Transocean

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Contactless Profiling of a Drill Pipe

CONTACTLESS PROFILING OF A DRILL PIPE

BACKGROUND

[0001] The interior of drill pipes can be inspected with the aid of so-called rabbits, internal drift diameter gauges that can be used to check casing or joints of drill pipes before the pipes are run into wellbores. Rabbits can get stuck or lost in pipes, leading to expensive remedial efforts or worse, in particular when the pipe is already part of a drill string downhole.

BRIEF DESCRIPTION OF THE DRAWINGS

[0002] **FIG. 1** is an example schematic illustration of the use of a light detection and ranging (LIDAR) sensor or camera to detect the interior profile of a drill pipe, according to some embodiments.

[0003] **FIGS. 2A-C** show an example illustrations of the inspection of a pipe by a LIDAR camera mounted on a pipe racker as the pipe racker transports the pipe between a wellbore and a pipe rack or fingerboard at drilling platform, according to some embodiments.

[0004] **FIGS. 3A-D** show an example illustration of the determination, based on LIDAR-based measurements taken from multiple observation points along the circumference of the pipe, of the location of an obstruction on an interior surface of a pipe, according to some embodiments.

[0005] **FIG. 4** shows a table illustrating an example implementation of the systems, methods and apparatus disclosed herein to determine the drift diameter or constant of a pipe caused by an obstruction on the interior surface of the pipe, according to some embodiments.

DETAILED DESCRIPTION

[0006] Pipes and other hollow tubular objects are used at drilling platforms for a variety of drilling operations, including as part of drill strings used to drill wellbores, i.e., holes that are dug in the Earth's sub-surface to facilitate the extraction of natural resources such as oil, gas, minerals, water, etc. In some cases, other objects such as tools may be passed through the pipes and the hollow tubular objects, and as such, one may wish to determine the amount of spacing available in the interior of the pipes and hollow tubular objects to pass the tools. In some embodiments, the nominal interior diameter of a pipe may not be the same as the actual and/or effective diameter of the pipe that is available for passing solid objects through the pipe, the so-called drift diameter. For example, the interior wall of the pipe may have obstructions (e.g., projections, etc.) that would block the passage of a tool if the tool came in contact with the obstructions. In other words, the obstructions effectively reduce the nominal diameter of the pipe to the drift diameter. Internal drift diameter gauges, such as the so-called rabbits, can be used to detect the presence of obstructions on the interior surfaces of pipes and determine drift diameters. For example, the successfully passing of a rabbit with a given outside diameter through a pipe may be understood as a confirmation that the drift diameter of the pipe is at least as large as the outside diameter of the rabbit. In some embodiments, it may be beneficial to profile the interior surfaces of pipes in a contactless manner (e.g., to avoid complications that arise when rabbits are used, such as rabbits being stuck, lost, and/or inadvertently left in pipes).

[0007] **FIG. 1** shows an example schematic illustration of the use of a light detection and ranging (LIDAR) sensor or camera to detect or scan the interior profile of a pipe, according to some embodiments. A pipe 102 may contain an obstruction 104 with a size (e.g., diameter) that reduces the diameter of the pipe 102 that is available for passing a solid object through the pipe 102 by a maximum drift constant 106. In other words, the presence of the obstruction 104 in the interior surface of the pipe 102 may reduce the nominal diameter 108 of the pipe 102 to the drift diameter 110. In some implementations, the pipe 102 may have one or more of such obstructions distributed on its interior surface from one end of the pipe 102 to another end, and a LIDAR camera 112 may be used to detect the presence (and in some cases, size) of said obstructions.

[0008] In some implementations, the LIDAR camera 112 may be placed at a distance from one end of the pipe 102 that is configured to allow light emitted by the LIDAR camera 112 to enter into the interior of the pipe 102 and irradiate the above-noted obstructions, and further to allow reflected light (e.g., including at least light reflected by the obstructions) to be received back at the LIDAR camera 112. In some implementations, the light emitted by the LIDAR camera 112 may be configured to facilitate the detection of all obstructions with size exceeding a predetermined size threshold and located at or proximate to the end of the pipe farther from the LIDAR camera 112. That is, the light emitted by the LIDAR camera 112 may have a range and/or horizontal angular accuracy that at least exceed the distance and/or natural angle created by the smallest obstruction with size greater than the predetermined size threshold.

