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(54) **GEAR MECHANISMS FOR FIXATION FRAME STRUTS**

(71) Applicant: **Stryker European Holdings I, LLC**, Kalamazoo, MI (US)

(72) Inventors: **Subash K. Mannanal**, Mahwah, NJ (US); **Daniel Greenberg**, Ramsey, NJ (US); **Patrick Valli**, Brookside, NJ (US); **Manoj Kumar Singh**, Mahwah, NJ (US); **Cem Adalioglu**, Mönkeberg (DE)

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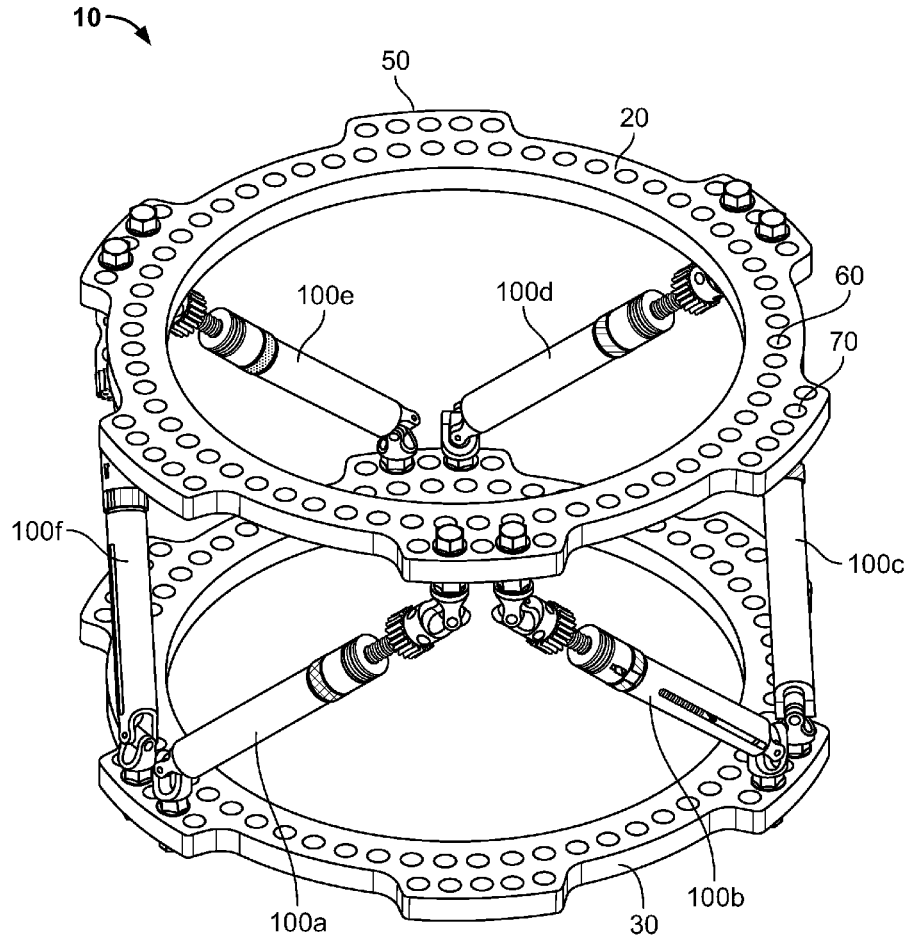
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(57) **ABSTRACT**

An adjustable length strut includes two joints, a threaded rod extending between the joints, and a tube adapted to receive the threaded rod. An actuation mechanism with gear teeth extending radially outward of the strut axis is rotatably fixed to the threaded rod. A protrusion may be coupled to an end of the threaded rod by a rotatable collar, with the protrusion extending through a slot in the tube to mark the length of the strut. A modular attachment member may be adapted to be couple to the first joint and include a worm gear adapted to engage gear teeth of the actuation mechanism. The modular attachment member may include a radiofrequency identity tag mechanism adapted to be read by a tag reader of a tool, the tool adapted to couple to the attachment member to rotate the worm gear to increase or decrease the effective length of the strut.



