United States Patent	12383343
Kind Code	B2
Date of Patent	August 12, 2025
Inventor(s)	Zhang; Zenan et al.

Surgical systems and methods for identifying tools guided by surgical robots

Abstract

Systems and methods for assisting users with accurate tool identification. A tool includes a tool feature, and a navigation system includes a localizer to detect a position of the tool feature. A memory stores identification data associated with a plurality of tools. Controller(s) is/are coupled to the navigation system, the memory and the display. The controller(s) receive, from the localizer, the detected position of the tool feature and compare the detected position of the tool feature with the identification data stored in the memory to determine an identity of the tool. The controller(s) present, on a display, the identity of the tool and an identity of at least one other tool.

Inventors: **Zhang; Zenan (Weston, FL), Bechtold; Kevin (Davie, FL), Gayle; Carl (Plantation, FL)**

Applicant: **MAKO Surgical Corp.** (Weston, FL)

Family ID: **65818594**

Assignee: **MAKO Surgical Corp. (Weston, FL)**

Appl. No.: **18/070562**

Filed: **November 29, 2022**

Prior Publication Data

Document Identifier	Publication Date
US 20230086467 A1	Mar. 23, 2023

Related U.S. Application Data

continuation parent-doc US 16279464 20190219 US 11534242 child-doc US 18070562
us-provisional-application US 62631995 20180219

Publication Classification

Int. Cl.: **A61B34/20** (20160101); **A61B34/10** (20160101); **A61B34/30** (20160101); **A61B90/00** (20160101); **A61B90/90** (20160101); **A61F2/34** (20060101); A61B34/00 (20160101); A61F2/46 (20060101)

U.S. Cl.:

CPC **A61B34/20** (20160201); **A61B34/10** (20160201); **A61B34/30** (20160201); **A61B90/361** (20160201); **A61B90/90** (20160201); **A61F2/34** (20130101); A61B2034/2051 (20160201); A61B2034/2055 (20160201); A61B2034/2057 (20160201); A61B2034/2063 (20160201); A61B2034/2068 (20160201); A61B2034/207 (20160201); A61B2034/2074 (20160201); A61B2034/252 (20160201); A61B2034/256 (20160201); A61F2/4607 (20130101); A61F2002/4632 (20130101)

Field of Classification Search

CPC: A61B (34/20); A61B (34/10); A61B (34/30); A61B (90/361); A61B (90/90); A61B (2034/2051); A61B (2034/2055); A61B (2034/2057); A61B (2034/2063); A61B (2034/2068); A61B (2034/207); A61B (2034/2074); A61B (2034/252); A61B (2034/256); A61F (2/34); A61F (2/4607); A61F (2002/4632)

References Cited

U.S. PATENT DOCUMENTS

Patent No.	Issued Date	Patentee Name	U.S. Cl.	CPC
7725162	12/2009	Malackowski et al.	N/A	N/A
7813784	12/2009	Marquart et al.	N/A	N/A
8010180	12/2010	Quaid et al.	N/A	N/A
8753346	12/2013	Suarez et al.	N/A	N/A
8979859	12/2014	Leparmentier et al.	N/A	N/A
9008757	12/2014	Wu	N/A	N/A
9119655	12/2014	Bowling	N/A	A61B 34/10
2004/0054489	12/2003	Moctezuma De La Barrera et al.	N/A	N/A
2012/0296203	12/2011	Hartmann et al.	N/A	N/A
2016/0022374	12/2015	Haider	N/A	N/A
2017/0000583	12/2016	Lechner et al.	N/A	N/A
2019/0254756	12/2018	Zhang et al.	N/A	N/A

FOREIGN PATENT DOCUMENTS

Patent No.	Application Date	Country	CPC
2007056743	12/2006	WO	N/A
2017205351	12/2016	WO	N/A

OTHER PUBLICATIONS

International Search Report for Application No. PCT/US2019/018500 dated May 31, 2019, 5 pages. cited by applicant

Stryker, “Mako THA Application User Guide”, PN 212026 Rev. 00, Sep. 2015, 141 pages. cited by applicant

---

Primary Examiner: Jos; Basil T.

Attorney, Agent or Firm: Howard & Howard Attorneys PLLC

Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION (1) The subject patent application is a continuation of U.S. patent application Ser. No. 16/279,464, filed Feb. 19, 2019, which claims priority to and all the benefits of U.S. Provisional Patent App. No. 62/631,995 filed on Feb. 19, 2018, the entire disclosure of each of the aforementioned applications being hereby incorporated by reference.

BACKGROUND
(1) Surgical robots are frequently used to assist medical professionals in carrying out various conventional surgical procedures. To this end, a surgeon may use a surgical robot to guide, position, move, actuate, or otherwise manipulate various tools, components, prostheses, and the like during surgery.
(2) It will be appreciated that surgical robots can be used to assist surgeons in performing a number of different types of surgical procedures. By way of illustrative example, surgical robots are commonly used in procedures involving the correction, resection, or replacement of degenerated joints to help improve patient mobility and reduce pain. For example, in hip replacement procedures, the surgeon replaces portions of the patient's hip joint with artificial prosthetic components. To this end, in total hip arthroplasty, the surgeon typically removes portions of the patient's femur to accommodate a prosthetic femoral component comprising a head, and resurfaces the acetabulum of the pelvis with a reamer to facilitate installing a prosthetic cup shaped to receive the head of the prosthetic femoral component.
(3) Depending on the specific procedure being performed, the surgeon may attach different types of tools to the surgical robot to help facilitate approaching the surgical site, removing portions of joints and/or bone, installing prosthetic components, and the like. For example, an end effector which supports a reamer tool may be used to resurface the acetabulum of the pelvis, and an end effector which supports an impactor tool may be used to facilitate installing the prosthetic cup into the reamed acetabulum of the pelvis. Here, the surgical robot helps keep the reamer tool and the impactor tool aligned relative to the surgical site along a trajectory, and the surgeon closely monitors the trajectory and depth of reaming and impacting to ensure proper installation and alignment of the cup into the reamed acetabulum.
(4) Depending on the configuration of the prosthetic components, the impaction tools, and the surgical robot, ensuring that the cup is implanted properly can be complicated by a lack of visibility and limited access to the surgical site. Moreover, maintaining a set trajectory can be difficult with certain approaches and surgical techniques. In order to accommodate different approaches and techniques, toolsets are provided to afford the surgeon with options for a particular type of tool. By way of example, a reamer toolset may comprise different sizes, shapes, and/or styles of reamer tools for the surgeon to select from for a particular surgical procedure, and an impactor toolset may comprise different sizes, shapes, and/or styles of impactor tools for the surgeon to select from for a particular surgical procedure.
(5) Because different tools of a given toolset have respectively different configurations, the surgeon generally needs to input the selected tool's identity into one or more controllers in communication

with the surgical robot so that the surgical robot can properly maintain the position, orientation, and/or trajectory of the tool with respect to the surgical site. Here, it will be appreciated that the process of properly inputting the identity of the selected tool into the controller takes time and may be susceptible to human error, such as where a toolset comprises a large number of visually-similar tools.

(6) Accordingly, there remains a need in the art for addressing one or more of these deficiencies.

SUMMARY

(7) According to a first aspect, a surgical system is provided, comprising: a tool comprising a tool feature; a navigation system comprising a localizer configured to detect a position of the tool feature; a display; a memory configured to store identification data associated with a plurality of tools; and one or more controllers coupled to the navigation system, the memory, and the display, the one or more controllers being configured to: receive, from the localizer, the detected position of the tool feature; compare the detected position of the tool feature with the identification data stored in the memory to determine an identity of the tool; and present, on the display, the identity of the tool and an identity of at least one other tool.

(8) According to a second aspect, a method is provided of operating a surgical system, the surgical system including a tool comprising a tool feature, a navigation system comprising a localizer, a display, a memory configured to store identification data associated with a plurality of tools, and one or more controllers coupled to the navigation system, the memory and the display, the method comprising: detecting, with the localizer, a position of the tool feature; receiving, with the one or more controllers, the detected position of the tool feature from the localizer; comparing, with the one or more controllers, the detected position of the tool feature with the identification data stored in the memory; in response to comparing, determining an identity of the tool with the one or more controllers; and instructing, with the one or more controllers, the display to present the identity of the tool and an identity of at least one other tool.

