of bucket **124** follows control path **402**. Operation point **408** of bucket **124** is the cutting edge of bucket **124** and is the portion of bucket **124** typically used by an operator to complete a job. In examples where the tool is not a bucket, or when a bucket is being used in other ways, the operational point **408** may be located at a different part of the tool. As shown, bucket **124** follows control path at a controlled angle **409** (e.g., the vertex of angle **409** is the operational point). This angle can be controlled to change the function of bucket **124** (e.g., from digging, to scraping or dumping). At some transition points along control path **402**, angle **409** might not be sustainable, in this case angle **409** can be changed at this point to avoid another portion of bucket **124** (e.g., a portion other than operational point **408**) from affecting the surface and effectively deviating from control path **402** as the portion of bucket **124** will likely displace the ground material.

[0044] Control surface **400** is a visual representation of a 3-D mesh and does represent a physical surface. However, in some examples it could correspond to a physical surface or a desired product surface. Control path **402** can be substantially parallel with control surface **400**. For example, transition **440** of control surface **400** has been smoothed to smooth transition **442** of control path

402. Control path **402** is offset from a distance of line **404**.

[0045] In one example, movement of joystick **422** in directions **430** and **426** causes bucket **124** and accompanying linkages to move left or right (e.g., out of the 2D plane of FIG. **4**A) and parallel with control surface **400**. Movement of joystick **422** in directions **424** and **428** causes bucket **124** to move along control path **402** (e.g., towards or away from machine **100**). Movement of joystick **420** in directions **434** and **438** causes bucket **124** to rotate (e.g., about operating point **408** which could be fixed to control path **402** or fixed in any direction as bucket **124** rotates). Movement of joystick **420** in directions **432** and **436** moves bucket **124** in a direction away from or towards control surface **400**. In one example, away from control surface **400** is directly perpendicular to control path **400**, as indicated by line **404**. In another example, away from control surface **400** is mapped to the axis of gravity (in the case where the path has some horizontal component), a Z-axis of machine **100**, or some other dimension, as indicated by line **406**.

[0046] FIG. **4**B is a diagram showing an example machine **100** executing a control command. Components of FIG. **4**B are similar to those in FIG. **4**A and similar components are similarly numbered. However, in FIG. **4**B a control surface **450** replaces control surface **400**. In this case, the control path and control surface **450** are the same since the operating point **408** is on control surface **450** and not offset from surface **450**. Bucket **124** is at angle **467** relative to surface **450**. Similar movements of joysticks **420** and **422** can move operation point **408** along control surface **450**, rotate bucket **124** about operational point **408** and move bucket **124** away from control surface **450**. When operational point **408** is actuated to restricted point **460** angle **467** has to be adjusted or bucket **124** will hit the bottom of the trench.

[0047] The present discussion has mentioned processors and servers. In one embodiment, the processors and servers include computer processors with associated memory and timing circuitry, not separately shown. They are functional parts of the systems or devices to which they belong and are activated by, and facilitate the functionality of the other components or items in those systems.

[0048] It will be noted that the above discussion has described a variety of different systems, components and/or logic. It will be appreciated that such systems, components and/or logic can be comprised of hardware items (such as processors and associated memory, or other processing components, some of which are described below) that perform the functions associated with those systems, components and/or logic. In addition, the systems, components and/or logic can be comprised of software that is loaded into a memory and is subsequently executed by a processor or server, or other computing component, as described below. The systems, components and/or logic can also be comprised of different combinations of hardware, software, firmware, etc., some examples of which are described below. These are only some examples of different structures that can be used to form the systems, components and/or logic described above. Other structures can be used as well.