[0009] In some implementations, as noted above, the LIDAR camera 112 can facilitate the detection of obstructions in the interior surface of the pipe 102 based on light reflected from said obstructions after light emitted by the LIDAR camera 112 irradiates those obstructions. For example, the LIDAR camera 112 can be used to identify the location of an obstruction 104 on the interior surface of the pipe 102. For instance, the LIDAR camera 112 can be used to determine the distance of the obstruction 104 as measured from one end of the pipe 102 or from the LIDAR camera 112 (e.g., 114) and the angle the obstruction 102 forms with respect to some point at the same end of the pipe 102 or the LIDAR camera 112 (e.g., 116). In some implementations, the distance may be determined based on the length of time that has passed since the emission of a light by the LIDAR camera 112 and the arrival of a reflected light back at the LADAR 112. The LIDAR camera 112 may be configured to distinguish between different obstructions based on differences in the length of time between the emission of the light from the LIDAR camera 112 and the arrival of the light reflected back to the LIDAR camera 112 by the different obstructions. For example, two instances of reflected light being received at the LIDAR camera 112 may be understood as having come from two different obstructions if the difference between the durations of time between light emission and reflected-light arrival at the LIDAR camera 112 is greater than a predetermined time threshold. In some implementations, the location of an obstruction located on an interior surface of a pipe may be determined based on multiple LIDAR-based measurements. For example, a LIDAR camera 112 placed at or in proximity to one end of a pipe may traverse along the circumference of the pipe as the LIDAR camera 112 is emitting light towards the obstruction to detect and determine the location of the obstruction as discussed above. The determination of the location of the obstruction based on multiple LIDAR measurements is discussed in more details with reference to **FIGS. 3A-D**.

[0010] Further, the LIDAR camera 112 may determine the profile of a given obstruction by scanning the obstruction along the radial axis of the pipe 102. In addition, the LIDAR camera 112 may scan the interior surface of the pipe 102 along the longitudinal axis of the pipe 102. In some implementations, the scanning processes by the LIDAR camera 112 can generate one-dimensional (1D) and/or two-dimensional (2D) point clouds representing, respectively, the 1D coordinates of the obstructions (e.g., along the longitudinal axis or the radial axis) and the 2D point coordinates (e.g., along the longitudinal axis and the radial axis), the 1D point cloud and the 2D point cloud being collections of points representing the 1D and the 2D coordinates of an obstruction.

[0011] In some implementations, a three-dimensional (3D) point cloud representing the 3D coordinates of the obstructions can be obtained by rotating 118 the LIDAR camera 112 while emitting light and receiving the resulting reflections as discussed above. For example, the LIDAR camera 112 may rotate around the circumference of the pipe 102 at a rate of about one full rotation, about a half rotation, etc., every about 10 seconds, about 12 seconds, about 15 seconds, about 20 seconds, about 25 seconds, about 30 seconds, etc., including values and subranges therebetween. During the rotation of LIDAR camera 112, the interior surface of the pipe 102 may be profiled or scanned and obstructions 104 may be detected as discussed above at multiple angles of rotations. **Table 1** below, presented with reference to **FIGS. 3A-D**, shows an example illustrative implementation of the systems, methods and apparatus disclosed herein to determine the drift diameter or constant of a pipe (e.g., caused by an obstruction on the interior surface of the pipe) by using a LIDAR that is rotating about the axis of the pipe at the rate of 20Hz.

[0012] In some implementations, the light emitted by the LIDAR camera 112 can be a pulsed light wave (e.g., a laser) and may have wavelength ranging from about 500nm to about 1600 nm, from about 800nm to about 1200 nm, from about 900nm to about 1100 nm, wavelengths of about 532nm, about 905nm, about 1064nm, about 1550nm, etc., including values and subranges therebetween. In some implementations, the LIDAR camera 112 can have a range of about 40m or greater such that it is suitable to work with a standard pipe arrangement and standard beam width.