(9) According to a third aspect, a navigation system is provided, comprising: a localizer configured to detect a position of a tool feature of a tool; a display; a memory configured to store identification data associated with a plurality of tools; and one or more controllers coupled to the localizer, the display, and the memory, and the one or more controllers being configured to: receive, from the localizer, the detected position of the tool feature; compare the detected position of the tool feature with the identification data stored in the memory to determine an identity of the tool; and present, on the display, the identity of the tool and an identity of at least one other tool.

(10) According to a fourth aspect, a method is provided of operating a navigation system, the navigation system comprising a localizer configured to detect a position of a tool feature of a tool, a display, a memory configured to store identification data associated with a plurality of tools, and one or more controllers coupled the localizer, the display, and the memory, the method comprising: detecting, with the localizer, a position of the tool feature; receiving, with the one or more controllers, the detected position of the tool feature from the localizer; comparing, with the one or more controllers, the detected position of the tool feature with the identification data stored in the memory; in response to comparing, determining an identity of the tool with the one or more controllers; and instructing, with the one or more controllers, the display to present the identity of the tool and an identity of at least one other tool.

(11) Other features and advantages of the present disclosure will be readily appreciated, as the same becomes better understood, after reading the subsequent description taken in conjunction with the accompanying drawings.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) FIG. **1** is a perspective view of a surgical system comprising a surgical robot with a robotic arm supporting an end effector to which a tool is supported along a trajectory adjacent to a surgical site on a patient's body, and shown with a pointer, a localizer, and a monitor adjacent to the surgical robot.

(2) FIG. **2** is a schematic diagram of the surgical system shown having a controller in communication with the surgical robot, the localizer, and the monitor of FIG. **1**.

(3) FIG. **3**A is an exemplary first interface image to be displayed on the monitor of FIGS. **1-2**, shown prompting a surgeon to place a distal top of the pointer of FIG. **1** in a divot formed in an end effector tool realized as a reamer.

(4) FIG. **3**B is an exemplary second interface image to be displayed on the monitor of FIGS. **1-2**, shown presenting an identity of the reamer tool.

(5) FIG. **3**C is an exemplary third interface image to be displayed on the monitor of FIGS. **1-2**, shown presenting an identity of the reamer tool alongside identities associated with other reamer tools of one toolset.

(6) FIG. **4**A is another exemplary first interface image to be displayed on the monitor of FIGS. **1-2**, shown prompting a surgeon to place a distal top of the pointer of FIG. **1** in a divot formed in an end effector tool realized as an impactor.

(7) FIG. **4**B is another exemplary second interface image to be displayed on the monitor of FIGS. **1-2**, shown presenting an identity of the impactor tool.

(8) FIG. **4**C is another exemplary third interface image to be displayed on the monitor of FIGS. **1-2**, shown presenting an identity of the impactor tool alongside identities associated with other impactor tools of another toolset.

(9) FIG. **5**A is a perspective view of an end effector with a tool realized as a straight impactor for use with the surgical system of FIG. **1**.

(10) FIG. **5**B is a partial, enlarged perspective view taken about indicia **5**B in FIG. **5**A, showing checkpoint features realized as divots (one divot shown in phantom) arranged about a circular checkpoint space.

(11) FIG. **6**A is a perspective view of an end effector with a tool realized as a first-option impactor for use with the surgical system of FIG. **1**.

(12) FIG. **6**B is a partial, enlarged perspective view taken about indicia **6**B in FIG. **6**A, showing a checkpoint feature realized as a divot (partially shown in phantom) arranged about a circular checkpoint space.

(13) FIG. **7**A is a perspective view of an end effector with a tool realized as a second-option impactor for use with the surgical system of FIG. **1**.

(14) FIG. **7**B is a partial, enlarged perspective view taken about indicia **7**B in FIG. **7**A, showing checkpoint features realized as divots (one divot shown in phantom) arranged about a circular checkpoint space.

(15) FIG. **8** is a perspective view of an end effector depicted in phantom, shown with the circular checkpoint spaces of FIGS. **5**B, **6**B, and **7**B spaced from each other and from a reference point.

(16) FIG. **9**A is a perspective view of an end effector with a tool realized as a straight reamer for use with the surgical system of FIG. **1**.

(17) FIG. **9**B is a partial, enlarged perspective view taken about indicia **9**B in FIG. **9**A, showing checkpoint features realized as divots (one divot shown in phantom) arranged about a circular checkpoint space.

(18) FIG. **10**A is a perspective view of an end effector with a tool realized as a first-option reamer for use with the surgical system of FIG. **1**.

(19) FIG. **10**B is a partial, enlarged perspective view taken about indicia **10**B in FIG. **10**A, showing checkpoint features realized as divots (one divot shown in phantom) arranged about a circular

checkpoint space.
(20) FIG. **11**A is a perspective view of an end effector with a tool realized as a second-option reamer for use with the surgical system of FIG. **1**, the second-option reamer shown arranged in a first orientation.
(21) FIG. **11**B is a partial, enlarged perspective view taken about indicia **11**B in FIG. **11**A, showing checkpoint features realized as divots (one divot shown in phantom) arranged along respective radial arc checkpoint spaces.
(22) FIG. **12**A is another perspective view of the end effector and second-option reamer of FIGS. **11**A-**11**B, shown arranged in a second orientation.
(23) FIG. **12**B is a partial, enlarged perspective view taken about indicia **12**B in FIG. **12**A, showing the checkpoint features realized as divots (one divot shown in phantom) arranged along respective radial arc checkpoint spaces.
(24) FIG. **13**A is another perspective view of the end effector and second-option reamer of FIGS. **11**A-**12**B, shown arranged in a third orientation.
(25) FIG. **13**B is a partial, enlarged perspective view taken about indicia **13**B in FIG. **13**A, showing the checkpoint features realized as divots (one divot shown in phantom) arranged along respective radial arc checkpoint spaces.
(26) FIG. **14** is a perspective view of an end effector depicted in phantom, shown with the circular checkpoint spaces of FIGS. **9**B and **10**B and the radial arc checkpoint spaces of FIGS. **11**B, **12**B, and **13**B spaced from each other and from a reference point.
DETAILED DESCRIPTION
(27) Referring now to the drawings, wherein like numerals indicate like or corresponding parts throughout the several views, a surgical system **30** comprising a surgical robot **32** is shown in FIG. **1**. The surgical robot **32** has a base **34**, a robotic arm **36**, and a coupler **38**. As is described in greater detail below, the robotic arm **36** is supported by the base **34** and is configured to move, drive, maintain, or otherwise control the position and/or orientation of the coupler **38** relative to the base **34** during use. The coupler **38** is adapted to releasably secure an end effector **40** which, in turn, supports a tool, generally indicated at **42**. The tool **42** is configured to support, position, or otherwise facilitate driving a workpiece, depicted generically at **44** in FIG. **1**, at a surgical site ST on a patient's body B along a trajectory T maintained by the surgical robot **32**. Thus, the surgical robot **32** moves the workpiece **44**, the tool **42**, and the end effector **40** via the robotic arm **36** to, among other things, assist medical professionals in carrying out various types of surgical procedures with precise control over movement and positioning of the end effector **40**, the tool **42**, and the workpiece **44**. One exemplary arrangement of the robotic arm **36** is described in U.S. Pat. No. 9,119,655, entitled, “Surgical Robotic arm Capable of Controlling a Surgical Instrument in Multiple Modes,” the disclosure of which is hereby incorporated by reference in its entirety. Another exemplary arrangement of the robotic arm **36** is described in U.S. Pat. No. 8,010,180, entitled, “Haptic Guidance System and Method,” the disclosure of which is hereby incorporated by reference in its entirety. It will be appreciated that the robotic arm **36** and other portions of the surgical robot **32** may be arranged in alternative configurations.
(28) While the workpiece **44** is depicted generically in FIG. **1**, it will be appreciated that the tool **42** and/or the workpiece **44** could be of a number of different styles, types, and/or configurations, depending on the specific surgical procedure being performed. By way of non-limiting example, surgical procedures such as total hip arthroplasty routinely involve the use of multiple tools **42** to facilitate approaching the surgical site ST, preparing the surgical site ST, and/or installing implants (e.g., prosthetic components), and the like at the surgical site ST. In this illustrative example, one tool **42** could be a reamer used to facilitate preparing the acetabulum by driving a workpiece **44** realized as a reamer head (not shown in detail), and another tool **42** could be an impactor used to facilitate implanting a workpiece **44** realized as a prosthesis (not shown). The Applicant has described these types of reaming, preparing, and impaction processes in greater detail in U.S. Pat.