[0049] Also, a number of user interface displays have been discussed. They can take a wide variety of different forms and can have a wide variety of different user actuatable input mechanisms disposed thereon. For instance, the user actuatable input mechanisms can be text boxes, check boxes, icons, links, drop-down menus, search boxes, etc. They can also be actuated in a wide variety of different ways. For instance, they can be actuated using a point and click device (such as a track ball or mouse). They can be actuated using hardware buttons, switches, a joystick or keyboard, thumb switches or thumb pads, etc. They can also be actuated using a virtual keyboard or other virtual actuators. In addition, where the screen on which they are displayed is a touch sensitive screen, they can be actuated using touch gestures. Also, where the device that displays them has speech recognition components, they can be actuated using speech commands.

[0050] A number of data stores have also been discussed. It will be noted they can each be broken into multiple data stores. All can be local to the systems accessing them, all can be remote, or some can be local while others are remote. A II of these configurations are contemplated herein.

[0051] Also, the figures show a number of blocks with functionality ascribed to each block. It will be noted that fewer blocks can be used so the functionality is performed by fewer components. Also, more blocks can be used with the functionality distributed among more components.

[0052] FIG. **5** is one embodiment of a computing environment in which elements of FIG. **2**, or parts of it, (for example) can be deployed. With reference to FIG. **5**, an exemplary system for implementing some embodiments includes a general-purpose computing device in the form of a computer **810**. Components of computer **810** may include, but are not limited to, a processing unit **820** (which can comprise controller **202**), a system memory **830**, and a system bus **821** that couples various system components including the system memory to the processing unit **820**. The system bus **821** may be any of several types of bus structures including a memory bus or memory controller, a peripheral bus, and a local bus using any of a variety of bus architectures. Memory and programs described with respect to FIG. **2** can be deployed in corresponding portions of FIG. **5**.

[0053] Computer **810** typically includes a variety of computer readable media. Computer readable media can be any available media that can be accessed by computer **810** and includes both volatile and nonvolatile media, removable and non-removable media. By way of example, and not limitation, computer readable media may comprise computer storage media and communication media. Computer storage media is different from, and does not include, a modulated data signal or carrier wave. It includes hardware storage media including both volatile and nonvolatile, removable and non-removable media implemented in any method or technology for storage of information such as computer readable instructions, data structures, program modules or other data. Computer storage media includes, but is not limited to, RAM, ROM, EEPROM, flash memory or other memory technology, CD-ROM, digital versatile disks (DVD) or other optical disk storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to store the desired information and which can be accessed by computer **810**. Communication media may embody computer readable instructions, data structures, program modules or other data in a transport mechanism and includes any information delivery media. The term “modulated data signal” means a signal that has one or more of its characteristics set or changed in such a manner as to encode information in the signal.

[0054] The system memory **830** includes computer storage media in the form of volatile and/or nonvolatile memory such as read only memory (ROM) **831** and random-access memory (RAM) **832**. A basic input/output system **833** (BIOS), containing the basic routines that help to transfer information between elements within computer **810**, such as during start-up, is typically stored in ROM **831**. RAM **832** typically contains data and/or program modules that are immediately accessible to and/or presently being operated on by processing unit **820**. By way of example, and not limitation, FIG. **8** illustrates operating system **834**, application programs **835**, other program modules **836**, and program data **837**.

[0055] The computer **810** may also include other removable/non-removable volatile/nonvolatile computer storage media. By way of example only, FIG. **8** illustrates a hard disk drive **841** that reads from or writes to non-removable, nonvolatile magnetic media, a magnetic disk drive **851**, nonvolatile magnetic disk **852**, an optical disk drive **855**, and nonvolatile optical disk **856**. The hard disk drive **841** is typically connected to the system bus **821** through a non-removable memory interface such as interface **840**, and magnetic disk drive **851** and optical disk drive **855** are typically connected to the system bus **821** by a removable memory interface, such as interface **850**.

[0056] Alternatively, or in addition, the functionality described herein can be performed, at least in part, by one or more hardware logic components. For example, and without limitation, illustrative types of hardware logic components that can be used include Field-programmable Gate Arrays (FPGAs), Program-specific Integrated Circuits (e.g., ASICs), Program-specific Standard Products (e.g., ASSPs), System-on-a-chip systems (SOCs), Complex Programmable Logic Devices (CPLDs), etc.