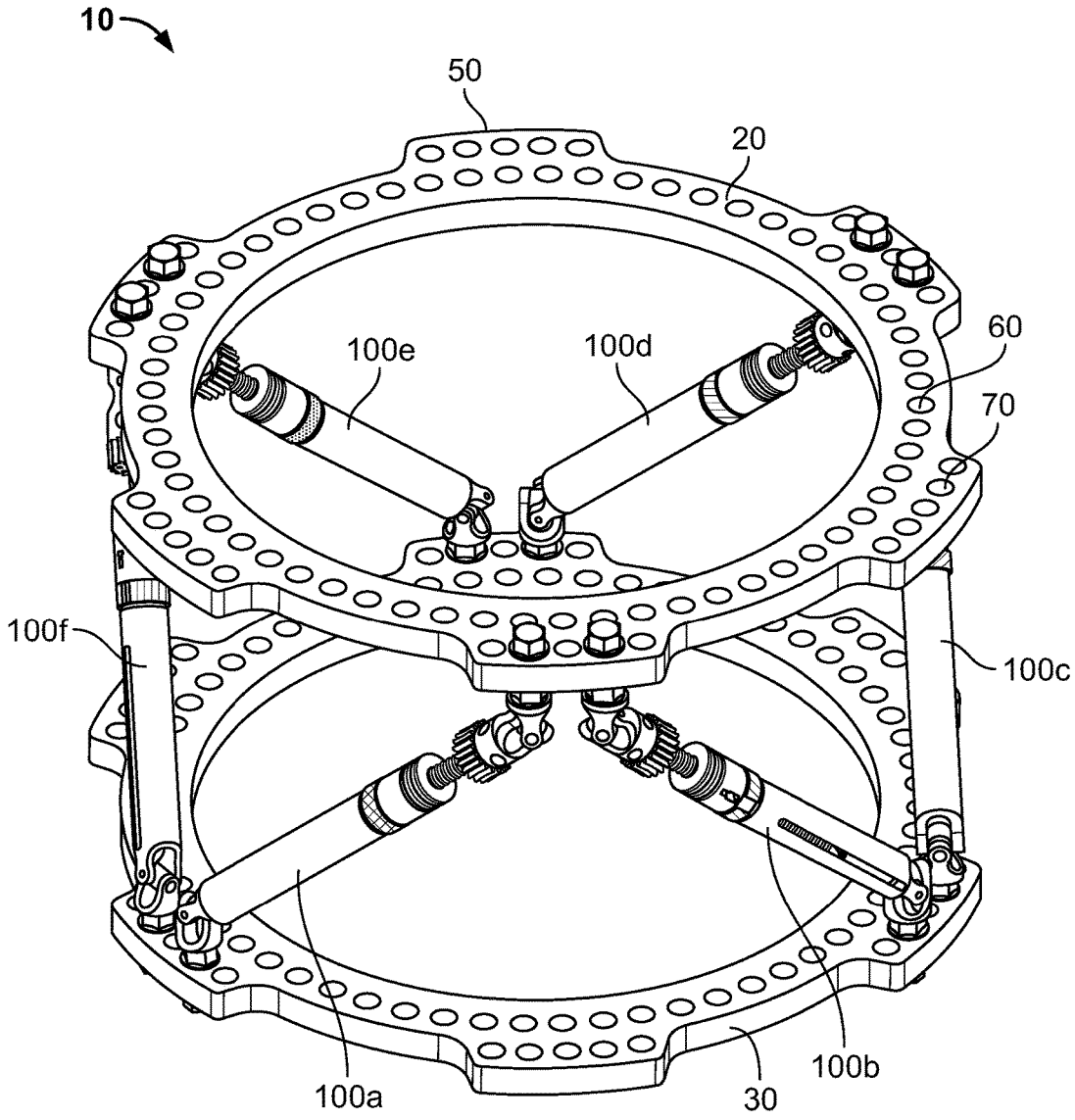


FIG. 1

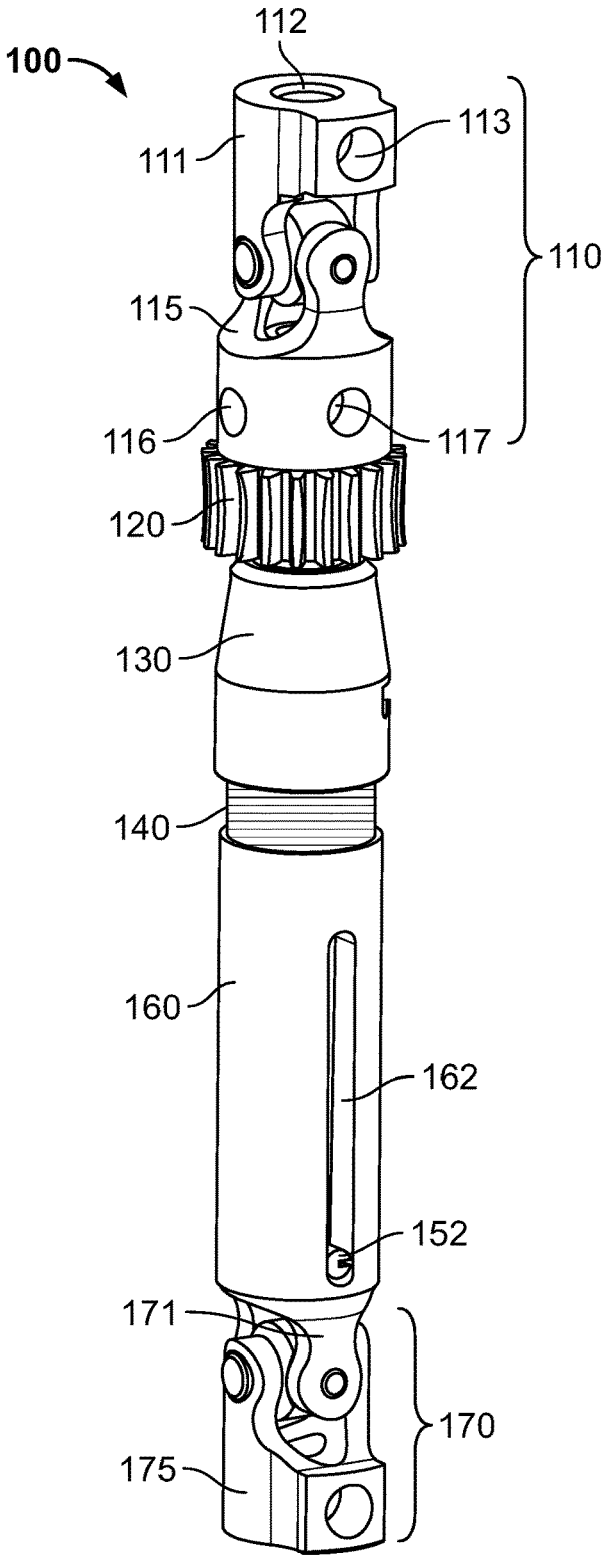

100
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171
170
175

FIG. 2A

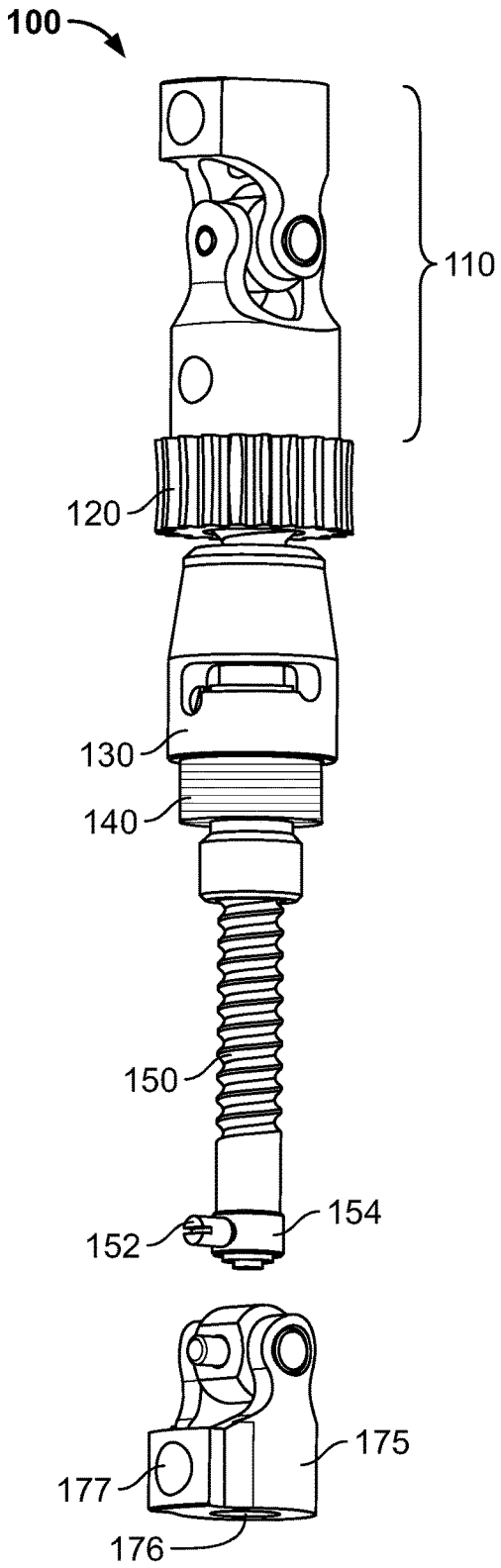


FIG. 2B

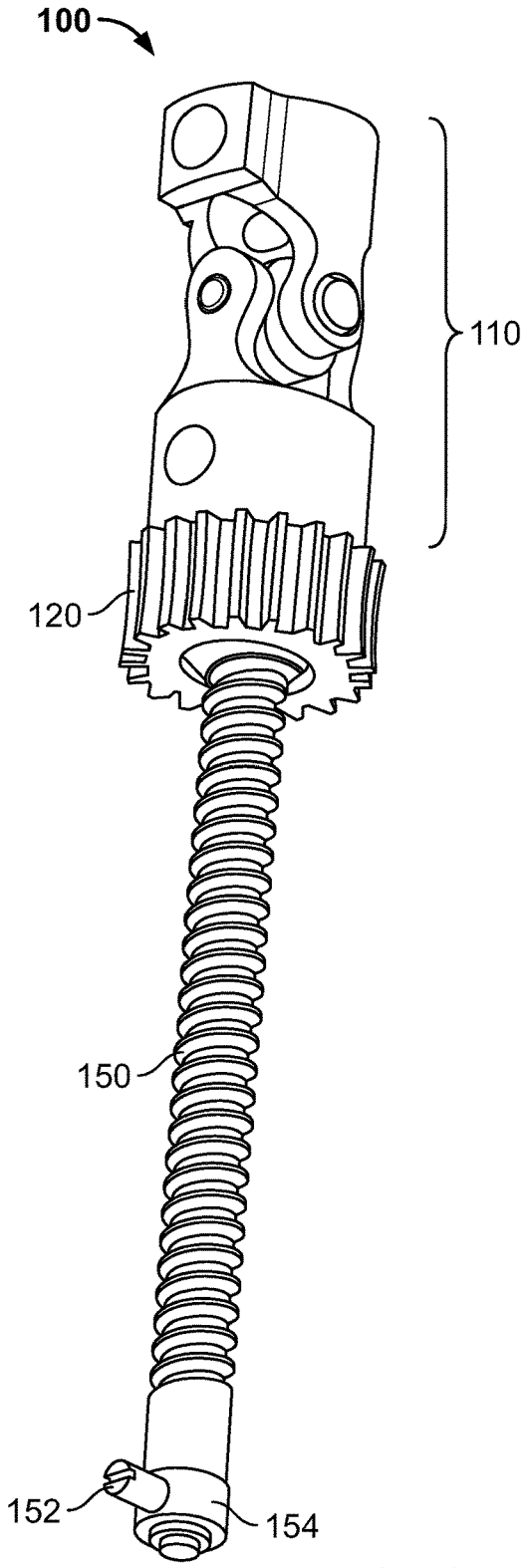


FIG. 2C

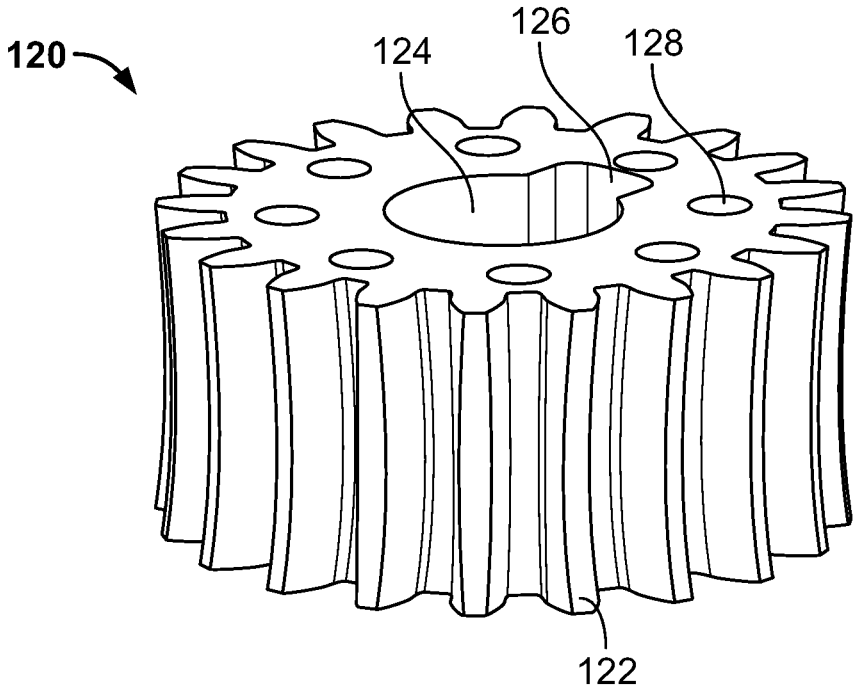


FIG. 2D

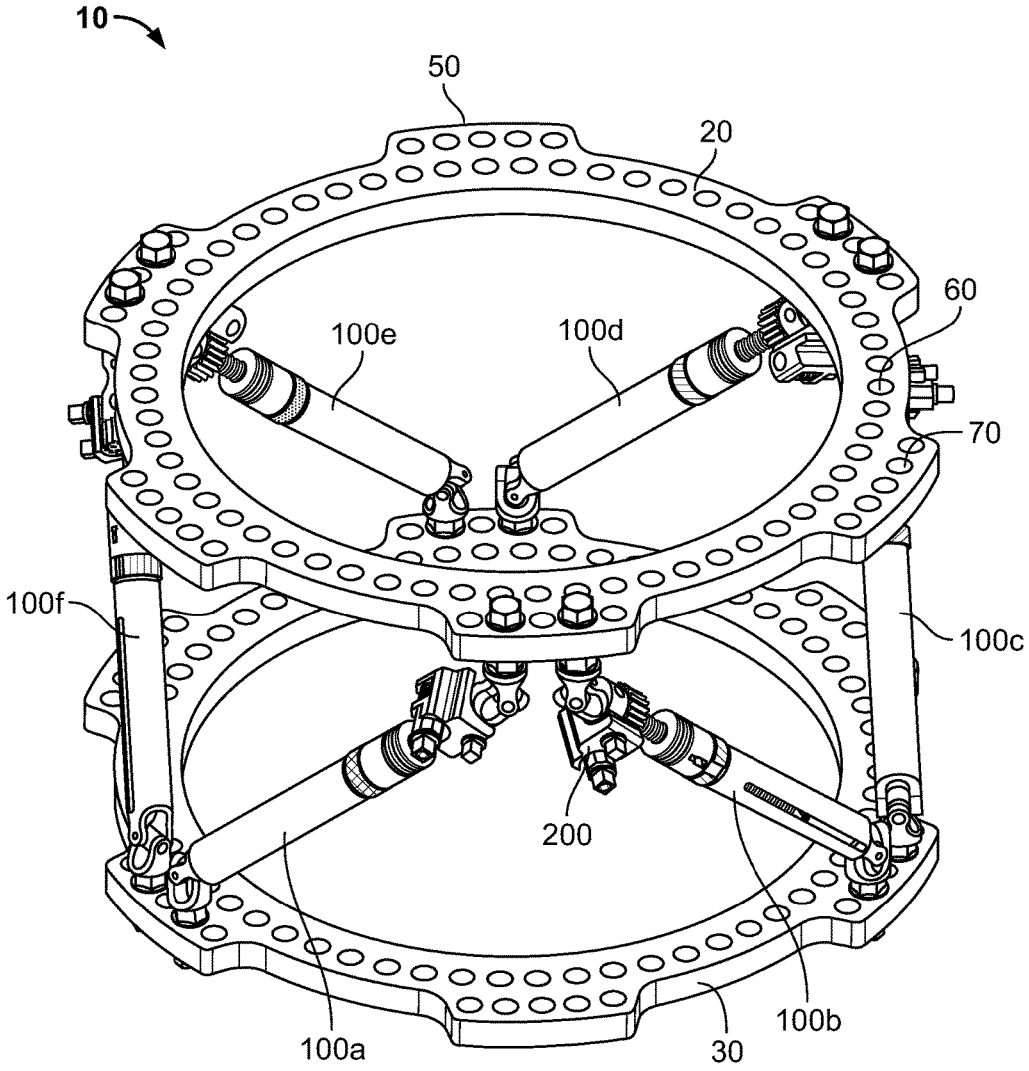


FIG. 3

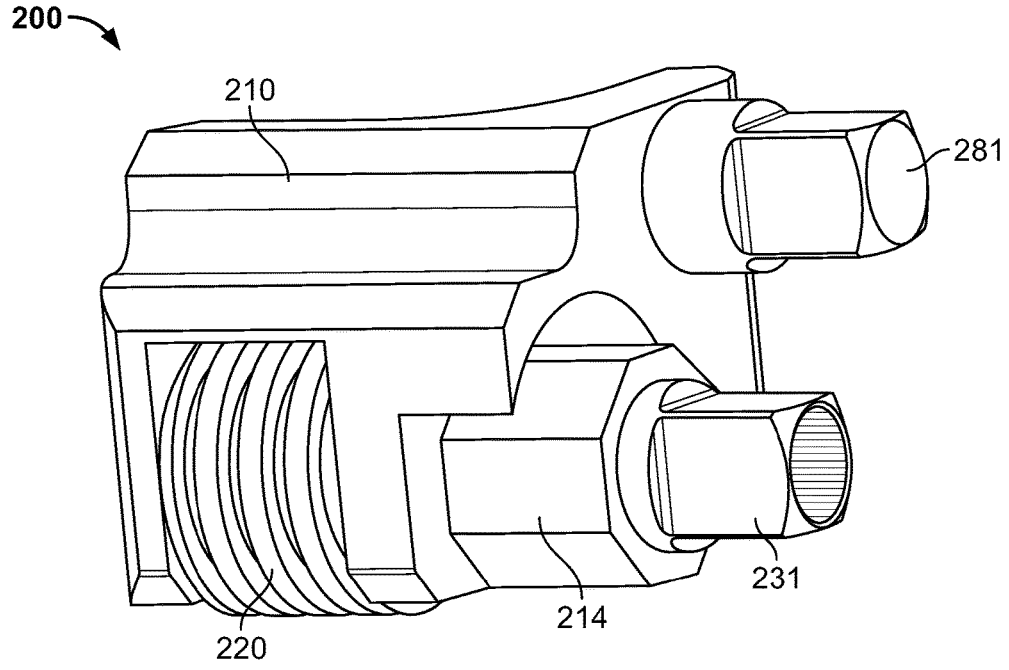