Nos. 8,979,859 and 8,753,346, the disclosures of which are hereby incorporated by reference in their entirety. While the present disclosure describes various orthopedic procedures involving hip joints, it will be appreciated that the subject matter described herein may be applicable to other joints in the patient's body B, such as, for example, shoulders, elbows, wrists, spines, knees, ankles, and the like.

(29) The surgical system **30** is able to monitor, track, and/or determine changes in the relative position and/or orientation of one or more parts of the surgical robot **32**, the robotic arm **36**, the end effector **40**, the tool **42**, and/or the workpiece **44**, as well as various parts of the patient's body B, within a common coordinate system by utilizing various types of trackers (e.g., multiple degree-of-freedom optical, inertial, and/or ultrasonic sensing devices), navigation systems (e.g., machine vision systems, charge coupled device cameras, tracker sensors, surface scanners, and/or range finders), anatomical computer models (e.g., magnetic resonance imaging scans of the patient's anatomy), data from previous surgical procedures and/or previously-performed surgical techniques (e.g., data recorded while reaming the acetabulum that are subsequently used to facilitate impacting the prosthesis), and the like.

(30) To these ends, and as is depicted schematically in FIGS. **1-2**, the surgical system **30** generally comprises a controller **46**, a memory **48** comprising identification data ID and interface images IM, a pointer **50** having a distal tip **50**D, a robotic control system **52**, and a navigation system **54** which cooperate to allow the surgical robot **32** maintain alignment of the tool **42** along the trajectory T. Each of these components will be described in greater detail below.

(31) With continued reference to FIGS. **1-2**, the controller **46** is disposed in communication with the robotic control system **52** and the navigation system **54**, such as via wired or wireless electronic communication. In the illustrated embodiment depicted in FIG. **1**, the controller **46** either communicates with or is realized by a robot controller **56** and/or a navigation controller **58**, as described in greater detail below. The robot controller **56** forms part of the robotic control system **52**, and the navigation controller **58** forms part of the navigation system **54**. The controller **46**, the robot controller **56**, and/or the navigation controller **58** may be realized as computers, processors, control units, and the like, and may be discrete components, may be integrated, and/or may otherwise share hardware, software, inputs, outputs, and the like.

(32) The surgical system **30** employs the robotic control system **52** to, among other things, articulate the robotic arm **36**, maintain the trajectory T, and the like. Here, the robot controller **56** of the robotic control system **52** is configured to articulate the robotic arm **36** by driving various actuators, motors, and the like disposed at joints of the robotic arm **36** (not shown). The robot controller **56** also gathers data from various sensors such as encoders located along the robotic arm **36** (not shown). Because the specific geometry of each of the components of the surgical robot, end effector **40**, and tools **42** are known, these sensor data can be used by the robot controller **56** to reliably adjust the position and/or orientation of the end effector **40** and the tool **42** within a manipulator coordinate system MNPL (see FIG. **1**). The manipulator coordinate system MNPL has an origin, and the origin is located relative to the robotic arm **36**. One example of this type of manipulator coordinate system MNPL is described in U.S. Pat. No. 9,119,655, entitled, “Surgical Robotic Arm Capable of Controlling a Surgical Instrument in Multiple Modes,” previously referenced.

(33) The surgical system **30** employs the navigation system **54** to, among other things, track movement of various objects such as the end effector **40**, the pointer **50**, and parts of the patient's body B (e.g. bones or other anatomy at the surgical site ST). To this end, the navigation system **54** employs a localizer **60** configured to sense the position and/or orientation of trackers **62** fixed to objects within a localizer coordinate system LCLZ. The navigation controller **58** is disposed in communication with the localizer **60** and gathers position and/or orientation data for each tracker **62** sensed within a field of view FV of the localizer **60** in the localizer coordinate system LCLZ. Thus, as is described in greater detail below, the localizer **60** is configured to determine a position

of the tool **42** within the field of view FV.

(34) It will be appreciated that the localizer **60** can sense the position and/or orientation of multiple trackers **62** to track correspondingly multiple objects within the localizer coordinate system LCLZ. By way of example, and as is depicted in FIG. **1**, trackers **62** may comprise a pointer tracker **62**P coupled to the pointer **50**, an end effector tracker **62**E coupled to the end effector **40**, a first patient tracker **62**A, and/or a second patient tracker **62**B, as well as additional patient trackers, trackers for additional medical and/or surgical tools, and the like. In FIG. **1**, the end effector tracker **62**E is firmly affixed to the end effector **40**, the first patient tracker **62**A is firmly affixed to one bone of the patient's body B at the surgical site ST (e.g., to the pelvis adjacent to the acetabulum), and the second patient tracker **62**B is firmly affixed to a different bone (e.g., to the femur adjacent to the head). The end effector tracker **62**E could be fixed to the end effector **40** in different ways, such as by integration into the end effector **40** during manufacture or by releasable attachment to the end effector **40**. The patient trackers **62**A, **62**B are firmly affixed to different bones in the patient's body B, such as by threaded engagement, clamping, or by other techniques. It will be appreciated that various trackers **62** may be firmly affixed to different types of tracked objects (e.g., discrete bones, tools, pointers, and the like) in a number of different ways.

(35) The position of the trackers **62** relative to the anatomy to which they are attached can be determined by known registration techniques, such as point-based registration in which the distal tip **50**D of the pointer **50** is used to touch off on bony landmarks on bone or to touch off on several points across the bone for surface-based registration as the localizer **60** monitors the position and orientation of the pointer tracker **62**P. Conventional registration techniques can then be employed to correlate the pose of the patient trackers **62**A, **62**B to the patient's anatomy (e.g., to each of the femur and acetabulum). Other types of registration are also possible, such as by using patient trackers **62**A, **62**B with mechanical clamps that attach to bone and have tactile sensors (not shown) to determine a shape of the bone to which the clamp is attached. The shape of the bone can then be matched to a 3D model of bone for registration. A known relationship between the tactile sensors and the three or more markers on the patient tracker **62**A, **62**B may be entered into or otherwise known by the navigation controller **58**. Based on this known relationship, the positions of the markers relative to the patient's anatomy can be determined.

(36) Position and/or orientation data may be gathered, determined, or otherwise handled by the navigation controller **58** using conventional registration/navigation techniques to determine coordinates of each tracker **62** within the localizer coordinate system LCLZ. These coordinates are communicated to the robotic control system **52** to facilitate articulation of the robotic arm **36** and/or to otherwise assist the surgeon in performing the surgical procedure, as described in greater detail below.

(37) In the representative embodiment illustrated in FIG. **1**, the robot controller **56** is operatively attached to the surgical robot **32**, and the navigation controller **58**, the localizer **60**, the controller **46**, and the memory **48** are supported on a mobile cart **64** which is movable relative to the base **34** of the surgical robot **32**. The mobile cart **64** also supports a user interface, generally indicated at **66**, to facilitate operation of the surgical system **30** by displaying information to, and/or by receiving information from, the surgeon or another user. The user interface **66** is disposed in communication with the controller **46**, the memory **48**, the navigation system **54**, and/or the robotic control system **52**, and may comprise one or more output devices **68** (e.g., monitors, indicators, display screens, and the like) to present information to the surgeon (e.g., images, video, data, a graphics, navigable menus, and the like), and one or more input devices **70** (e.g., buttons, touch screens, keyboards, mice, gesture or voice-based input devices, and the like). In the illustrated embodiment, the user interface **66** comprises an output device **68** realized as a monitor **68**M to display interface images IM, as described in greater detail below. One type of mobile cart **64** and user interface **66** is described in U.S. Pat. No. 7,725,162, entitled “Surgery System,” the disclosure of which is hereby incorporated by reference in its entirety.