[0057] The drives and their associated computer storage media discussed above and illustrated in FIG. **5**, provide storage of computer readable instructions, data structures, program modules and other data for the computer **810**. In FIG. **5**, for example, hard disk drive **841** is illustrated as storing operating system **844**, application programs **845**, other program modules **846**, and program data **847**. Note that these components can either be the same as or different from operating system **834**, application programs **835**, other program modules **836**, and program data **837**.

[0058] A user may enter commands and information into the computer **810** through input devices such as a keyboard **862**, a microphone **863**, and a pointing device **861**, such as a mouse, trackball or touch pad. Other input devices (not shown) may include a joystick, game pad, satellite dish, scanner, or the like. These and other input devices are often connected to the processing unit **820** through a user input interface **860** that is coupled to the system bus, but may be connected by other interface and bus structures. A visual display **891** or other type of display device is also connected to the system bus **821** via an interface, such as a video interface **890**. In addition to the monitor, computers may also include other peripheral output devices such as speakers **897** and printer **896**, which may be connected through an output peripheral interface **895**.

[0059] The computer **810** is operated in a networked environment using logical connections (such as a local area network—LAN, or wide area network WAN) to one or more remote computers, such as a remote computer **880**.

[0060] When used in a LA N networking environment, the computer **810** is connected to the LAN **871** through a network interface or adapter **870**. When used in a WAN networking environment, the computer **810** typically includes a modem **872** or other means for establishing communications over the WAN **873**, such as the Internet. In a networked environment, program modules may be stored in a remote memory storage device. FIG. **5** illustrates, for example, that remote application programs **885** can reside on remote computer **880**.

[0061] It should also be noted that the different embodiments described herein can be combined in different ways. That is, parts of one or more embodiments can be combined with parts of one or more other embodiments. All of this is contemplated herein. The flow diagrams are shown in a given order it is contemplated that the steps may be done in a different order than shown.

[0062] Example 1 is a mobile machine comprising: [0063] a tool coupled to the mobile machine by one or more controllable linkages; [0064] a user interface mechanism configured to receive input from an operator; and [0065] one or more controllers configured to implement: [0066] surface follow logic configured to receive the input from the user interface mechanism and identify a desired movement of the tool relative to a control surface, based on the input; and [0067] control signal generator logic that generates a control signal to control the one or more controllable linkages, based on the identified movement.

[0068] Example 2 is the mobile machine of any or all previous examples, wherein the desired movement of the tool relative to the control surface comprises a tool movement parallel to the control surface and the control signal generator logic generates the control signal to control the one or move controllable linkages to move the tool in a direction parallel to the control surface.

[0069] Example 3 is the mobile machine of any or all previous examples, wherein the control signal generator logic generates the control signal to control the one or move controllable linkages to maintain an angle of the tool relative to the direction parallel to the control surface as the tool moves parallel to the control surface.

[0070] Example 4 is the mobile machine of any or all previous examples, wherein the desired movement of the tool relative to the control surface comprises a tool movement away from the control surface and the control signal generator logic generates the control signal to control the one or more controllable linkages to move the tool in a direction away from the control surface.

[0071] Example 5 is the mobile machine of any or all previous examples, wherein the control signal generator logic generates the control signal to control the one or move controllable linkages to move the tool in a direction perpendicular to the control surface.

[0072] Example 6 is the mobile machine of any or all previous examples, wherein the desired movement of the tool relative to the control surface comprises a tool rotation and the control signal