200
210
281
231
214
220

FIG. 4A

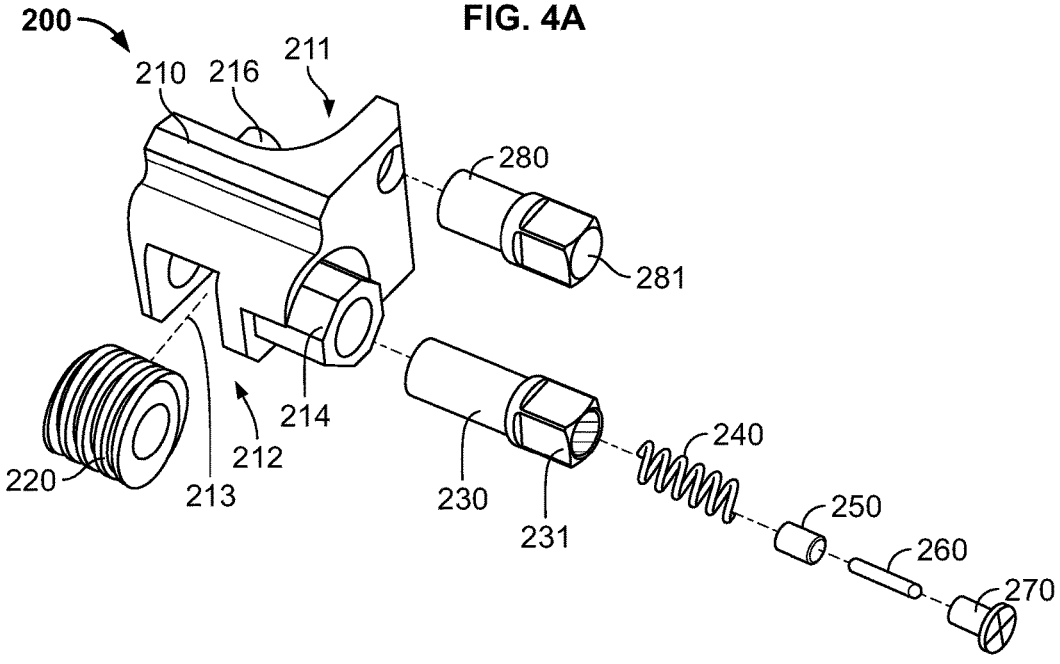

200
210
216
211
280
281
214
212
220
213
230
231
240
250
260
270

FIG. 4B

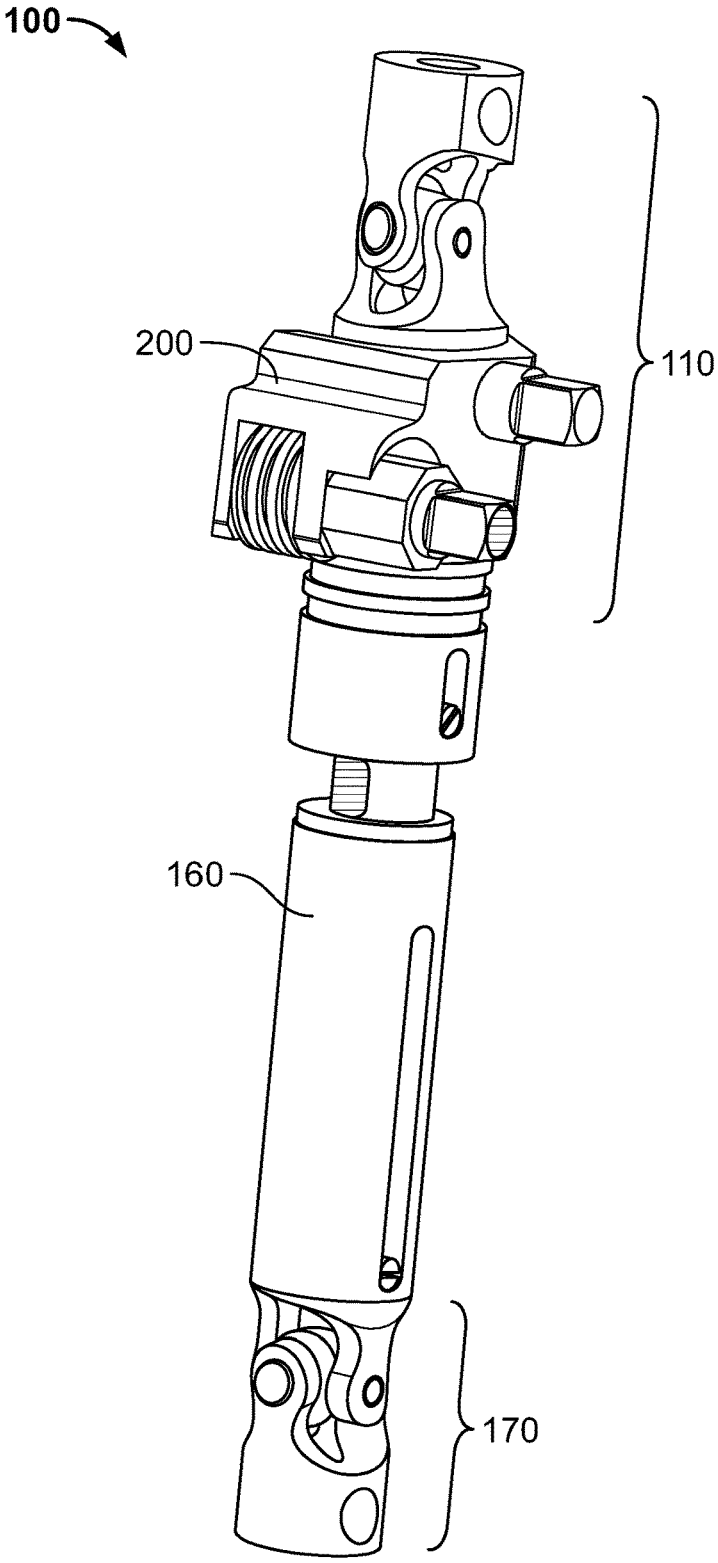


FIG. 4C

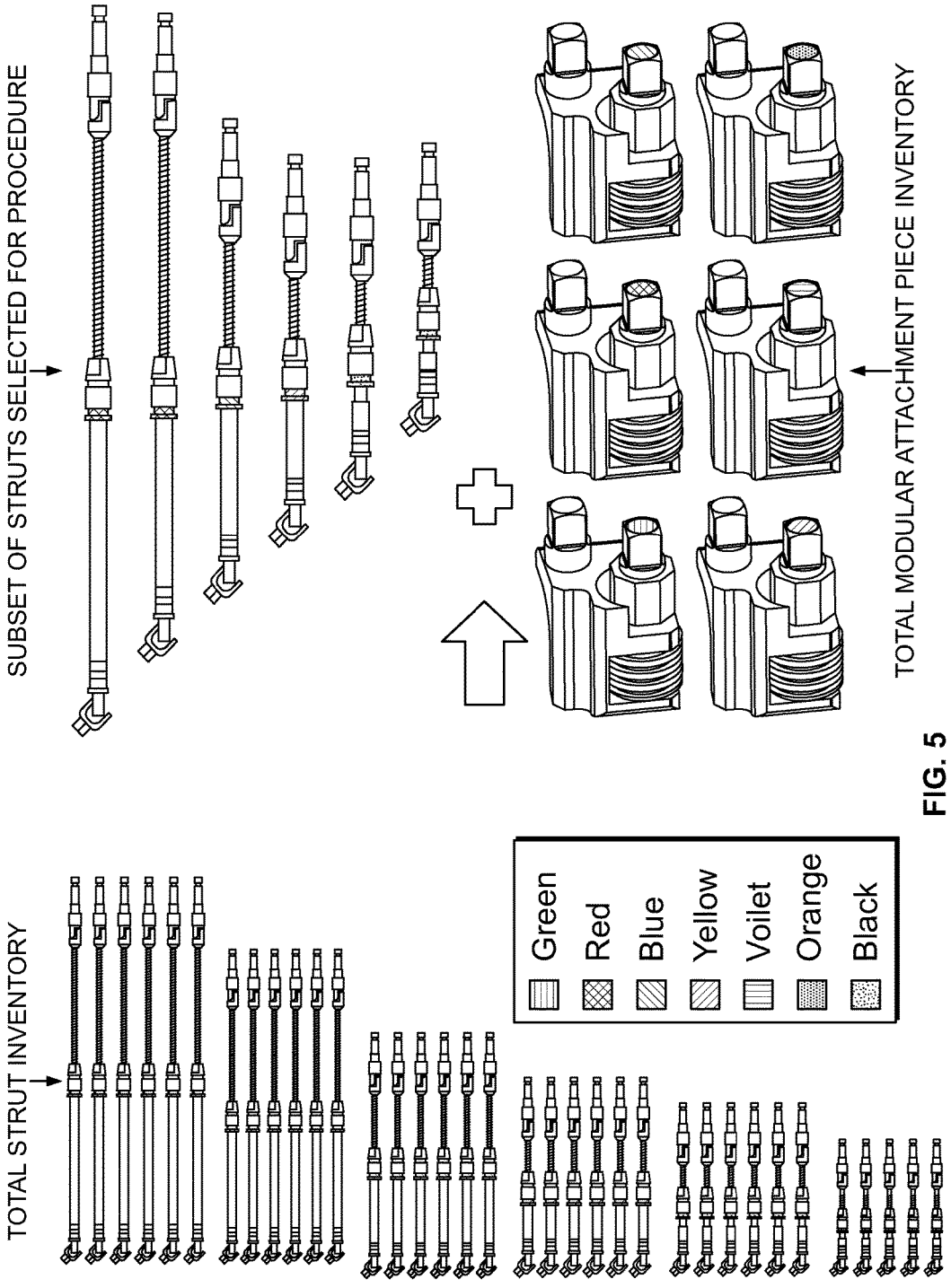

TOTAL STRUT INVENTORY
Green
Red
Blue
Yellow
Voilet
Orange
Black
SUBSET OF STRUTS SELECTED FOR PROCEDURE
TOTAL MODULAR ATTACHMENT PIECE INVENTORY