(38) Because the mobile cart **64** and the base **34** of the surgical robot **32** can be positioned relative to each other and also relative to the patient's body B, the surgical system **30** transforms the coordinates of each tracker **62** within the field of view FV from the localizer coordinate system LCLZ into the manipulator coordinate system MNPL, or vice versa, so that articulation of the robotic arm **36** can be performed based at least partially on the relative positions and orientations of each tracker **62** within a single, common coordinate system (the manipulator coordinate system MNPL, the localizer coordinate system LCLZ, or another common coordinate system). It will be appreciated that coordinates within the localizer coordinate system LCLZ can be transformed into coordinates within the manipulator coordinate system MNPL, and vice versa, using a number of different conventional coordinate system transformation techniques.
(39) In the illustrated embodiment, the localizer **60** is an optical localizer and includes a camera unit **72** with one or more optical position sensors **74**. The navigation system **54** employs the optical position sensors **74** of the camera unit **72** to sense the position and/or orientation of the trackers **62** within the localizer coordinate system LCLZ. In the representative embodiment illustrated herein, the trackers **62** each employ markers **76** which can be sensed by the optical position sensors **74** of the camera unit **72**. One example of a navigation system **54** of this type is described in U.S. Pat. No. 9,008,757, entitled, “Navigation System Including Optical and Non-Optical Sensors,” the disclosure of which is hereby incorporated by reference in its entirety. In some embodiments, the markers **76** are active markers (e.g., light emitting diodes “LEDs”) which emit light that is sensed by the optical position sensors **74**. In other embodiments, the markers **76** may be passive markers (e.g., reflectors) which reflect light emitted from the camera unit **72** or another light source. It should be appreciated that other suitable tracking systems and methods not specifically described herein may be utilized (e.g., ultrasonic, electromagnetic, radio frequency, and the like).
(40) In some embodiments, the surgical system **30** is capable of displaying a virtual representation of the relative positions and orientations of tracked objects to the surgeon or other users of the surgical system **30**, such as with images and/or graphical representations of the anatomy of the patient's body B, the end effector **40**, and/or the tool **42** presented on one or more output devices **68**, such as the monitor **68**M. The controller **46**, the robot controller **56**, and/or navigation controller **58** may also utilize the user interface **66** to display instructions or request information such that the surgeon or other users may interact with the robotic control system **52** to facilitate articulation of the robotic arm **36**. By way of example, the controller **46** is configured to send different interface images IM stored in the memory **48** to the monitor **68**M as described in greater detail below. Other configurations are contemplated.
(41) It will be appreciated that the robotic control system **52** and the navigation system **54** can cooperate to facilitate control over the position and/or orientation of the end effector **40** and/or tool **42** in different ways. By way of example, in some embodiments, the robot controller **56** is configured to control the robotic arm **36** (e.g., by driving joint motors) to provide haptic feedback to the surgeon via the robotic arm **36**. Here, haptic feedback helps constrain or inhibit the surgeon from manually moving the end effector **40** and/or tool **42** beyond predefined virtual boundaries associated with the surgical procedure (e.g., to maintain alignment of the tool **42** along the trajectory T). One type of haptic feedback system and associated haptic objects that define virtual boundaries are described, for example, in U.S. Pat. No. 8,010,180, “entitled, “Haptic Guidance System and Method,” the disclosure of which is hereby incorporated by reference in its entirety. In one embodiment, the surgical system **30** is the RIO™ Robotic Arm Interactive Orthopedic System manufactured by MAKO Surgical Corp. of Fort Lauderdale, FL, USA.
(42) Referring now to FIGS. **1-14**, as noted above, the surgical system **30** employs the end effector **40** to position the tool **42** at the surgical site ST along the trajectory T maintained by the surgical robot **32** to assist the surgeon in carrying out various types of surgical procedures with precise control over the relative position and orientation of the workpiece **44** attached to the tool **42** with respect to the patient's body B. Those having ordinary skill in the art will appreciate that different

types of surgical procedures routinely involve the use of a number of different types of surgical devices, tools, and the like. Thus, for surgical procedures carried out in connection with surgical robots **32**, different end effectors **40** and/or tools **42**, of various types, sizes, and/or configurations, may be utilized during a single surgical procedure. Here, the surgical system **30** is configured so as to allow the surgeon to attach different types of end effectors **40** and/or tools **42** to the coupler **38** of the surgical robot **32**, and also to allow the surgeon to select between variations of the same type of end effector **40** and/or tool **42**. To this end, and in the representative embodiment illustrated herein, the surgical system **30** comprises first and second toolsets **78**A, **78**B, each of which includes first, second, and third tools **42** which, as described in greater detail below, are variations of the same general type of tool **42**.

(43) FIGS. **5**A-**8** generally depict the first toolset **78**A, which includes first, second, and third variations of tools **42** configured as impactors: a straight impactor **80** (see FIGS. **5**A-**5**B), a first-option impactor **82** (see FIGS. **6**A-**6**B), and a second-option impactor **84** (see FIGS. **7**A-**7**B). Furthermore, FIGS. **9**A-**14** generally depict the second toolset **78**B, which includes first, second, and third variations of tools **42** configured as reamers: a straight reamer **86** (see FIGS. **9**A-**9**B), a first-option reamer **88** (see FIGS. **10**A-**10**B), and a second-option reamer **90** (see FIGS. **11**A-**13**B). It will be appreciated that the types of first and second toolsets **78**A, **78**B illustrated and described herein, as well as the variations **80**, **82**, **84**; **86**, **88**, **90** of tools **42** in the toolsets **78**A, **78**B, are exemplary and non-limiting. Thus, while the present disclosure is directed toward an impactor toolset **78**A and a reamer toolset **78**B each having three variations **80**, **82**, **84**; **86**, **88**, **90** of tools **42**, other configurations are contemplated and the surgical system **30** could comprise any suitable number of toolsets each having any suitable number of variations of tools **42** configured for use in any type of surgical procedure where surgical robots **32** are employed.

(44) Those having ordinary skill in the art will appreciate that the variations **80**, **82**, **84**; **86**, **88**, **90** of tools **42** within the toolsets **78**A, **78**B affords the surgeon with flexibility in carrying out different types of surgical procedures in different ways. By way of non-limiting example, the surgeon may select a variation **80**, **82**, **84**; **86**, **88**, **90** of one or more types of tools **42** to facilitate a particular approach, improve visibility of the surgical site ST, accommodate handling and/or orientation preferences, and the like. While this flexibility is advantageous, variations **80**, **82**, **84**; **86**, **88**, **90** of tools **42** generally position workpieces **44** (e.g., a prosthetic cup for the impactors **80**, **82**, **84**, and a reamer head for the reamers **86**, **88**, **90**) in different ways with respect to the coupler **38** of the surgical robot **34**. As is described in greater detail below, the controller **46** cooperates with the memory **48**, the pointer **50**, the localizer **60**, and the monitor **68**M to ensure that the surgical system **30** can distinguish between variations **80**, **82**, **84**; **86**, **88**, **90** of tools **42** and thereby determine the position and orientation of the workpiece **44** based on the identity of the tool **42** being utilized.

(45) Referring now to FIGS. **5**A-**14**, the illustrated tools **42** are each configured for releasable attachment to a common end effector **40**. Put differently, in one embodiment, the end effector **40** is configured to releasably secure the straight impactor **80** (see FIG. **5**A), the first-option impactor **82** (see FIG. **6**A), the second-option impactor **84** (see FIG. **7**A), the straight reamer **86** (see FIG. **9**A), the first-option reamer **88** (see FIG. **10**A), and/or the second-option reamer **90** (see FIGS. **11**A, **12**A, and **13**A). While this configuration advantageously allows the surgeon to quickly change between different tools **42** without detaching the end effector **40** from the coupler **38** of the surgical robot **32**, it will be appreciated that each toolset **78**A, **78**B or even each individual tool **42** could be provided with its own end effector **40** in certain embodiments.