[0013] In some implementations, the LIDAR camera 112 may include a communications system 120 that is configured for transmitting the results of the obstruction detection to an external system (not shown). For example, the communication system 120 can include a network interface card (NIC), a Wi-Fi™ module, a Bluetooth® module and/or any other suitable wired and/or wireless communication device. In some instances, the communication system 120 can be configured to connect to a communication network such as, for example, the Internet, an intranet, a local area network (LAN), a wide area network (WAN), a metropolitan area network (MAN), a worldwide interoperability for microwave access network (WiMAX®), an optical fiber (or fiber optic)-based network, a Bluetooth® network, a virtual network, and/or any combination thereof. In some embodiments, the communication system 120 can include or be operationally coupled to a user interface (e.g., a touch screen).

[0014] In some embodiments, the detection of obstructions on the interior surface of a pipe as discussed above can be performed onsite at drilling platforms. For example, **FIGS. 2A-C**

show example illustrations of the inspection of a pipe by a LIDAR camera mounted on a pipe racker as the pipe racker transports the pipe between a wellbore and a pipe rack (i.e., fingerboard). In some implementations, the pipe racker 202 may have coupled to it a LIDAR camera 204 that is configured to be positioned in the vicinity of one end of a pipe 206 that is being hoisted out of a wellbore 208 to be transported to the fingerboard 210 where pipes are stored. In some implementations, the pipe racker 202 may also transport pipes 206 from the fingerboard 210 towards the wellbore 208 for insertion into the wellbore 208. In such implementations, the LIDAR camera 204 may be configured to emit light into the interior of the pipe 206 and receive reflected light from obstructions on the interior surface of the pipe 206 as the pipe 206 is being transported between the wellbore 208 and the fingerboard 210. As such, the LIDAR camera 204 may be configured to perform the above discussed detection of obstructions located on the interior surface of the pipe 206 during the transportation of the pipe 206 onsite at a drilling platform.

[0015] **FIGS. 3A-D** show an example illustration of the determination, based on LIDAR-based measurements taken from multiple observation points along the circumference of the pipe 308, of the location of an obstruction on an interior surface of a pipe 308, according to some embodiments. In some implementations, when scanning the interior surface of a pipe 308, a LIDAR camera 302 may project at different angles from multiple observation points along the circumference of the pipe 308 (at one end, for example) to the obstruction such that multiple scanning results or images can be obtained for use in image formation or 2D or 3D surface reconstruction of the interior of the pipe 308. For example, with reference to **FIG. 3A**, the LIDAR camera 302 at observation point P1 may scan or capture one or more images of the interior surface of the pipe (including obstructions on the surface). Further, by traversing along the circumference of the pipe 308 to observation point P2 and scanning or capturing one or more additional images of the interior surface of the pipe (including the obstructions on the surface) from observation point P2, the LIDAR camera may obtain additional images of the obstructions from a different angle than the angle at P1. In some implementations, the LIDAR camera 302 may traverse along the entire circumference (or some portion thereof) of the pie 308 and obtain multiple scans or images of the interior surface including obstructions thereon from perspectives of multiple angles. For a same portion of the interior surface of the pipe 308 or for a same feature (e.g., obstruction) on the interior surface, in some instance, the images may carry similar but not identical information, and as such can be processed (e.g., via super-resolution reconstruction techniques) to acquire enhanced resolution of the portion or feature. In other words, the use of multiple images captured from multiple angles (e.g., from multiple observation points) can improve the effective resolution capabilities of the LIDAR camera 302 in detecting obstructions located on the interior surface of the pipe 308 (and in particular obstructions located at the opposite end of the pipe 308 from the end at which the LIDAR camera 302 is positioned). Examples of super-resolution reconstruction techniques, and details thereof, can be found in “Super-Resolution Reconstruction for Multi-Angle Remote Sensing Images Considering Resolution Differences,” by H. Zhang *et al*., Remote Sens., 6, 637-657 (2014), attached herein as appendix A and incorporated herein by reference in its entirety.