FIG. 5

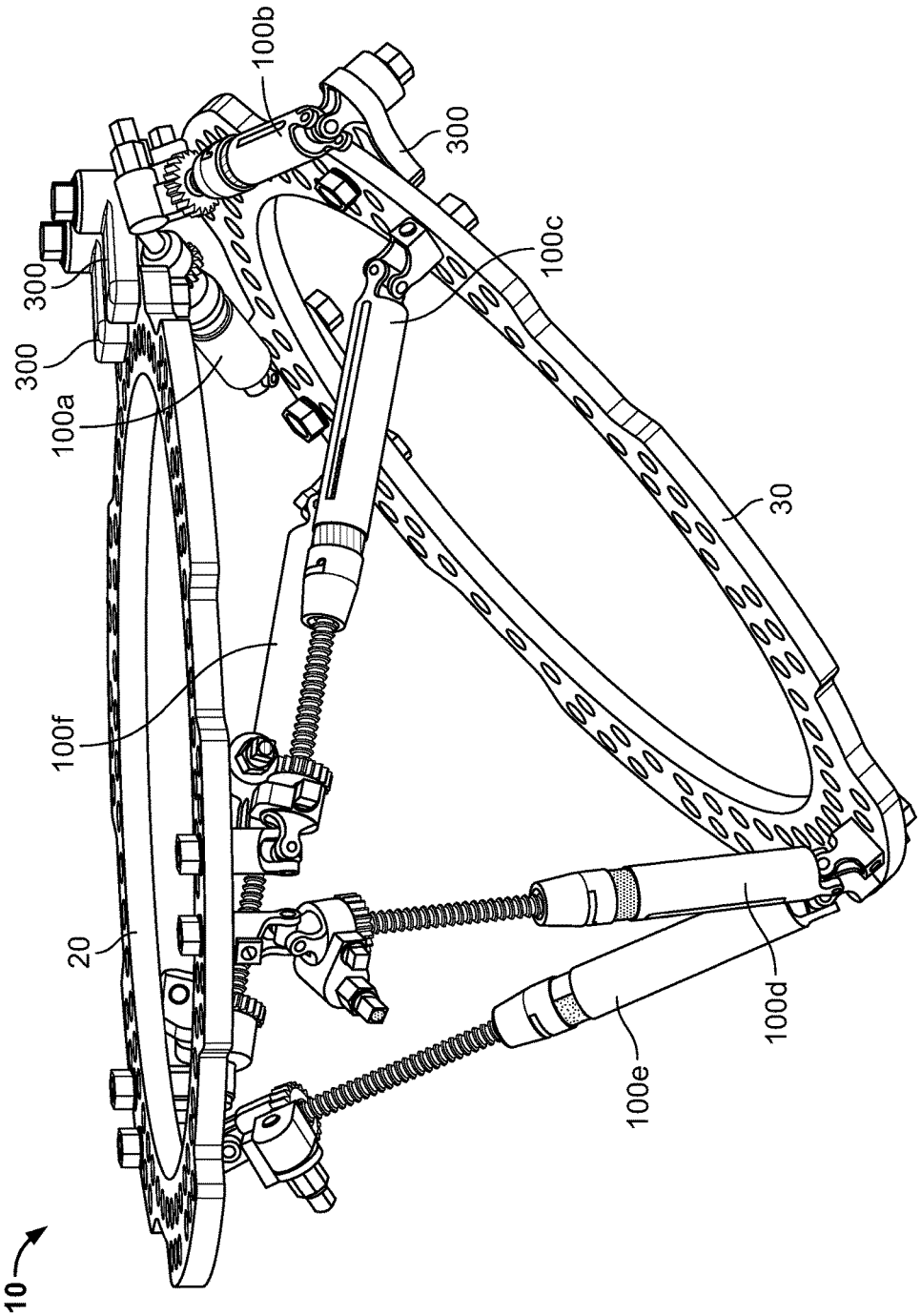


FIG. 6A

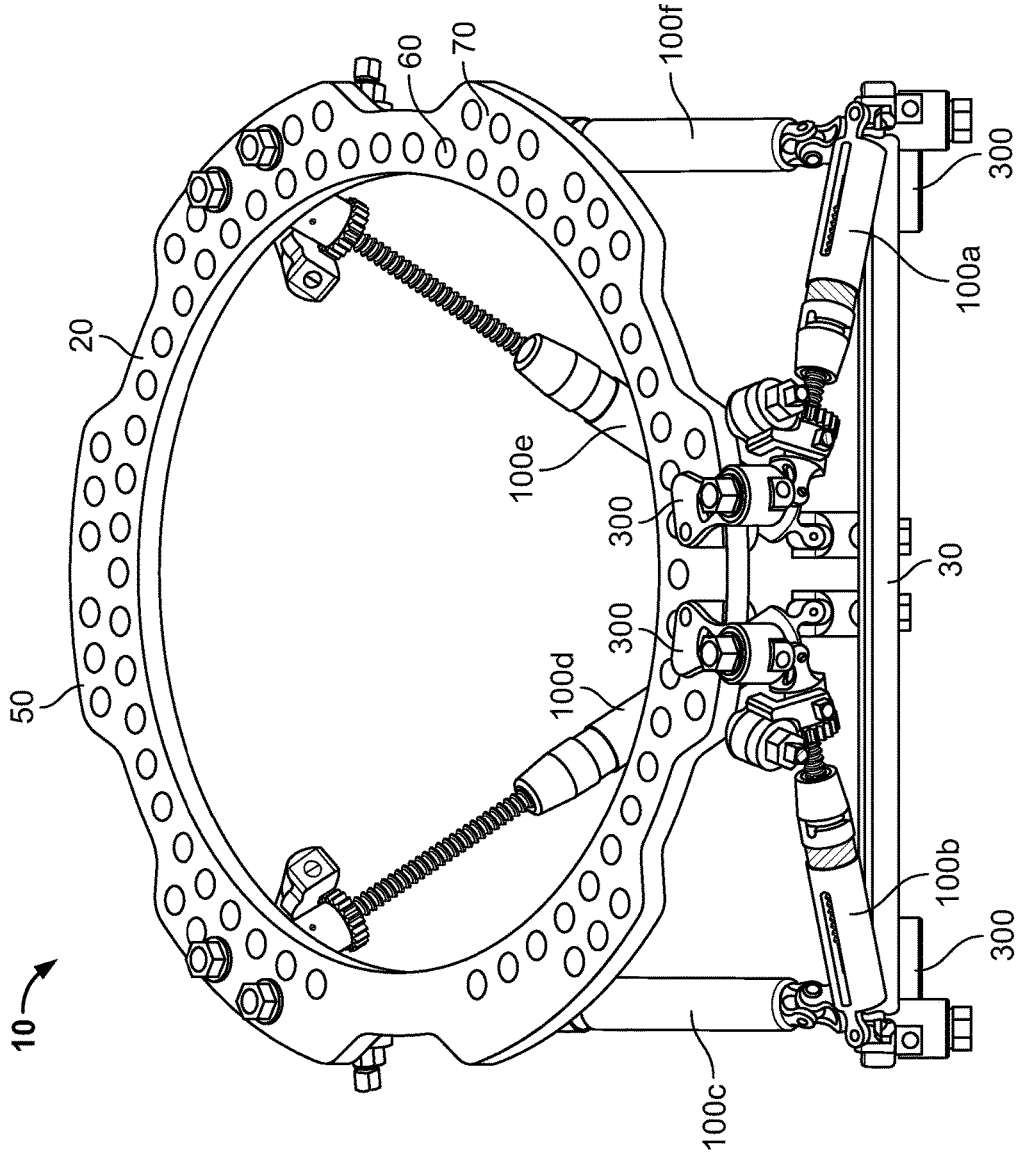


FIG. 6B

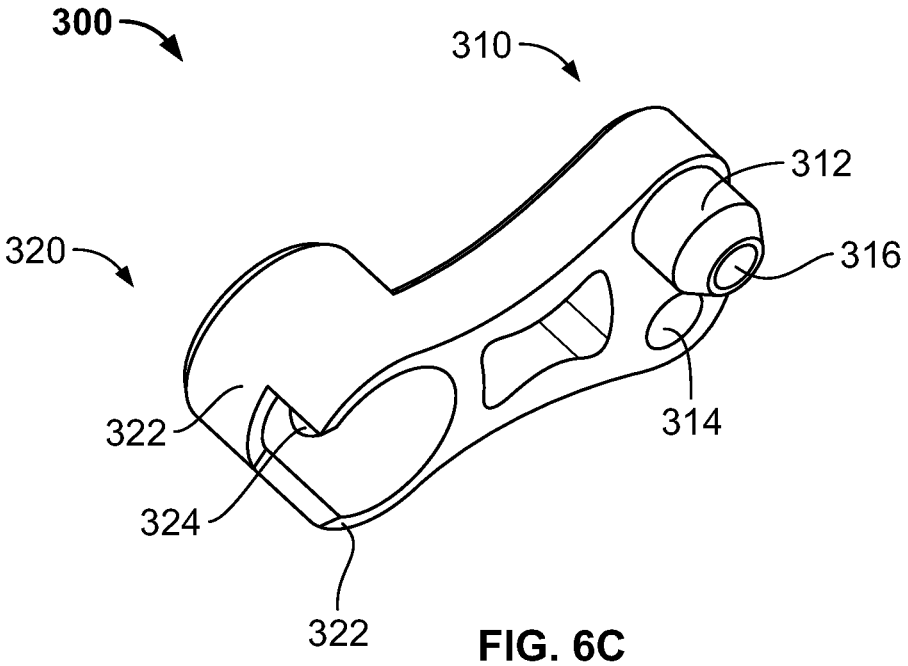


FIG. 6C

GEAR MECHANISMS FOR FIXATION FRAME STRUTS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application is a continuation of U.S. patent application Ser. No. 15/181,614 filed Jun. 14, 2016, the disclosure of which is hereby incorporated by reference herein.

BACKGROUND OF THE DISCLOSURE

[0002] The present disclosure relates to systems and components of external fixation frames. More particularly, the present disclosure relates to struts and strut components using gear mechanisms for manipulation of an external fixation frame.

[0003] Many different types of bone deformities can be corrected using external fixation systems to perform the distraction osteogenesis process. For example, an Ilizarov device or similar external fixation system may be used. Such systems generally use rings also designated as fixation plates connected by threaded rods or struts for manipulation, lengthening, angulation, rotation, and translation of deformities of bones.

[0004] As the struts are manipulated, the rings or fixation plates change positions relative to one another, causing the bones or bone segments attached to the fixation plates to change positions relative to one another, until the bone segments are in a desired position relative to one another. Fixation systems have many areas which may be improved including, for example, the ease and precision with which the fixation system may be adjusted by a user, whether a clinician or a patient.

BRIEF SUMMARY

[0005] According to a first aspect of the disclosure, an adjustable length strut includes a first joint member proximate a first end of the strut, a second joint member proximate a second end of the strut opposite the first end, and a rod member extending between the first joint member and the second joint member, the rod member including external threads. A tube member extends between the first joint member and the second joint member, the tube member including a hollow portion adapted to receive the rod member and an engagement feature adapted to engage the external threads of the rod member. An actuation mechanism is rotatably fixed to the rod member, the actuation mechanism including a plurality of gear teeth extending radially outward of a longitudinal axis of the rod member. A protrusion member may be coupled to an end portion of the rod member, the protrusion member extending substantially orthogonal to the longitudinal axis of the rod member. The protrusion member may include a collar portion substantially surrounding the end portion of the rod member, and the collar portion may be freely rotatable with respect to the end portion of the rod member. The tube member may include an elongate slot extending through inner and outer surfaces of the tube member. A portion of the protrusion member may extend through a portion of the elongate slot. The tube member may include visual indicia on the outer surface thereof adjacent the slot.

[0006] According to another aspect of the disclosure, an external fixation frame system includes a first support ring having a plurality of first apertures extending therethrough, a second support ring having a plurality of second apertures extending therethrough, and at least one telescopic strut. The telescopic strut includes a first joint member proximate a first end of the strut, the first joint member adapted to be coupled to the first support ring, and a second joint member proximate a second end of the strut opposite the first end, the second joint member adapted to be coupled to the second support ring. The telescopic strut also includes a rod member extending between the first joint member and the second joint member, the rod member including external threads. A tube member extends between the first joint member and the second joint member, the tube member including a hollow portion adapted to receive the rod member and an engagement feature adapted to engage the external threads of the rod member. An actuation mechanism is rotatably fixed to the rod member, the actuation mechanism including a plurality of gear teeth extending radially outward of a longitudinal axis of the rod member. The first joint member may include a first borehole extending along the longitudinal axis of the rod member. A first fastener may be adapted to extend through one of the first apertures in the first support ring and into the first borehole of the first joint member to rotatably fix the first joint member about the longitudinal axis of the rod member. The first joint member may include a second borehole extending substantially orthogonally to the first borehole, the second borehole adapted to receive a tool therein to prevent rotation of the first joint member about the longitudinal axis of the rod member as the first fastener is coupled within the first borehole. The second joint member may include a third borehole extending along the longitudinal axis of the rod member. A second fastener may be adapted to extend through one of the second apertures in the second support ring and into the third borehole of the second joint member to rotatably fix the second joint member and the tube member about the longitudinal axis of the rod member. The second joint member may include a fourth borehole extending substantially orthogonally to the third borehole, the fourth borehole adapted to receive a tool therein to prevent rotation of the second joint member and the tube member about the longitudinal axis of the rod member as the second fastener is coupled within the third borehole.

[0007] The external fixation frame system may also include a modular attachment member adapted to be coupled to the first joint, the modular attachment member including a worm gear adapted to engage the gear teeth of the actuation mechanism. The modular attachment member may include a bolt extending at least partially within the worm gear, the bolt being rotatably fixed with respect to the worm gear. A radiofrequency identification tag member may be positioned at least partially within the modular attachment member. The bolt may be adapted to extend along an axis substantially orthogonal to a longitudinal axis of the rod member when the modular attachment piece is coupled to the strut. The bolt may include visual indicia and the strut may include an indicator member coupled to the strut, the indicator member and the visual indicia each having a corresponding marking. The first joint member may be coupled to the first support ring by a first offset plate so that the first joint member is positioned radially outward of the first support ring and the second joint member is coupled to