(46) In order to facilitate releasable attachment of the tools **42** to the end effector **40**, the end effector **40** generally comprises a mount **92**, a guide **94**, and a receiver **96**. The mount **92** is adapted to releasably attach to the coupler **38** of the surgical robot **32** (see FIG. **1**). The guide **94** is coupled to the mount **92** and comprises the receiver **96** which, in turn, is configured to releasably secure the tool **42** to the guide **94**. Examples of this type of guide **94** and receiver **96** are described in U.S. Pat.

No. 8,753,346, previously referenced.

(47) The guide **94** has a generally cylindrical region **98** which defines a tool axis TA and extends to a distal guide end **100**. The receiver **96** (depicted schematically as a sphere in FIGS. **5**A and **9**A) is configured to restrict movement of the tool **42** relative to the guide **94** in different ways depending on the type of tool **42**. By way of illustrative example, the receiver **96** is generally configured to permit free rotation of the impactors **80**, **82**, **84** about the tool axis TA, and to permit limited translation along the tool axis TA (not shown in detail). By way of further illustrative example, the receiver **96** is generally configured to inhibit translation of the reamers **86**, **88**, **90** along the tool axis TA (see FIGS. **5**A, **6**A, and **7**A), to permit free rotation of the straight reamer **86** and the first-option reamer **88** about the tool axis TA (see FIGS. **9**A and **10**A), and to permit selective positioning of the second-option reamer **90** about the tool axis TA between first, second, and third orientations O**1**, O**2**, O**3** (see FIGS. **11**A, **12**A, and **13**A) as described in greater detail below.

(48) The tools **42** each generally comprise a respective working end **102**, a proximal end **104**, a coupling **106**, a tool body **108**, and a checkpoint feature **110**. The working end **102** is configured to releasably secure and support the workpiece **44** (e.g., a prosthetic cup for the impactors **80**, **82**, **84**, and a reamer head for the reamers **86**, **88**, **90**). The coupling **106** of the tool **42** (depicted schematically as an elongated recess in FIG. **5**A and as an indent in FIG. **9**A) is formed in the tool body **110** and is configured to engage the receiver **96** of the guide **94** of the end effector **40** to restrict or inhibit axial translation of the tool **42**, as noted above. The tool body **108** extends between the working end **102** and the proximal end **104**, with the coupling **106** arranged adjacent to the proximal end **104**. The checkpoint feature **110** is generally formed in the tool body **108**, and is arranged relative to a common reference point RP at a predetermined location that is specific to each tool **42**, as described in greater detail below.

(49) The working end **102** of each tool **42** defines a respective workpiece axis WA, which may be coincident with the tool axis TA for some tools **42** (e.g., the straight impactor **80** depicted in FIG. **5**A), parallel to and offset from the tool axis TA for some tools **42** (e.g., the second-option reamer **90** depicted in FIGS. **11**A, **12**A, and **13**A), or angled with respect to the tool axis TA (e.g., the first-option reamer **88** depicted in FIG. **10**A). Generally, the workpiece axis WA is coincident with the trajectory T maintained by the surgical robot **32**.

(50) The working ends **102** of the tools **42** each generally rotate and translate concurrently with their respective tool bodies **108**. For the impactors **80**, **82**, **84**, a head (not shown) may be coupled to the proximal end **104** to receive external impact force, such as from a mallet (not shown) to translate the tool body **108** and the working end **102** relative to the guide **94** and thereby facilitate installing the prosthetic cup (not shown) at the surgical site ST. For the reamers **86**, **88**, **90**, a rotary instrument (not shown) may be coupled to the proximal end **104** to rotate the tool body **108** and the working end **102** relative to the guide **94** and thereby facilitate reaming (not shown) or otherwise preparing the surgical site ST for impaction. The tool bodies **108** of the reamers **86**, **88**, **90** also comprise handles, generally indicated at **112**, and may include one or more universal joints, generally indicated at **114** where the tool axis TA is not coincident with the workpiece axis WA (see FIGS. **10**A, **11**A, **12**A, and **13**A). The handles **112** may be grasped by the surgeon and do not rotate concurrently with the working end **102** in response to rotational torque applied to the proximal end **104**. The checkpoint features **110** of the reamers **86**, **88**, **90** are formed in the handles **112** of the tool bodies **108**, as described in greater detail below. The universal joints **114** are employed in the first-option reamer **88** and the second-option reamer **90** to allow the tool body **108**, which may be comprised of discrete sections (not shown in detail) to rotate between the proximal end **104** and the working end **102**.

(51) Referring again to FIGS. **1-14**, the tools **42** within each toolset **78**A, **78**B each comprise one or more checkpoint features **110** formed in the tool body **108** at respective predetermined locations relative to the common reference point RP, as noted above. In the representative embodiment illustrated herein, the reference point RP is established when the coupling **106** of the tool **42** is

engaged with the receiver **96** of the guide **94**, and the end effector **40** is attached to the coupler **38** of the surgical robot **32**. While the reference point RP could be defined or otherwise established in a number of different ways, because each of the exemplary tools **42** described and illustrated herein can be releasably attached to the same end effector **40**, the reference point RP depicted in the drawings is located adjacent to the mount **92** of the end effector **40**. As will be appreciated from the subsequent description below, because the surgical system **30** is able to determine the specific position and orientation of the coupler **38** of the surgical robot **32** within either coordinate system MNPL, LCLZ (e.g., via encoder data ED from the robotic arm **36** and/or via location data from the localizer **60** about the end effector tracker **62**E), the location of the reference point RP is similarly known by the surgical system **30** during use. The reference point RP may also be known in a tool coordinate system associated with the end effector tracker **62**E, with the reference point RP being stored as a coordinate, plane, line, or the like in the tool coordinate system and capable of being tracked by virtue of tracking the end effector tracker **62**E. The relationship of the reference point RP to the end effector tracker **62**E can be established by calibration, such as during manufacture or intraoperatively, or may be measured.

(52) The surgical system **30** is configured to differentiate between the tools **42** of one or more toolsets **78**A, **78**B based on the location of the checkpoint features **110** with respect to the reference point RP to, among other things, ensure proper operation of the robotic control system **52** and/or the navigation system **54** by correctly positioning the tool **42** and/or workpiece **44**. Here, each tool **42** comprises one or more checkpoint features **110** arranged at predetermined locations which are unique to that particular tool **42** within its respective toolset **78**A, **78**B. In the representative embodiment illustrated herein, the checkpoint features **110** are realized as divots **116** formed in the respective tool bodies **108**: the straight impactor **80** comprises two divots **116**ISTA, **116**ISTB (see FIG. **5**B); the first-option impactor **82** comprises one divot **1161**FO (see FIG. **6**B); the second-option impactor **84** comprises two divots **116**ISOA, **116**ISOB (see FIG. **7**B); the straight reamer **86** comprises two divots **116**RSTA, **116**RSTB (see FIG. **9**B); the first-option reamer **88** comprises two divots **116**RFOA, **116**RFOB (see FIG. **10**B); and the second-option reamer **90** comprises two divots **116**RSO**1**, **116**RSO**2** (see FIGS. **11**B, **12**B, and **13**B). The divots **116** each have a generally frustoconical profile which is shaped to receive the distal tip **50**B of the pointer **50**, as described in greater detail below. However, it will be appreciated that the checkpoint features **110** could be configured in other ways, with or without the use of divots **116**, sufficient to differentiate between tools **42** relative to the reference point RP. For the purposes of clarity and consistency, the arrangement, orientation, and configuration of the divots **116** will be described for each toolset **78**A, **78**B separately.

(53) Referring now to FIGS. **5**A-**8**, the impactors **80**, **82**, **84** of the first toolset **78**A are shown. The straight impactor **80** is depicted in FIGS. **5**A-**5**B. As shown in FIG. **5**B, the checkpoint feature **110** of the straight impactor **80** comprises two divots **116**ISTA, **116**ISTB which are each formed in the tool body **108** at respective predetermined locations relative to the reference point RP. Because the tool body **108** of the straight impactor **80** is arranged for rotation about the tool axis TA relative to the mount **92** of the end effector **40**, as noted above, movement of the tool body **108** effects corresponding movement of the checkpoint feature **110** relative to the reference point RP within a predetermined checkpoint space **118**. In the illustrated embodiment of the straight impactor **80**, the checkpoint space **118**I_ST is defined by a circle disposed about and concentrically aligned with the tool axis TA (see FIGS. **5**B and **8**). Thus, irrespective of how the straight impactor **80** is rotated about the tool axis TA, its divots **116**ISTA, **116**ISTB will be positioned somewhere along the circular checkpoint space **118**I_ST.