generator logic generates the control signal to control the one or move controllable linkages to rotate the tool relative to a point on the control surface.
[0073] Example 7 is the mobile machine of any or all previous examples, wherein the control signal generator logic generates the control signal to control the one or move controllable linkages to maintain a portion of the tool at a location in space as the tool rotates, wherein the portion of the tool is a distance away from a pivot point of the tool.
[0074] Example 8 is the mobile machine of any or all previous examples, wherein the user interface mechanism comprises: one or more joysticks.
[0075] Example 9 is the mobile machine of any or all previous examples, wherein a movement of one of the one or more joysticks in one direction is indicative of a movement of the tool parallel to the control surface.
[0076] Example 10 is the mobile machine of any or all previous examples, wherein a movement of one of the one or more joysticks in a second direction is indicative of movement of the tool away from the control surface.
[0077] Example 11 is the mobile machine of any or all previous examples, wherein a movement of one of the one or more joysticks in a third direction is indicative of rotation of the tool relative to a point on the control surface.
[0078] Example 12 is a method of controlling an excavator, the method comprising: [0079] generating a control coordinate system relative to a control surface; [0080] receiving an input from an operator via a user interface mechanism; [0081] mapping the input to a tool transformation on the control coordinate system; and [0082] controlling the excavator based on the tool transformation on the control surface.
[0083] Example 13 is the method of any or all previous examples, wherein the control coordinate system includes an axis parallel to the control surface and an axis perpendicular to the control surface.
[0084] Example 14 is the method of any or all previous examples, wherein the tool transformation on the control coordinate system comprises movement of a tool in the axis parallel to the control surface.
[0085] Example 15 is the method of any or all previous examples, wherein controlling the excavator comprises maintaining an angle of the tool relative to a direction of movement of the tool.
[0086] Example 16 is the method of any or all previous examples, wherein the tool transformation comprises rotating a tool; and wherein controlling the excavator comprises rotating the tool about an operating point of the tool that is separate from a linkage pin of the tool.
[0087] Example 17 is the method of any or all previous examples, wherein the operating point is on the control surface.
[0088] Example 18 is a control system for an excavator comprising: [0089] control surface logic that receives a control surface; [0090] user interface logic that receives user input from a joystick; [0091] binding correlation logic that correlates the user input to a movement parallel to the control surface; and [0092] control signal generator logic that generates and sends a control signal to a controllable subsystem to move a tool based on the identified movement parallel to the control surface.
[0093] Example 19 is the control system of any or all previous examples, wherein the user interface logic receives a second user input from a second joystick and the binding correlation logic correlates the second user input to a movement away from or towards the control surface and the control signal generator logic generates and sends a second control signal to the controllable subsystem to move the tool based on the movement away from or towards the control surface.
[0094] Example 20 is the control system of any or all previous examples, wherein the user interface logic receives a second user input from a second joystick and the binding correlation logic correlates the second user input to a rotation of the tool and the control signal generator logic

generates and sends a tool control signal to an actuator of the tool to move the tool based on the rotation of the tool.
[0095] Although the subject matter has been described in language specific to structural features and/or methodological acts, it is to be understood that the subject matter defined in the appended claims is not necessarily limited to the specific features or acts described above. Rather, the specific features and acts described above are disclosed as example forms of implementing the claims.