the second support ring by a second offset plate so that the second joint member is positioned radially outward of the second support ring.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. **1** is a perspective view of an external fixation system according to an embodiment of the disclosure.

[0009] FIG. **2**A is a perspective view of a strut of the external fixation system of FIG. **1**.

[0010] FIGS. **2**B-C are a perspective views of the strut of FIG. **2**A with certain components omitted.

[0011] FIG. **2**D is a perspective view of an actuation mechanism of the strut of FIG. **2**A.

[0012] FIG. **3** is a perspective view of the external fixation system of FIG. **1** with modular attachment members coupled to the struts.

[0013] FIG. **4**A is a perspective view of a modular attachment member of FIG. **3**.

[0014] FIG. **4**B is an exploded view of the modular attachment member of FIG. **4**A.

[0015] FIG. **4**C is a perspective view of the modular attachment member of FIG. **4**A coupled to the strut of FIG. **2**A.

[0016] FIG. **5** is a conceptual illustration of an inventory reduction using the modular attachment members of FIG. **3**.

[0017] FIGS. **6**A-B are perspective views of the external fixation system of FIG. **3** with offset plates attached to certain struts of the system.

[0018] FIG. **6**C is a perspective view of an offset plate of FIGS. **6**A-B.

DETAILED DESCRIPTION

[0019] FIG. **1** shows an external fixation frame **10** in an assembled condition according to one aspect of the disclosure. Generally, fixation frame **10** includes a first ring **20** and a second ring **30**, with six telescopic struts **100***a-f* coupling the first ring **20** to the second ring **30**. The first ring **20** may also be referred to as a proximal ring or a reference ring, while the second ring **30** may also be referred to as a distal ring or a moving ring. In the illustrated embodiment, each strut **100***a-f* includes a threaded portion that may thread into or out of a tube portion, for example by interaction with quick release mechanism **130**, to decrease or increase the length, respectively, of the telescopic strut. Each end of each strut **100***a-f* may be coupled to the first ring **20** and second ring **30** via a joint mechanism, such as a ball joint, a constrained hinge joint, or a universal joint as illustrated. The use of universal joints on each end of the strut provides for six degrees of freedom of motion of the external fixation system **10**. It should be understood that although the disclosure is generally described in the context of closed circular rings, the concepts described herein may apply with equal force to other types of rings, such as open rings and/or U-shaped rings.

[0020] In external fixation system **10**, telescopic struts **100***a-f* are used to reduce fractures and correct deformities over time. Patients correct the deformities by prescribed adjustments of the struts **100***a-f*. The lengths of the struts **100***a-f* are adjusted over time to change the position and orientation of the two rings **20**, **30** with respect to one another, which in turn repositions and reorients the bone fragments, with a goal of correcting the bone deformity. The adjustment of the external fixator **10** should strictly comply with the predetermined correction plan.

[0021] Rings **20** and **30** of external fixation system **10** may include a plurality of extension tabs **50**. In the illustrated example, each ring **20** and **30** includes six extension tabs **50** spaced circumferentially around the perimeter of the respective rings, although more or fewer may be suitable depending on the particular components of the fixation system. In addition to what is described directly below, extension tabs **50** may help increase the cross-sectional area of rings **20**, **30** and thus provide for increased stiffness of the rings.

[0022] With this configuration, each ring **20**, **30** includes a first inner circumferential row of holes **60** and a second outer circumferential row of holes **70**. As illustrated, the second outer circumferential row of holes **70** may be only positioned on the plurality of extension tabs **50** on the rings **20** and **30**. It should be understood that although the second outer circumferential row of holes **70** is shown in FIG. **1** as being positioned solely on extension tabs **50**, top ring **20** and/or bottom ring **30** may contain two complete rows of holes, for example with a completely circular (or nearly completely circular) geometry. The use of extension tabs **50**, compared to two full circumferential rows of holes, may help reduce overall bulk of rings **20**, **30** and also provide for intuitive strut placement for surgical personnel. The completely circular version of rings **20**, **30** with two full (or nearly full) rows of circumferential holes may be particularly suited for relatively small diameter rings, although indentations or other features may be introduced to provide an intuitive interface for strut placement by surgical personnel. Further, in the illustrated embodiment, the first and second circumferential rows of holes **60** and **70** are positioned so that the first row of holes **60** does not align radially with the second row of holes **70**. In other words, the first row of holes **60** has a staggered configuration with respect to the second row of holes **70**. The additional hole options may also be utilized for connecting other components, such as fixation pins to couple the rings **20**, **30** to the respective bone fragments. Still further, the staggered configuration of holes between the first and second rows **60**, **70** may also help prevent interference between components attached to nearby holes, for example such as a strut **100***a-f* positioned in a first hole and a fixation pin or other fixation member attached to an adjacent or nearby second hole. For example, a relatively thin wire extending radially from one of the holes in the first circumferential row **60** may not radially interfere with a hole positioned in the second circumferential row **70** because of the radial staggering. It should be understood that the size of the tabs **50** may increase or decrease depending on the diameter of the rings **20** and **30**, with greater diameter rings **20** and **30** having larger tabs **50** with more holes **70** compared to smaller diameter rings. For example, the illustrated tabs **50** include six holes **70**, and a smaller ring may include smaller tabs with four holes each, for example.