(54) The first-option impactor **82** is depicted in FIGS. **6**A-**6**B. As shown in FIG. **6**B, the checkpoint feature **110** of the first-option impactor **82** comprises one divot **1161**FO which is formed in the tool body **108** at a predetermined location relative to the reference point RP. Here too, because the tool body **108** of the first-option impactor **82** is arranged for rotation about the tool axis TA relative to

the mount **92** of the end effector **40**, movement of the tool body **108** effects corresponding movement of the checkpoint feature **110** relative to the reference point RP within a predetermined checkpoint space **118**I_FO defined by a circle disposed about and concentrically aligned with the tool axis TA (see FIGS. **6**B and **8**). Thus, irrespective of how the first-option impactor **82** is rotated about the tool axis TA, its divot **1161**FO will be positioned somewhere along the circular checkpoint space **118**I_FO.
(55) The second-option impactor **84** is depicted in FIGS. **7**A-**7**B. As shown in FIG. **7**B, the checkpoint feature **110** of the second-option impactor **84** comprises two divots **116**ISOA, **116**ISOB which are each formed in the tool body **108** at respective predetermined locations relative to the reference point RP. Here too, because the tool body **108** of the second-option impactor **84** is arranged for rotation about the tool axis TA relative to the mount **92** of the end effector **40**, movement of the tool body **108** effects corresponding movement of the checkpoint feature **110** relative to the reference point RP within a predetermined checkpoint space **118**I_SO defined by a circle disposed about and concentrically aligned with the tool axis TA (see FIGS. **7**B and **8**). Thus, irrespective of how the second-option impactor **80** is rotated about the tool axis TA, its divots **116**ISOA, **116**ISOB will be positioned somewhere along the circular checkpoint space **118**I_SO.
(56) In FIG. **8**, the checkpoint space **118**I_ST of the straight impactor **80**, the checkpoint space **118**I_FO of the first-option impactor **82**, and the checkpoint space **118**I_SO of the second-option impactor **84** are each shown at their respective predetermined locations relative to the reference point RP established or otherwise defined by the end effector **40**, as noted above. Each of the checkpoint spaces **118**I_ST, **118**I_FO, **118**I_SO shown in FIG. **8** are spaced from each other such that a predetermined distance **120** (or more) separates adjacent checkpoint spaces **118**I_ST, **118**I_FO, **118**I_SO from each other. Put differently, the predetermined location of the checkpoint feature **110** of each of the impactors **80**, **82**, **84** are arranged so as to be spaced from the checkpoint features **110** of each of the other impactors **80**, **82**, **84** at a minimum of the predetermined distance **120**. Here, because the impactors **80**, **82**, **84** are each arranged for rotation about the tool axis TA, it will be appreciated that the predetermined distance **120** extends in 3D space between any point along two adjacent checkpoint spaces **118**I_ST, **118**I_FO, **118**I_SO (see FIG. **8**). In one embodiment, the predetermined distance **120** is at least 10 mm.
(57) Referring now to FIGS. **9**A-**14**, the reamers **86**, **88**, **90** of the second toolset **78**B are shown. The straight reamer **86** is depicted in FIGS. **9**A-**9**B. As shown in FIG. **9**B, the checkpoint feature **110** of the straight reamer **86** comprises two divots **116**RSTA, **116**RSTB which are each formed in the tool body **108** at respective predetermined locations relative to the reference point RP. Because the tool body **108** of the straight reamer **86** is arranged for rotation about the tool axis TA relative to the mount **92** of the end effector **40**, as noted above, movement of the tool body **108** effects corresponding movement of the checkpoint feature **110** relative to the reference point RP within a predetermined checkpoint space **118**. In the illustrated embodiment of the straight reamer **86**, the checkpoint space **118**R_ST is defined by a circle disposed about and concentrically aligned with the tool axis TA (see FIGS. **9**B and **14**). Thus, irrespective of how the straight reamer **86** is rotated about the tool axis TA, its divots **116**RSTA, **116**RSTB will be positioned somewhere along the circular checkpoint space **118**R_ST.
(58) The first-option reamer **88** is depicted in FIGS. **10**A-**10**B. As shown in FIG. **10**B, the checkpoint feature **110** of the first-option reamer **88** comprises two divots **116**RFOA, **116**RFOB which are formed in the tool body **108** at respective predetermined locations relative to the reference point RP. Here too, because the tool body **108** of the first-option reamer **88** is arranged for rotation about the tool axis TA relative to the mount **92** of the end effector **40**, movement of the tool body **108** effects corresponding movement of the checkpoint feature **110** relative to the reference point RP within a predetermined checkpoint space **118**R_FO defined by a circle disposed about and concentrically aligned with the tool axis TA (see FIGS. **10**B and **14**). Thus, irrespective of how the first-option reamer **88** is rotated about the tool axis TA, its divots **116**RFOA, **116**RFOB

will be positioned somewhere along the circular checkpoint space **118**R_FO.

(59) The second-option reamer **90** is depicted in FIGS. **11**A-**13**B. As shown in FIGS. **11**B, **12**B, and **13**B, the checkpoint feature **110** of the second-option reamer **90** comprises two divots **116**RSO**1**, **116**RSO**2** which are each formed in the tool body **108** at respective predetermined locations relative to the reference point RP. As noted above, the second-option reamer **90** does not freely rotate about the tool axis TA relative to the mount **92** of the end effector **40**. Rather, in this embodiment, as is depicted schematically in FIGS. **11**B, **12**B, and **13**B, the handle **112** of the second-option reamer **90** comprises a key **122** which can be received in either a first, second, or third keyways **124**A, **124**B, **124**C formed in the cylindrical region **98** of the guide **94** adjacent to the distal guide end **100**. Thus, the surgeon can position the key **122** in the first keyway **124**A to place the second-option reamer **90** in the first orientation O**1** (see FIGS. **11**A-**11**B), in the second keyway **124**B to place the second-option reamer **90** in the second orientation O**2** (see FIGS. **12**A-**12**B), or in the third keyway **124**C to place the second-option reamer **90** in the third orientation O**3** (see FIGS. **13**A-**13**B). Furthermore, the illustrated embodiment of the second-option reamer **90** comprises different checkpoint features **110** respectively defined by the divots **116**RSO**1**, **116**RSO**2**. Here, movement between the first, second, and third orientations O**1**, O**2**, O**3** effects corresponding movement of the checkpoint features **110** relative to the reference point RP within respective predetermined checkpoint spaces **118**R_SOA, **118**R_SOB each defined by a radial arc disposed about and concentrically aligned with the tool axis TA (see FIGS. **11**B, **12**B, **13**B, and **14**). Thus, irrespective of which orientation O**1**, O**2**, O**3** the second-option impactor **80** is placed in, its divots **116**RSO**1**, **116**RSO**2** will be positioned somewhere along the respective radial arc checkpoint spaces **118**R_SOA, **118**R_SOB. Furthermore, while the checkpoint features **110** of the illustrated embodiment of the second-option impactor **80** are configured such that the checkpoint spaces **118**R_SOA, **118**R_SOB are also spaced from each other at the predetermined distance **120**, it is conceivable that the checkpoint spaces **118**R_SOA, **118**R_SOB could be arranged differently in some embodiments.