[0016] In some implementations, with reference to **FIG. 3A**, a LIDAR camera 302 located at a first observation point P1 at or in proximity to one end of the pipe may emit light into the interior of the pipe 308 and receive light reflected by various features such as, but not limited to, obstructions located on the interior surface. For example, the LIDAR camera 302 may, from a given observation point at the circumference of the pipe 308, sweep the light along one or more axes (e.g., radial, longitudinal, etc.) of the pipe 308, generating a collection of distance measurements within the LIDAR’s field of view (FOV), the range of horizontal and vertical angles through which it can capture data (e.g., obstruction location data). In some instances, for example as shown with reference to **FIG. 3B**, moving mirrors may be used to scan in one or two axes, or the entire laser assembly of the LIDAR camera may move, or scanning may be a combination of both. In some implementations, a two-axis scanning LIDAR camera can be used to capture detailed shape information in the horizontal and vertical directions from a stationary location. In some implementations, one-axis scanners can be used to capture distance and angle information (of the interior of a pipe 308, which may include obstructions, for example) along a single scan line, and the relative motion of the scanner and the target surface may be used to build a full image of the pipe features being scanned (e.g., obstructions). In some instances, for example with reference to **FIG. 3C**, an accuracy angle 304 associated with the one-axis scanning operation of the LIDAR camera 302 may set the minimum size of obstruction that can be detected within the interior of the pipe 308 (e.g., the minimum size of an obstruction located at or in proximity to the farther end of the pipe 308 from the LIDAR camera 302).

[0017] Returning to **FIG. 3A**, in some implementations, a two-axis scanning LIDAR camera 302 may sweep the light beam along a sweep or scan line 306 (e.g., along one or more axes of the pipe) and receive reflected light back to determine the distance from the LIDAR camera 302 to the object or objects (e.g., obstructions) that reflected back the light as discussed above. For example, the distance to an obstruction may be calculated using $d = 0.5*c*T$, where c is the speed of light and T is the round trip time between light being emitted by the LIDAR camera

302 and its reflected being received at the LIDAR camera 302. For example, with reference to **FIG. 3D**, a LIDAR camera at P1 (corresponding to P1 in **FIG. 3A**), may emit light towards the obstruction 310 as the LIDAR camera 302 is sweeping the interior of the pipe 308, and the emitted light may travel a distance r1 before being reflected back by the obstruction 310 towards the LIDAR camera 302. In such instances, the distance r1 may be determined using the above formula, r1 = 0.5*c*T1, where T1 is the time between light emission from the LIDAR camera at P1 and reflected light being received back at P1.

[0018] In some implementations, the distance r1 from the LIDAR camera P1 to the obstruction 310 may be expressed mathematically in terms of the three-dimensional (3D) coordinates of the locations of the LIDAR camera 302 (i.e., (x,y,z)) and the 3D coordinates of the obstruction 310 (i.e., (x1,y1,z1)) as follows: $(r1)^2 = (x\text{-}x1)^2 + (y\text{-}y1)^2 + (z\text{-}z1)^2$. In other words, the 3D coordinates of the obstruction 310, i.e., (x,y,z), may have values that minimize or reduce to zero, for example, the expression $f1 = [((x\text{-}x1)^2 + (y\text{-}y1)^2 + (z\text{-}z1)^2)^{0.5} - r1]^2$. In some implementations, as there are three unknown parameters or values (i.e., x,y,z) in the expression f1, one may use four equations or expressions to fully determine the values of (x,y,z), as explained below.