[0023] FIG. **2**A illustrates a perspective view of one telescopic strut **100** from the external fixation system **10** of FIG. **1**. It should be understood that the components of struts **100***a-f* may be identical to one another, although some struts **100***a-f* may have different sizes than other struts **100***a-f* and may include different indicia, such as colors or markings for identification purposes, as described in greater detail below. For purposes of this disclosure, the term proximal refers to the top of the strut **100** in the orientation of FIG. **2**A, and the term distal refers to the bottom of the strut **100** in the

orientation of FIG. **2**A. The proximal end portion of strut **100** may include a first joint **110**, which is shown in this example as a universal joint. Joint **110** may include a proximal portion **111**, which may include a first aperture **112** aligned substantially parallel with the longitudinal axis of strut **100** and a second aperture **113** aligned substantially transverse or orthogonal to the first aperture **112**. The first aperture **112** may be configured to receive a fastener that passes through a hole in proximal ring **20** to secure the proximal portion **111** of joint **110** to proximal ring **20**. The fastener may be connected so that the proximal portion **111** does not rotate relative to proximal ring **20**. The second aperture **113** may be configured to receive a portion of a tool to prevent proximal portion **111** from rotating, for example while a fastener is being screwed into or otherwise inserted into first aperture **112**. Joint **110** may also include a distal portion **115** with a first aperture **116** and a second aperture **117**, the first and second apertures **116**, **117** being aligned substantially transverse and/or orthogonal to one another and to the longitudinal axis of strut **100**. First and second apertures **116**, **117** may be used as attachment points for attaching additional components to strut **100**, which is explained in greater detail below in connection with FIGS. **4**A-C.

[0024] Still referring to FIG. **2**A, strut **100** may include additional components including an actuation mechanism **120**, a quick-release mechanism **130**, a strut identifier **140**, a threaded rod **150** (not visible in FIG. **2**A), a tube **160**, and a second joint **170**. As noted above, the effective length of strut **100**, which may be thought of as the distance between the proximal end and distal end of strut **100**, may be adjusted by threading the threaded rod **150** of strut **100** into or out of tube **160** through interaction with quick-release mechanism **130**.

[0025] FIG. **2**B illustrates strut **100** with tube **160** omitted for clarify of illustration. FIG. **2**C illustrates strut **100** with tube **160**, as well as quick-release mechanism **130**, strut identified **140**, and second joint **170** omitted for clarity of illustration.

[0026] Actuation mechanism **120** is shown isolated in FIG. **2**D. Actuation mechanism **120** may be generally a short, cylindrical component with a plurality of ridges or gear teeth **122** extending around the circumference of actuation mechanism **120**. The actuation mechanism **120** may be rotatably coupled to threaded rod **150** so that rotation of actuation mechanism **120** causes a corresponding rotation of threaded rod **150**. For example, actuation mechanism **120** may have a channel **124** extending therethrough, with an extension **126** in channel **124** that mates with a corresponding extension in threaded rod **150**, so that rotation of actuation mechanism **120** causes rotation of threaded rod **150**. It should be understood that the threaded rod **150** may rotate with respect to the first joint **110**, the first joint **110** and second joint **170** being rotatably fixed to rings **20** and **30**, respectively. The proximal surface of actuation mechanism may include a plurality of divots of grooves **128** sized to accept a ball which is biased into the groove via a spring. The spring may have a first end in contact with a distal surface of first joint **110**, with a distal end pressing a ball into the proximal surface of actuation mechanism **120**. With this configuration, an amount of force is required to rotate actuation mechanism **120** to overcome the force of the spring pushing the ball into the divot **128**. As rotation of actuation mechanism **120** continues, the ball will eventually be positioned adjacent an adjacent groove **128**. As rotation continues further, the spring will force the ball into the next groove **128** when the ball is aligned with the groove **128**, causing a tactile and/or audible click. Each "click" may correspond to a particular axial change in length so that a user knows, for example, that four "clicks" correspond to 1 mm of length adjustment. Similar "clicking mechanisms" are described in greater detail in U.S. Pat. No. 8,834,467, the contents of which are hereby incorporated by reference herein.

[0027] Referring now to FIGS. **2**A-B, quick-release mechanism **130** may generally take the form of an outer housing that surrounds a portion of threaded rod **150**. Quick-release mechanism **130** may have a disengaged state and an engaged state. In the disengaged state, threaded rod **150** may be capable of moving into or out of tube **160** without rotation of the threaded rod **150**, for quick adjustments of the length of strut **100**, which may be useful for example while initially assembling the fixation frame **10**. Rotating the quick-release mechanism **130** may transition the quick-release mechanism **130** into the engaged state, in which threated rod **150** may only move axially into or out of tube **160** via rotation of the threaded rod **150**. The mechanism for keeping the quick-release mechanism **130** in the engaged state may include a ball or other feature that is forced between adjacent threads of threaded rod **150** so that axial translation of the threaded rod **150** is only possible via rotation, so that rotation of threaded rod **150** axially moves the threaded rod **150** into the tube **160**, without requiring the tube **160** to have internal threading. It should be understood that the quick-release mechanism **130** is not a necessary component of strut **100**, and may be omitted from strut **100** if desired. If quick-release mechanism **130** is omitted, it may be preferably to include internal threads on tube **160** to correspond to external threads on threaded rod **150**. Further details of quick-release mechanisms have been described elsewhere, including, for example, in U.S. Pat. No. 9,101,398, the contents of which are hereby incorporated by reference herein.

[0028] A strut identifier **140** may be coupled to strut **100** at any desired location, for example between the quick-release mechanism **130** and the tube **160**. Strut identifier **140** may take the form of a clip or any other suitable shape that can be quickly and securely clipped onto the strut **100** and removed from strut **100**. For example, in the illustrated embodiment, strut identifier **140** is a "C"-shaped clip that is flexible enough to open for easy connection to strut **100**, but rigid enough that the strut identifier **140** is not easily removed from strut **100** without intentional application of force. Strut identifier **140** may have a color or other identifier such as a number, letter, or shape pattern. Each strut **100***a-f* may have a strut identifier **140** that is structurally similar or identical, but that each has easily distinguishable indicia, such as different colors, different numbers, etc. Strut identifiers **140** may be used so that each strut **100***a-f* is easily distinguished from one another, and so that other matching indicia may be provided on other components, described in greater detail below, that may be added onto struts **100***a-f* so that each additional component may be easily matched with the correct corresponding strut **100***a-f*. Strut identifier **140** may also function to prevent unintentional disengagement of the quick release mechanism **130**.

[0029] Referring again to FIG. **2**A, tube **160** may be a generally hollow cylindrical tube configured to allow

threaded rod **150** to move axially into or out of tube **160** to decrease or increase the effective length of strut **100**, respectively. As noted above, such axial movement may be produced by rotation of threaded rod **150** when the quick release mechanism **130** is in the engaged position, so that the threads of the threaded rod **150** engage the ball or other mechanism within the quick release mechanism **130**. If omitting the quick release mechanism **130**, the tube **160** may include internal threads that mate directly with the external threads of the threaded rod **150**. A slot **162** may extend along part of the length of the tube **160**, the slot **162** opening the hollow inside of the tube **160** to the exterior of the tube. The slot **162** may have a width slightly larger than the width of button **152**. Referring now to FIGS. **2**B-C, the distal end of threaded rod **150** may include a button **152** coupled to a collar **154**, the collar **154** surrounding the distal end of threaded rod **150**. Collar **154** may be positioned with a groove at the distal end of threaded rod **150** so that collar **154** may rotate freely around the axis of the strut **100** while being axially fixed with respect to the threaded of **150**. Referring again to FIG. **2**A, as threaded rod **150** is threaded into or out of tube **160**, button **152** travels up or down the slot **162** of the tube **160**, which is possible because button **152** and collar **154** are free to rotate with respect to threaded rod **150**. Tube **160** may include indicia, such as hash marks and/or measurements, on or adjacent to slot **162**. The position of button **152** along slot **162** may correspond to the effective length of the strut **100**, so that a user can easily determine the effective length of the strut based on the indicia adjacent to the position of button **152** at any particular time.

[0030] Referring still to FIG. **2**A, the distal end of tube **160** may include two extensions that form a proximal portion **171** of second joint **170**. Second joint **170** may include a distal portion **175** that, together with proximal portion **171** and an internal mechanism form a universal joint similar to first joint **110**. Distal portion **175** may include a first aperture **176** that is aligned substantially parallel with strut **100**. Aperture **176** may be adapted to receive a fastener therein to couple second joint **170** to distal ring **30**. The fastener may be a screw or other type of fastener, and may be adapted to tightly couple the second joint **170** to the distal ring **30** so that the second joint **170** does not rotate with respect to distal ring **30**. With this configuration, the slot **162** of tube **160** may be positioned outward (away from the center of proximal and distal rings **20**, **30**) so that the position of button **152** with respect to indicia on tube **160** may be easily read at all times. The distal portion **175** of second joint **170** may include a second aperture **177** aligned substantially orthogonal to first aperture **176** and adapted to receive a tool to keep second joint **170** from rotating, for example while a fastener is screwed into first aperture **176**. This may help ensure, for example, the slot **162** of tube **160** is facing away from the center of the rings **20**, **30** as the strut **100** is tightened to the rings **20**, **30**. It should also be understood that in some prior art devices, rotational freedom of the strut was provided by loosely coupling the joint(s) to the ring(s) so that the joints themselves could swivel. In the present disclosure, the rotational degree of freedom is provided by the ability of threaded rod **150** to rotate, while the tight attachment of the first joint **110** and second joint **170** to the first ring **20** and second ring **30** provides for a more stable connection.