(60) In FIG. **14**, the checkpoint space **118**R_ST of the straight reamer **86**, the checkpoint space **118**R_FO of the first-option reamer **88**, and the checkpoint spaces **118**R_SOA, **118**R_SOB of the second-option reamer **90** are each shown at their respective predetermined locations relative to the reference point RP established or otherwise defined by the end effector **40**, as noted above. Each of the checkpoint spaces **118**R_ST, **118**R_FO, **118**R_SOA, **118**R_SOB shown in FIG. **14** are similarly spaced from each other such that the predetermined distance **120** (or more) separates adjacent checkpoint spaces **118**R_ST; **118**R_FO; **118**R_SOA, **118**R_SOB from each other. Put differently, the predetermined location of the checkpoint features **110** of each of the reamers **86**, **88**, **90** are arranged so as to be spaced from the checkpoint features **110** of each of the other reamers **86**, **88**, **90** at a minimum of the predetermined distance **120**. Here, because the reamers **86**, **88**, **90** are each arranged for some form of movement about the tool axis TA (either free rotation or movement between discrete positions), it will be appreciated that the predetermined distance **120** similarly extends in 3D space between any point along two adjacent checkpoint spaces **118**R_ST; **118**R_FO; **118**R_SOA, **118**R_SOB (see FIG. **14**).

(61) While some of the tools **42** described above are able to freely rotate about the tool axis TA such that their checkpoint feature **110** could be disposed in a number of different predetermined locations about its respective circular checkpoint space **118**, it will be appreciated that other configurations are contemplated. By way of non-limiting example, while the handle **112** of the second-option reamer **90** does not freely rotate about the tool axis TA and can be moved between the three orientations O**1**, O**2**, O**3**, it is conceivable that only a single orientation could be utilized in some embodiments such that the checkpoint feature **110** is defined by a point in space as opposed to a point along a circle or a radial arc. Furthermore, while some of the tools **42** described above employ checkpoint features **110** defined by multiple divots **116** that can occupy a common checkpoint space **118**, only a single divot **116** could be employed in some embodiments. Moreover,

multiple checkpoint features **110** with one or more divots **116** that occupy respective checkpoint spaces **118** could also be employed. Other configurations are contemplated.
(62) Referring again to FIGS. **1-14**, as noted above, the surgical system **30** is configured to differentiate between the tools **42** of one or more toolsets **78**A, **78**B based on the location of the checkpoint features **110** with respect to the reference point RP via the controller **46**. Here, the controller **46** is configured to identify the tool **42** that is attached to the coupler **38** of the end effector **40** by monitoring the position and orientation of the pointer tracker **62**P of the pointer **50** via the localizer **60** under certain operating conditions.
(63) The controller **46** is configured to send different interface images IM (see FIGS. **3**A-**4**C) stored in the memory **48** to the monitor **68**M to assist the surgeon (or another user) in performing the surgical procedure. The interface images IM may be static images or may be defined as a part of a dynamic, navigable graphical user interface. In one embodiment, the controller **46** is configured to send a first interface image IM**1** (see FIGS. **3**A and **4**A) to the monitor **68**M prompting the surgeon (or another user) to position the distal tip **50**D of the pointer **50** at the checkpoint feature **110** of the tool **42** attached to the coupler **38** of the surgical robot **32**. Here, the controller **46** is further configured to receive position data PD (see FIG. **2**) from the localizer **60** associated with the pointer tracker **62**P of the pointer **50** within the field of view FV, and use this position data PD in order to compare the current position of the checkpoint feature **110** against the identification data ID stored in the memory **48** to determine the identity of (or “recognize”) the tool **42**.
(64) In some embodiments, the coordinates of the distal tip **50**D of the pointer **50** relative to its pointer tracker **62**P is calibrated or known to the localizer **60** or the navigation controller **58** via calibration data stored in memory and accessible by the localizer **60** and/or the navigation controller **58**. As a result, the localizer **60** and/or the navigation controller **58** are able to determine coordinates of the distal tip **50**D of the pointer **50** in the localizer coordinate system LCLZ, the manipulator coordinate system MNPL, the tool coordinate system (via transformation techniques described above), or in some other common coordinate system. Current coordinates of the reference point RP can similarly be determined using position data PD associated with the end effector tracker **62**E. For example, coordinates of the reference point RP relative to the end effector tracker **62**E can be calibrated or known to the localizer **60** or the navigation controller **58** via calibration data stored in memory and accessible by the localizer **60** and/or the navigation controller **58**. Thus, by knowing the current coordinates of the reference point RP and the current coordinates of the checkpoint feature **110** in the common coordinate system, the localizer **60** and/or the navigation controller **58** can compare the relationship (e.g., positional relationship between coordinates) of the reference point and the checkpoint feature **110** and compare this relationship to stored, expected relationships for each of the different tools **42**, e.g., the identification data ID.
(65) In some embodiments, the identification data ID associated with the tools **42** and stored in the memory **48** comprise coordinates of the predetermined locations associated with the checkpoint features **110** of each tool **42** within the respective toolset **78**A, **78**B. More specifically, the identification data ID may comprise coordinates and/or areas disposed along the checkpoint spaces **118** of each tool **42** within the respective toolset **78**A, **78**B, and relative to the reference point RP. In some cases, these coordinates and/or areas, along with the coordinates of the reference point RP, can be stored in the tool coordinate system to establish a known relationship between the reference point RP and the checkpoints **110** and/or checkpoint spaces **118**. Thus, the actual coordinates of the checkpoint **110** determined by the pointer **50** can be determined in the tool coordinate system (e.g., via transformation techniques described above), compared to the stored, possible coordinates of the checkpoint **110** in the tool coordinate system, with the best fit selected to thereby identify the correct tool **42**. If no match is found because the measured coordinates differ beyond a predetermined threshold from each of the stored coordinates, then the surgeon may be prompted with instructions on the monitor **68**M to recalibrate the pointer **50** or to ensure that the tool **42** is

fully seated in the receiver **96**.

(66) Once the controller **46** has determined the identity of the tool **42**, it sends a second interface image IM**2** (see FIGS. **3**B and **4**B) to the monitor **68**M to present the surgeon (or another user) with the identity of the tool **42**. In some embodiments, the controller **46** is further configured to send a third interface image IM**3** (see FIGS. **3**C and **4**C) to the monitor **68**M to present the surgeon (or another user) with the identity of the tool **42** alongside a predetermined number of identities associated with the other tools **42** in the respective toolset **78**A, **78**B based on the identification data ID stored in the memory **48**. In the embodiment illustrated in FIGS. **3**A-**4**C, the second interface image IM**2** (see FIGS. **3**B and **4**B) presents the identity of the tool **42** as a selection of a "drop down" list of identities (see FIGS. **3**C and **4**C). It will be appreciated that this configuration affords advantages in situations where the localizer **60** operates with less than optimal accuracy, such as where the field of view FV is narrow or obscured, where user error places the distal tip **50**D of the pointer **50** out of alignment with the pointer tracker **62**P, and the like. In such situations, the surgical system **30** could still be configured to present the surgeon (or another user) with the assumed identity of the tool **42** while, at the same time, requesting the surgeon to manually verify the identity of the tool **42** and notifying the surgeon to check for misalignment or to use a different pointer **50**. Other configurations are contemplated.

(67) It should be appreciated that the controller **46** may be configured to receive position data PD from the localizer **60** associated with the tool **42** within the field of view FV by tracking a base tracker (not shown) attached to the robotic arm **36**, such as by monitoring the position and/or orientation of the base tracker, with the base tracker being registered to the manipulator coordinate system MNPL, and with encoder data ED being additionally used to determine a position of the reference point RP in the manipulator coordinate system MNPL. Similarly, the controller **46** can then compare the current position of the checkpoint **110** in the manipulator coordinate system MNPL relative to the current position of the reference point RP to the stored, possible positions of the checkpoint **110** based on its stored relationship to the reference point RP, e.g., against the identification data ID stored in the memory **48**, to determine the identity of the tool **42**. In some embodiments, position data PD associated with the tool **42** may be at least partially determined using encoder data ED from the robot controller **56**.

(68) The present disclosure is also directed toward a method of assisting the surgeon (or another user) in performing the surgical procedure with the surgical system **30**. The method comprises different steps, including attaching the tool **42** having the checkpoint feature **110** to the surgical robot **32**, and sending the first interface image IM**1** to the monitor **68**M prompting the surgeon to position the distal tip **50**D of the pointer **50** at the checkpoint feature **110** of the tool **42**. The method also comprises tracking the pointer **50** with the localizer **60** to determine position data PD associated with the pointer **50**, identifying the tool **42** by comparing the position data PD from the localizer **60** with stored identification data ID, and sending a second interface image IM**2** to the monitor **68**M presenting the surgeon with the identity of the tool **42**.