Claims

1. A system for controlling a work machine, the system comprising: one or more processors; and memory storing instructions executable by the one or more processors that, when executed by the one or more processors, cause the system to: generate a target control surface, the target control surface representing a surface to be generated by the work machine; generate a control coordinate system referenced to the target control surface; receive an input via an interface mechanism; map the input to a tool transformation on the control coordinate system referenced to the target control surface, wherein the tool transformation comprises rotating a tool of the work machine; and adjust, based on the tool transformation on the control coordinate system referenced to the target control surface, a movement speed of a linkage actuator on the work machine from a first speed to a second speed to rotate the tool about an operating point of the tool that is separate from a linkage pin of the tool.
2. The system of claim 1, wherein the work machine comprises an excavator.
3. The system of claim 1, wherein the interface mechanism comprises a joystick.
4. The system of claim 1, wherein the target control surface comprises a target multi-planar control surface representing, as the surface to be generated by the work machine, a multi-planar surface to be generated by the work machine and wherein the control coordinate system comprises a three-dimensional control coordinate system having a plurality of axes.
5. The system of claim 4, wherein at least one axis of the plurality of axes is parallel to the target multi-planar control surface.
6. The system of claim 4, wherein at least one axis of the plurality of axes is non-linear.
7. A control system for a work machine comprising: one or more processors; and memory storing instructions executable by the one or more processors that, when executed by the one or more processors, cause the control system to: obtain a target control surface, the target control surface representing a surface to be generated by the work machine; generate a control coordinate system referenced to the target control surface; receive an input via one or more interface mechanisms; correlate the input to a feed rate value; controls a controllable subsystem of the work machine to cause movement of a tool of the work machine parallel to the target control surface based on the feed rate value.
8. The control system of claim 7, wherein the target control surface comprises a target multi-planar control surface representing, as the surface to be generated by the work machine, a multi-planar surface to be generated by the work machine and wherein the control coordinate system comprises a three-dimensional control coordinate system having a plurality of axes.
9. The control system of claim 8, wherein at least one axis of the plurality of axes is parallel to the target multi-planar control surface.
10. The control system of claim 8, wherein at least one axis of the plurality of axes is non-linear.
11. The control system of claim 7, wherein the one or more interface mechanisms comprises at least one joystick.
12. The control system of claim 7, wherein the work machine comprises an excavator.
13. The control system of claim 7, wherein the controllable subsystem comprises a plurality of controllable linkages and wherein the instructions, when executed by the one or more processors, further cause the system to: determine, based on the feed rate value, a respective speed for each

controllable linkage of the plurality of controllable linkages; control each controllable linkage of the plurality of controllable linkages based on the respective movement speed for each controllable linkage to cause the movement of the tool of the work machine parallel to the target control surface.

14. The control system of claim 7, wherein the controllable subsystem comprises at least a first controllable linkage and a second controllable linkage and wherein the instructions, when executed by the one or more processors, further cause the system to: determine, based on the feed rate value, a first speed for the first controllable linkage and a second speed for the second controllable linkage; scale the first speed for the first controllable linkage to a scaled first speed for the first controllable linkage based, at least, on the second speed for the second controllable linkage; and control the first controllable linkage based on scaled first speed and control the second controllable linkage based on the second speed to cause movement of the tool of the work machine parallel to the target control surface.

15. The control system of claim 7, wherein the input comprises a first input and wherein the feed rate value comprises a first feed rate value and wherein the instructions, when executed by the one or more processors, further cause the system to: receive a second input via the one or more interface mechanisms; correlate the second input to a second feed rate value; controls, based on the second feed rate value, the controllable subsystem of the work machine to cause at least one of: (i) movement of the tool away from or towards to the target control surface; or (ii) rotation of the tool.

16. A mobile work machine comprising: a tool coupled to the mobile work machine by one or more controllable linkages; an interface mechanism; and one or more processors; and memory storing instructions executable by the one or more processors that, when executed by the one or more processors, cause the mobile work machine to: generate a target multi-planar control surface, the target multi-planar control surface representing a multi-planar surface to be generated by the mobile work machine; generate a three-dimensional control coordinate system referenced to the target multi-planar control surface, the three-dimensional control coordinate system comprising a plurality of axes, where at least one axis of the plurality of axes is a non-linear axis; receive an input from the user interface mechanism and identify, based, at least, on the input, a desired movement of the tool in the three-dimensional control coordinate system referenced to the target multi-planar control surface; and control the one or more controllable linkages based on the desired movement of the tool in the three-dimensional control coordinate system referenced to the target multi-planar control surface.

17. The mobile work machine of claim 16, wherein the non-linear axis follows the target multi-planar control surface in a first set of directions and comprises a curve.

18. The mobile work machine of claim 17, wherein the non-linear axis comprises a first non-linear axis and wherein another axis, of the plurality of axes, is a second non-linear axis that follows the target multi-planar control surface in a second set of directions, is transverse to the first non-linear axis, and comprises a curve.

19. The mobile work machine of claim 16, wherein the interface mechanism comprises one or more joysticks.

20. The mobile work machine of claim 16, wherein the mobile work machine comprises an excavator.