[0031] It should be understood that strut **100** as described above may be designed for manual actuation, for example by a user gripping the actuation mechanism **120** with his hand and manually rotating the actuation mechanism **120**. However, it should be understood that a tool may be used, either directly on actuation mechanism **120** or with intervening components, to adjust the length of strut **100**. For example, FIG. **3** illustrates the external fixation system **10** of FIG. **1** with completely identical components, with the exception that each strut **100***a-f* includes a modular attachment piece **200** coupled to a corresponding strut **100***a-f*. As is described in greater detail below, modular attachment piece **200** provides a variety of benefits, including a simple way to allow a user to adjust struts **100***a-f* with a tool rather than through manual adjustment.

[0032] Attachment piece **200** is shown in greater detail in FIGS. **4**A-B. Generally, attachment piece includes a main body **210** having a first contoured side **211** and a second side **212** defining a recess **213**. The first contoured side **211** is adapted to be positioned on strut **100** adjacent the actuation mechanism **120**. A worm-type gear **220** is adapted to be positioned within recess **213** of second side **212**. When attachment piece **200** is attached to strut **100**, teeth of the worm gear **220** mesh with gear teeth **122** of actuation mechanism **120**, so that rotation of worm gear **220** causes rotation of actuation mechanism **120**.

[0033] Body **210** of attachment pieces **200** may include a counter-torque feature **214**, which may be a piece solidly coupled to, or integrally formed with, body **210** and which may include at least one flat side, for example a hexagonal or octagonal shape. Counter-torque feature **214** may include a bore therethrough leading to recess **213**, so that when worm gear **220** is positioned within recess **213**, a bolt **230** may be inserted into counter-torque feature **214**, with a shaft of bolt **230** extending through worm gear **220** and into an aperture of body **210** on the opposite side of the recess **213** from counter-torque feature **214**. When the bolt **230** is assembled to the worm gear **220** and body **210**, rotation of the bolt **230** is translated to the worm gear **220**. Further, when assembled to the body **210**, a head **231** of the bolt **230** may protrude from the counter-torque feature **214**. The head **231** of bolt **230** may also include at least one flat surface, such as a square shape, that corresponds to a shape of a recess in a tool, such as a manual or automatic screwdriver type tool. The head **231** of bolt **230** may also include an aperture adapted to receive additional components. For example, in one embodiment, a spring **240** may be situated within the recess of head **231**, with an abutment **250** abutting one end of the spring **240**. Abutment **250** may be generally any structure sized to fit within the recess of head **231** and to provide a surface against which an end of spring **240** can press, without the abutment **250** getting caught within the internal area of spring **240**. The other side of abutment **250** is adapted to provide a surface to bias an RFID tag **260** away from the head **231** of bolt **230** and toward end cap **270**. Although described in terms of an RFID tag **260**, other suitable near-field wireless identification mechanisms may be used instead of an RFID tag. End cap **270** may take any suitable form and is adapted to be positioned within the recess of the head **231** of bolt **230** and to be secured thereto in order to keep the other components, including spring **240**, abutment **250**, and RFID tag **260**, within the head **231** of bolt **230**. End cap **270** may also have an identifying feature, such as a color, number, or other symbol. The purpose of RFID tag **260** and the identifying feature of end cap **270** is

discussed in greater detail below in connection with the description of the operation of strut **100** with attachment piece **200** attached thereto.

[0034] Attachment piece may include a fastener **280** which may be in the form of a bolt or screw, for example. Fastener **280** includes a head **281** which may include at least one flat surface, such as a square, to mate with an end of a driving tool such as a screwdriver. Fastener **280** may be adapted to be received through an aperture leading to the contoured side **211** of body **210**. In order to assemble attachment piece **200** to strut **100**, the components of attachment piece **200** other than fastener **280** are first assembled together. A first protrusion **216** of body **210** is inserted into aperture **116** of the first joint **110** of strut **100** (see FIG. **2**A). In this position, the teeth **122** of actuation mechanism **120** will mesh with teeth of worm gear **220**. Further, in this position, the contoured side **211** of body **210** corresponds to the contoured surface of the distal portion **115** of first joint **110**. The fastener **280** is then inserted into its corresponding aperture in body **210**, and further into aperture **117** of first joint **110**. A screwdriver may be positioned on the head **281** of fastener **280** to screw the fastener into aperture **117**, firmly locking the attachment piece **200** to strut **100**. The strut **100** with attachment piece **200** coupled thereto is shown in FIG. **4**C.

[0035] With strut **100** coupled to rings **20**, **30** of external fixation system **10**, and attachment piece **200** coupled to strut **100**, the length of strut **100** may be adjusted using a manual or automated tool. Examples of such tools are described in greater detail in U.S. Patent Application Publication No. 2016/0113681 and Provisional Patent Application No. 62/203,179 titled filed Aug. 10, 2015 and titled "Manual Smart Tool with Clicking Mechanism," the disclosures of which are both hereby incorporated by reference herein. Such driver tools may be motorized or manual, and may include electronic and power components. For example, in one embodiment, the driver tool includes a counter-torque feature that has a corresponding shape (e.g. hexagonal or octagonal) to the counter-torque feature **214** of attachment piece **200**. With the counter-torque portion of the driver tool coupled to the counter-torque mechanism **214**, a secure connection between the driver tool and the attachment piece is provided. An internal rotating member of the driver may have a corresponding shape to the head **231** of bolt **230** (e.g. square) and be positioned so that, once the counter-torque feature of the driver is positioned over the counter-torque mechanism **214** of the attachment piece, the rotating member of the driver is positioned over the head **231** of bolt **230**. At this point, manual rotation of a handle of the driver will cause bolt **230** to rotate, in turn causing worm gear **220** to rotate, actuation mechanism **120** to rotate, and the strut **100** to lengthen or shorten. If the driver tool is motorized, a button may be pressed on the driver to cause the same movement as the manual driver. Whether the driver tool is motorized or not, it may include an RFID reader near the portion that mates with the head **231** of bolt **230**. If the driver tool is motorized, the driver tool may only rotate if the driver tool recognizes that it is attached to the correct strut via recognition of the correct RFID tag **160**. If the driver tool is manual but includes electronics, the driver tool may display a confirmation that the driver tool is corrected to a particular or desired strut **100**. As should be clear from the above description, spring **240** helps push the RFID tag **260** close to the end cap **270** to minimize the distance between the RFID tag **260** and an RFID reader of the driver tool when the driver tool is positioned over the head **231** of the bolt **230**.

[0036] Providing attachment piece **200** as a modular item may provide a number of benefits compared to providing the strut **100** with attachment piece **200** integrally coupled to the strut **100**. First, it becomes possible to easily manipulate the length of strut **100** manually by hand with actuation mechanism **120**, if desired. Second, it should be understood that the exact size and type of struts to be attached to external fixation frame **10** may not be known until the just prior to the struts being coupled to the rings **20**, **30** of external fixation system **10**. For example, if an external fixation system **10** is intended for use with six total struts, and up to six available strut sizes are available for use, a total of thirty six struts may be provided in a kit along with the other components of fixation frame **10**. In this case, thirty-six struts will be required in order to cover any possible combination of the six struts chosen for external fixation frame. If attachment piece **200**, along with the particular RFID tag **260** for a given attachment piece **200**, was provided integrally formed with or otherwise previously coupled to strut **100**, then in this example thirty-six attachment pieces **200** with thirty-six corresponding RFID tags **260** would be required. However, as shown in FIG. **5**, the use of a modular attachment piece **200** allows the use of only six attachment pieces **200** total (in a six-strut system), despite the need for thirty-six struts. It should be understood that this may be a significant reduction in inventory requirements and corresponding expenses. Still further, in the case of a malfunction of any electronics in either the attachment piece **200** or a screwdriver tool, the attachment pieces **200** may simply be removed and the correction may continue on a manual basis.

[0037] Since each RFID tag **260** should be unique with respect to the other RFID tags **260** in a set of modular attachment pieces **200**, it is preferable that the marking or other indicia on each end cap **270** coupled to each bolt **230** matches or otherwise corresponds to a particular strut identifier **140**. For example, each of the six positions for a strut on the fixator system may be represented by a color. In one example, a first position for a strut which may be labelled "Position **1**" may correspond to a green identifier. Once it is determined that a particular strut **100**, for example "Strut **1**" is to be used Position **1**, a green strut identifier **140** may be snapped onto Strut **1**, either before or after attaching Strut **1** to the frame in Position **1**. Once Strut **1** is in Position **1** with green strut identifier **140** attached to Strut **1**, an attachment piece **200** with a corresponding green-colored end cap **270** may be attached to Strut **1**. Because the green identifier corresponds to Position **1**, any later identification of Strut **1** will alert a user (for example via a driving tool) that the adjustment for the strut in Position **1** should be made only to Strut **1**. During the correction procedure, a user may be instructed to couple a motorized driver tool to "Strut **1**" for a scheduled length change. The instructions may include a corresponding green-colored indicator so that patient knows exactly which strut needs to be adjusted. The RFID reader in the driver tool may provide for confirmation upon connection to "Strut **1**" and reading the RFID tag **260** that corresponds to "Strut **1**." These steps help ensure that a patient is unlikely or unable to adjust the length of a strut other than the particular strut length adjustment called for by the prescribed strut length adjustment plan.

[0038] A number of additional benefits may arise from the positioning of the adjustment mechanism **120** and/or the modular attachment pieces **200** just distal to the first joint **110**. Since external fixation system **10** may often be used for correcting deformities in bones in the lower extremities, a patient may find it generally difficult to reach down to adjust the length of a strut, depending on where the adjustment mechanism is attached. The disclosed adjustment mechanism **120** is relatively proximal, or in other words closer to the "top" of the external fixation system **10** compared to other components of the fixation system **10**. Thus, it may be easier for the patient to reach down to activate adjustment mechanism **120** compared to an adjustment mechanism that is closer to the middle of a strut or even further distal to the middle of the strut. IT should be understood that, even when the struts **100** are lengthened, the adjustment mechanism **120** stays in a substantially constant position with respect to the patient's upper body. Further, if a medical image such as an X-ray is to be taken, the modular attachment pieces **200** may be removed temporarily to provide a better view of the patient's tissue. Often, a bone resection is made in a location that is generally near the middle of the space between rings **20**, **30**, so it may be beneficial to reduce bulk of struts **100** or related components near the middle of the system **10**, since that area may be of highest interest in an X-ray or other image. In other cases, the bone resection is formed in a position that is relatively close to first ring **20**. In those cases, struts **100** could be inverted from how they are shown in the Figures, with the attachment piece **200** being positioned closer to the distal ring **30** rather than close to the proximal ring **20** for enhanced visibility during X-ray or other imaging procedures.