(69) The embodiments of the surgical system **30**, end effector **40**, tools **42**, and methods described herein afford advantages in connection with a broad number of medical and/or surgical procedures including, for example, where surgical robots **32** are utilized in connection with total hip arthroplasty. Specifically, it will be appreciated that the embodiments described and illustrated herein are configured to facilitate identification of different variations of tools **42** in one or more toolsets **78**A, **78**B quickly, reliably, and efficiently while, at the same time, affording the surgeon with guided assistance in carrying out different types of surgical procedures.

(70) It will be further appreciated that the terms "include," "includes," and "including" have the same meaning as the terms "comprise," "comprises," and "comprising." Moreover, it will be appreciated that terms such as "first," "second," "third," and the like are used herein to differentiate certain structural features and components for the non-limiting, illustrative purposes of clarity and consistency.

(71) Several configurations have been discussed in the foregoing description. However, the configurations discussed herein are not intended to be exhaustive or limit the invention to any particular form. The terminology which has been used is intended to be in the nature of words of description rather than of limitation. Many modifications and variations are possible in light of the above teachings and the invention may be practiced otherwise than as specifically described.

Claims

1. A surgical system, comprising: a tool comprising a tool feature; a navigation system comprising a localizer configured to detect a position of the tool feature; a display; a memory configured to store identification data associated with a plurality of tools; and one or more controllers coupled to the navigation system, the memory, and the display, the one or more controllers being configured to: receive, from the localizer, the detected position of the tool feature; compare the detected position of the tool feature with the identification data stored in the memory to determine an identity of the tool; and present, on the display, the identity of the tool and an identity of at least one other tool.
2. The surgical system of claim 1, wherein the memory is further configured to store identification data associated with a plurality of toolsets, each toolset comprising a group of tools, and each tool of the toolset being a variation of a same type of tool.
3. The surgical system of claim 2, wherein the one or more controllers are configured to: compare the detected position of the tool feature with the identification data stored in the memory to determine: the identity of the tool, an identity of the toolset of the tool, and an identity of at least one other tool of the toolset; and present, on the display, the identity of the tool and the identity of the at least one other tool of the toolset.
4. The surgical system of claim 3, wherein: the tool is a first reamer of a reamer toolset, the reamer toolset comprising the first reamer and at least one other reamer; and the one or more controllers are configured to present, on the display, the identity of the first reamer and the identity of the at least one other reamer of the reamer toolset.
5. The surgical system of claim 3, wherein: the tool is a first impactor of an impactor toolset, the impactor toolset comprising the first impactor and at least one other impactor; and the one or more controllers are configured to present, on the display, the identity of the first impactor and the identity of the at least one other impactor of the impactor toolset.
6. The surgical system of claim 1, further comprising a surgical robot, and wherein: the tool is adapted to attach to the surgical robot; when attached to the surgical robot, the tool feature is arranged at a first location with respect to a reference point located on the surgical robot; and the identification data comprises expected coordinates of the first location with respect to the reference point.
7. The surgical system of claim 6, further comprising: a second tool comprising a second tool feature; the second tool adapted to attach to the surgical robot; when attached to the surgical robot, the second tool feature is arranged at a second location with respect to the reference point located on the surgical robot, wherein the first location and the second location are spaced from each other by a known distance; and the identification data comprises expected coordinates of the second location with respect to the reference point.
8. The surgical system of claim 6, wherein: the navigation system further comprises a tracker coupled to the surgical robot, the tracker comprising a known relationship relative to the reference point located on the surgical robot; the localizer is configured to detect a position of the tracker and detect the position of the tool feature in a common coordinate system; the one or more controllers are configured to utilize the detected position of the tracker, the detected position of the tool feature, and the known relationship to determine actual coordinates of the first location with respect to the reference point; and the one or more controllers are configured to compare, with respect to

the reference point, the actual coordinates of the first location with the expected coordinates of the first location to determine the identity of the tool.

9. The surgical system of claim 1, wherein the one or more controllers are configured to: receive a user selection to manually verify the identity of the tool presented on the display, wherein the user selection comprises selection of the identity of the tool or selection of the identity of the at least one other tool.

10. The surgical system of claim 1, wherein the localizer of the navigation system is further defined as one or more of: a machine vision system, a surface scanner, and a range finder.

11. A method of operating a surgical system, the surgical system including a tool comprising a tool feature, a navigation system comprising a localizer, a display, a memory configured to store identification data associated with a plurality of tools, and one or more controllers coupled to the navigation system, the memory and the display, the method comprising: detecting, with the localizer, a position of the tool feature; receiving, with the one or more controllers, the detected position of the tool feature from the localizer; comparing, with the one or more controllers, the detected position of the tool feature with the identification data stored in the memory; in response to comparing, determining an identity of the tool with the one or more controllers; and instructing, with the one or more controllers, the display to present the identity of the tool and an identity of at least one other tool.

12. The method of claim 11, comprising the memory storing identification data associated with a plurality of toolsets, each toolset comprising a group of tools, and each tool of the toolset being a variation of a same type of tool.

13. The method of claim 12, comprising: comparing, with the one or more controllers, the detected position of the tool feature with the identification data stored in the memory for determining: the identity of the tool, an identity of the toolset of the tool, and an identity of at least one other tool of the toolset; and instructing, with the one or more controllers, the display to present the identity of the tool and the identity of the at least one other tool of the toolset.

14. The method of claim 13, wherein the tool is a first reamer of a reamer toolset, the reamer toolset comprising the first reamer and at least one other reamer, the method comprising: instructing, with the one or more controllers, the display to present the identity of the first reamer and the identity of the at least one other reamer of the reamer toolset.

15. The method of claim 13, wherein the tool is a first impactor of an impactor toolset, the impactor toolset comprising the first impactor and at least one other impactor, the method comprising: instructing, with the one or more controllers, the display to present the identity of the first impactor and the identity of the at least one other impactor of the impactor toolset.

16. The method of claim 11, wherein the surgical system further comprises a surgical robot, the method comprising: attaching the tool to the surgical robot for arranging the tool feature at a first location with respect to a reference point located on the surgical robot; and obtaining, with the one or more controllers, the identification data comprising expected coordinates of the first location with respect to the reference point.

17. The method of claim 16, wherein the navigation system further comprises a tracker coupled to the surgical robot, the tracker comprising a known relationship relative to the reference point located on the surgical robot, the method comprising: detecting, with the localizer, a position of the tracker and the position of the tool feature in a common coordinate system; utilizing, with the one or more controllers, the detected position of the tracker, the detected position of the tool feature, and the known relationship for determining actual coordinates of the first location with respect to the reference point; and comparing, with the one or more controllers, with respect to the reference point, the actual coordinates of the first location with the expected coordinates of the first location; and in response to comparing, determining the identity of the tool with the one or more controllers.

18. The method of claim 11, comprising: receiving, with the one or more controllers, a user selection for manually verifying the identity of the tool presented on the display, wherein the user

selection comprises selecting the identity of the tool or selecting the identity of the at least one other tool.

19. A navigation system, comprising: a localizer configured to detect a position of a tool feature of a tool; a display; a memory configured to store identification data associated with a plurality of tools; and one or more controllers coupled to the localizer, the display, and the memory, and the one or more controllers being configured to: receive, from the localizer, the detected position of the tool feature; compare the detected position of the tool feature with the identification data stored in the memory to determine an identity of the tool; and present, on the display, the identity of the tool and an identity of at least one other tool.

20. A method of operating a navigation system, the navigation system comprising a localizer configured to detect a position of a tool feature of a tool, a display, a memory configured to store identification data associated with a plurality of tools, and one or more controllers coupled the localizer, the display, and the memory, the method comprising: detecting, with the localizer, a position of the tool feature; receiving, with the one or more controllers, the detected position of the tool feature from the localizer; comparing, with the one or more controllers, the detected position of the tool feature with the identification data stored in the memory; in response to comparing, determining an identity of the tool with the one or more controllers; and instructing, with the one or more controllers, the display to present the identity of the tool and an identity of at least one other tool.