[0039] The interaction between the worm gear **220** of attachment piece **200** and the actuation mechanism **120** may provide additional benefits. For example, the gear ratios between the worm gear **220** and the actuation mechanism **120** may be controlled to result in a desired torque to change the length of the struts. Further, the gear ratio may provide greater accuracy compared to a traditional strut actuation mechanism including, for example, a screw driver tool that is coupled to a strut along the strut axis where one revolution of the tool results in one revolution of the strut. In such a traditional actuation mechanism, if the tool is rotated too much or too little, there is a one-to-one correlation between the error imparted onto the strut revolution. With an appropriate gear ratio chosen for the worm gear **220** and the actuation mechanism **120**, such an error can be reduced if one revolution of the worm gear **220** produces less than one revolution of the actuation mechanism **120**, reducing the effect of errors in rotation of the tool.

[0040] In some deformity corrections using external fixation system **10** (or other similar systems), in order to correct a bone deformity, one or more struts **100***a-f* will need to be adjusted to move one portion of top ring **20** very close to one portion of bottom ring **30**. However, if the top of a strut **100** is attached directly to top ring **20** and the bottom of that strut **100** is attached directly to bottom ring **30**, there may be a significant amount of structure of strut **100** limiting how close the two rings **20**, **30** may be able to get to one another. In order to help solve that problem, one or more offset plates **300** may be used. FIGS. **6**A-B illustrate external fixation frame **10** with struts **100***a-f* and six corresponding attachment pieces **200**, with both the proximal and distal ends of struts **100***a* and **100***b* each attached to top ring **20** and bottom ring **30** via an offset plate **300**, which is shown in greater detail in FIG. **6**C.

[0041] Referring now to FIG. **6**C, offset plate may include a first end **310** and a second end **320**. The first end **310** may be configured to couple to one of the rings **20**, **30**, and the second end **320** may be configured to couple to an end of a strut **100**. In particular, the first end **310** may include an extension **312** and an aperture **314**. Extension **312** may be generally cylindrical and shaped to extend into or through an aperture in one of the rings **20**, **30**. Extension **312** may also include a borehole **316** so that a fastener can pass into an aperture of the ring **20**, **30** in which the extension **312** is positioned, the fastener threading into or otherwise fastening the offset plate **300** to the corresponding ring **20**, **30**. It should be understood that, instead of inserting protrusion **312** into a ring **20**, **30**, a fastener may be inserted through a ring hole **20**, **30** and into aperture **314** to bolt or otherwise secure offset plate **300** to the corresponding ring **20**, **30**.

[0042] When the first end **310** of offset plate **300** is coupled to a ring **20**, **30**, the second end **320** extends radially outward of the ring **20**, **30**. The second end **320** of offset plate **300** may include a substantially cylindrical extension **322** having a borehole **324** extending along a longitudinal axis of the extension **322**. The cylindrical extension **322** of the offset plate **300** may include a substantially circular rim that defines a generally cylindrical recess, which may be open (as is shown in FIG. **6**C) or which may otherwise fully circumscribe borehole **324**. With the first end **310** of offset plate **300** coupled to one of the rings **20**, **30**, the aperture **112** in the proximal portion **111** of first joint **110** is lined up adjacent the borehole **324**, with the proximal portion **111** of first joint **110** generally sitting in contact with the circular rim of extension **322**, and the aperture **113** being accessible through the open portion of the recess defined by the circular rim. It should be understood that, since the proximal portion **111** of the first joint **110** is substantially identical to the distal portion **175** of the second joint **170**, the method of connection the second joint **170** to an offset plate **300** is substantially the same as described in connection with the first joint **110**. Although FIGS. **6**A-B illustrate that the first and second joints **110**, **120** of struts **100***a* and **100***b* are all coupled to offset plates **300**, it should be understood that one end of a strut **100** may be coupled to one of the rings **20**, **30** directly while the other end is coupled to the other of the rings **20**, **30** via offset plate **300**.

[0043] With the use of one or more offset plates **300** as described above, the structure of the strut **100** coupled to the offset plate(s) **300** is moved out of radial alignment with the structure of the rings **20**, **30**. As can be seen particularly well in FIGS. **6**A-B, this allows for the rings **20**, **30** to be positioned closer to one another than would be possible if all struts **100** were directly connected to the top ring **20** and bottom ring **30**. This allows for an additional range of motion of the top ring **20** relative to the bottom ring **30** which may not be otherwise achievable. In other words, the closest ring-to-ring distance may be determined by the maximum angle of the joint (e.g. universal joint **110** or **170**) at which the struts angle and/or pivot. If a strut is connected directly to a ring, it may have a first maximum pivot angle at that location. If the joints are positioned in between the two rings and are positioned a certain distance from the adjacent ring, the range of angulation of the strut will be limited. However, if the joint pivot points are moved radially

outward and out of the way so that they are beyond the rings, the struts are able to angulate a greater degree which may result in closer possible ring-to-ring distance.

[0044] Although the invention herein has been described with reference to particular embodiments, it is to be understood that these embodiments are merely illustrative of the principles and applications of the present invention. For example, features described in relation to one particular embodiment may be combined with features of other embodiments described herein. It is therefore to be understood that numerous modifications may be made to the illustrative embodiments and that other arrangements may be devised without departing from the spirit and scope of the present invention as defined by the appended claims.

1. An external fixation frame system, comprising:

a first support ring extending along a first ring plane and having a plurality of first apertures extending through the first support ring in a direction orthogonal to the first ring plane;

a second support ring extending along a second ring plane and having a plurality of second apertures extending through the second support ring in a direction orthogonal to the second ring plane;

a plurality of telescopic struts each having a first joint proximate a first end of the strut and a second joint proximate a second end of the strut, wherein the plurality of struts can be lengthened to change a distance between the first joint and the second joint; and

a first offset plate having a first end adapted to couple to one of the first apertures of the first support ring, and a second end adapted to receive the first end of one of the telescopic struts, the second end of the first offset plate being positioned radially outward of the first support ring when the first end of the first offset plate is coupled to the first support ring,

wherein the first ends of the telescopic struts are adapted to couple to either (i) the first support ring via one of the first apertures directly, or (ii) the second end of the first offset plate when the first end of the first offset plate is coupled to the first support ring.

2. The system of claim **1**, further comprising a second offset plate having a first end adapted to couple to one of the second apertures of the second support ring, and a second end adapted to receive the second end of one of the telescopic struts, the second end of the second offset plate being positioned radially outward of the second support ring when the first end of the second offset plate is coupled to the second support ring.

3. The system of claim **1**, wherein the first offset plate and the second offset plate are substantially identical to one another.

4. The system of claim **1**, wherein the first end of the first offset plate includes a first extension sized and shaped to be received within one of the first apertures of the first support ring.

5. The system of claim **4**, wherein the first extension includes a first borehole extending therethrough for receiving a fastener therein.

6. The system of claim **1**, wherein the first end of the first offset plate includes a first aperture, and when the first aperture of the first offset plate is positioned coaxially with one of the first apertures of the first support ring, a fastener may pass through both the first aperture of the first offset plate and the one of the first apertures of the first support ring to secure the first offset plate to the first support ring.

7. The system of claim **6**, wherein the first end of the first offset plate includes a first extension sized and shaped to be received within one of the first apertures of the first support ring, the first extension being positioned adjacent to the first aperture of the first offset plate.

8. The system of claim **1**, wherein the second end of the first offset plate includes a receiving portion including a recess at least partially defined by a circumferential rim, the receiving portion sized and shaped to receive the first end of the strut.

9. The system of claim **8**, wherein the circumferential rim is substantially continuous so that the circumferential rim fully circumscribes the recess.

10. The system of claim **8**, wherein the circumferential rim is discontinuous so that the circumferential rim defines an opening, the circumferential rim less than fully circumscribing the recess.

11. The system of claim **10**, wherein when the first end of the strut is received within the recess of the second end of the first offset plate, a first aperture in the first end of the strut is aligned with the opening of the circumferential rim so that the first aperture in the first end of the strut is accessible while the first end of the strut is received within the recess.

12. An offset plate for use in an external fixation system, the offset plate comprising:

a first end adapted to couple to a support ring of the external fixation system, the first end having a cylindrical extension adapted to be received within an aperture of the support ring; and

a second end spaced from the first end, the second end including a circumferential rim defining a recess adapted to receive an end of a strut of the external fixation system therein, the recess being in communication with a borehole in the second end, the borehole in the second end adapted to align with a corresponding aperture of the strut when the strut is received within the recess.

13. The offset plate of claim **12**, wherein the cylindrical extensions includes a borehole extending therethrough for receiving a fastener therein.

14. The offset plate of claim **12**, wherein the first end of the offset plate includes a first aperture therein, and when the first aperture of the first offset plate is positioned coaxially with a corresponding aperture of the support ring, a fastener may pass through both the first aperture of the first end of the offset plate and the corresponding aperture of the support ring to secure the offset plate to the support ring.

15. The offset plate of claim **12**, wherein the circumferential rim is substantially continuous so that the circumferential rim fully circumscribes the recess.

16. The system of claim **12**, wherein the circumferential rim is discontinuous so that the circumferential rim defines an opening, the circumferential rim less than fully circumscribing the recess.

17. A method of constructing an external fixation frame, the method comprising:

coupling a first support ring to a second support ring, the first support ring extending along a first ring plane and having a plurality of first apertures extending through the first support ring in a direction orthogonal to the first ring plane, the second support ring extending along a second ring plane and having a plurality of second

apertures extending through the second support ring in a direction orthogonal to the second ring plane, wherein coupling the first support ring the second support ring includes coupling a first end of a first telescopic strut to the first support ring via one of the first apertures in the first support ring, and coupling a second end of the first telescopic strut to the second support ring via one of the second apertures in the second support ring;

coupling a first end of a first offset plate to the first support ring via one of the first apertures of the first support ring;

coupling a first end of a second telescopic strut to a second end of the first offset plate so that the first end of the second telescopic strut is positioned radially outward of the first support ring; and

coupling a second end of the second telescopic strut to the second support ring.

18. The method of claim **17**, wherein coupling the second end of the second telescopic strut to the second support ring comprises directly coupling the second end of the second telescopic strut to the second support ring via one of the second apertures in the second support ring.

19. The method of claim **17**, further comprising coupling a first end of a second offset plate to the second support ring via one of the second apertures of the second support ring.

20. The method of claim **19**, wherein coupling the second end of the second telescopic strut to the second support ring comprises coupling the second end of the second telescopic strut to a second end of the second offset plate so that the second end of the second telescopic strut is positioned radially outward of the second support ring.

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