[0019] In some implementations, additional equations or expressions that can be used in determining (x,y,z) may be obtained by using the LIDAR camera 302 to perform additional distance measurements from a different observation point P2 (that is, P2 is different from the first observation point P1). For example, with reference to **FIG. 3A**, the LIDAR camera 302 located at P1 may travel along the circumference of the end of the pipe 308 towards a second observation point P2, and perform same or substantially similar measurement from observation point P2. For example, the LIDAR camera, located at observation point P2, may sweep the light beam along a sweep or scan line 312 (e.g., along one or more axes of the pipe) and receive reflected light back to determine the distance from the LIDAR camera 302 at observation point P2 to the object or objects (e.g., obstructions) that reflected back the light as discussed above. For instance, with reference to **FIG. 3D**, the LIDAR camera 302 may be positioned at observation point P2 with coordinates (x2,y2,z2) and may be used to determine, as discussed above, the distance r2 from observation point P2 to the obstruction 310 (e.g., the same obstruction 310 that is a distance r1 away from P1). The determined distance r2 may be expressed in terms of the coordinates of P2 and the coordinates of the obstruction 310 that reflected the light back, i.e., (x,y,z), as follows: , $(r2)^2 = (x\text{-}x2)^2 + (y\text{-}y2)^2 + (z\text{-}z2)^2$. Similar to the case with respect to P1, the coordinates of the obstruction 310, i.e., (x,y,z), may have values that minimize or reduce to zero, for example, the expression $f2 = [(x-x2)^2 + (y-y2)^2 + (z-z2)^2)^{0.5} - r2]^2$.

[0020] In some implementations, the LIDAR camera 302 may travel along the circumference of the pipe 308 and perform additional measurements of distances rn to the obstruction 310 from observation point Pn, allowing one to have the expressions $fn = [(x-xn)^2 + (y-yn)^2 + (z-zn)^2)^{0.5} - rn]^2$ where n=1,2,3, …. In some implementations, the multiple expressions may be combined into one expression,

$$F = \sum_{i=1}^{n} fi = \sum_{i=1}^{n}[(x-xi)^2 + (y-yi)^2 + (z-zi)^2)\text{^}0.5 - \text{ri}]\text{^}2$$

In some implementations, LIDAR camera 302 may rotated around the circumference of the pipe 308 at a rate of about one full rotation, about a half rotation, etc., every about 10 seconds, about 12 seconds, about 15 seconds, about 20 seconds, about 25 seconds, about 30 seconds, etc., including values and subranges therebetween.

[0021] As noted above, the coordinates (x,y,z) of the location of the obstruction 310 have values that minimize f1, f2, …fn, and as such also minimize F, which is the sum of f1, f2, …fn (since f1, f2, …fn are all positive values, for instance). In some implementations, the values of (x,y,z) that minimize F may be obtained by taking the partial derivatives of F with respect to each of the coordinates x, y and z, and setting the derivatives to zero. For example, one may obtain the values of x, y, z, from the following expressions:

$$\frac{\partial \mathrm{F}}{\partial \mathrm{x}} = 0; \frac{\partial \mathrm{F}}{\partial \mathrm{y}} = 0; \frac{\partial \mathrm{F}}{\partial \mathrm{z}} = 0.$$

Such equations may be solved, for example, by applying the iterative Newtown’s method.

[0022] In some implementations, to determine 3D coordinates of the obstruction 310 (i.e., to determine (x,y,z)), n=4 may be sufficient, i.e., four LIDAR measurements of the distances to the obstruction 310 may be sufficient. In some implementations, one may have more than four measurements, i.e., n > 4, and F may be an overdetermined equation. In such implementations, the overdetermined equation may also be solved, for example, by applying the iterative Newtown’s method. Further, in such implementations, the use of an overdetermined equation to determine the 3D coordinates of the obstruction 310 allows for an improved 3D reconstruction or determination of the location of the obstruction 310. **FIG. 4** shows a table illustrating an example non-limiting implementation of the systems, methods and apparatus disclosed herein to determine the location and the size of an obstruction on the interior surface of a pipe as discussed in detail above, according to some embodiments. In the example implementation depicted in **FIG. 4**, the LIDAR camera, positioned about half a meter from one end of a pipe that is about 37m long, rotates along the circumference of the pipe at 20Hz, and sweeps the light beam at the obstructions in the interior surface of the pipe with field of view of about 45 degrees. From the sample measurements, it was determined that the pipe, with a nominal interior diameter of about 83mm, has a drift constant of about 3.18mm, i.e., one or more obstructions on the interior surface of the pipe has effectively reduced the diameter of the pipe by this amount.

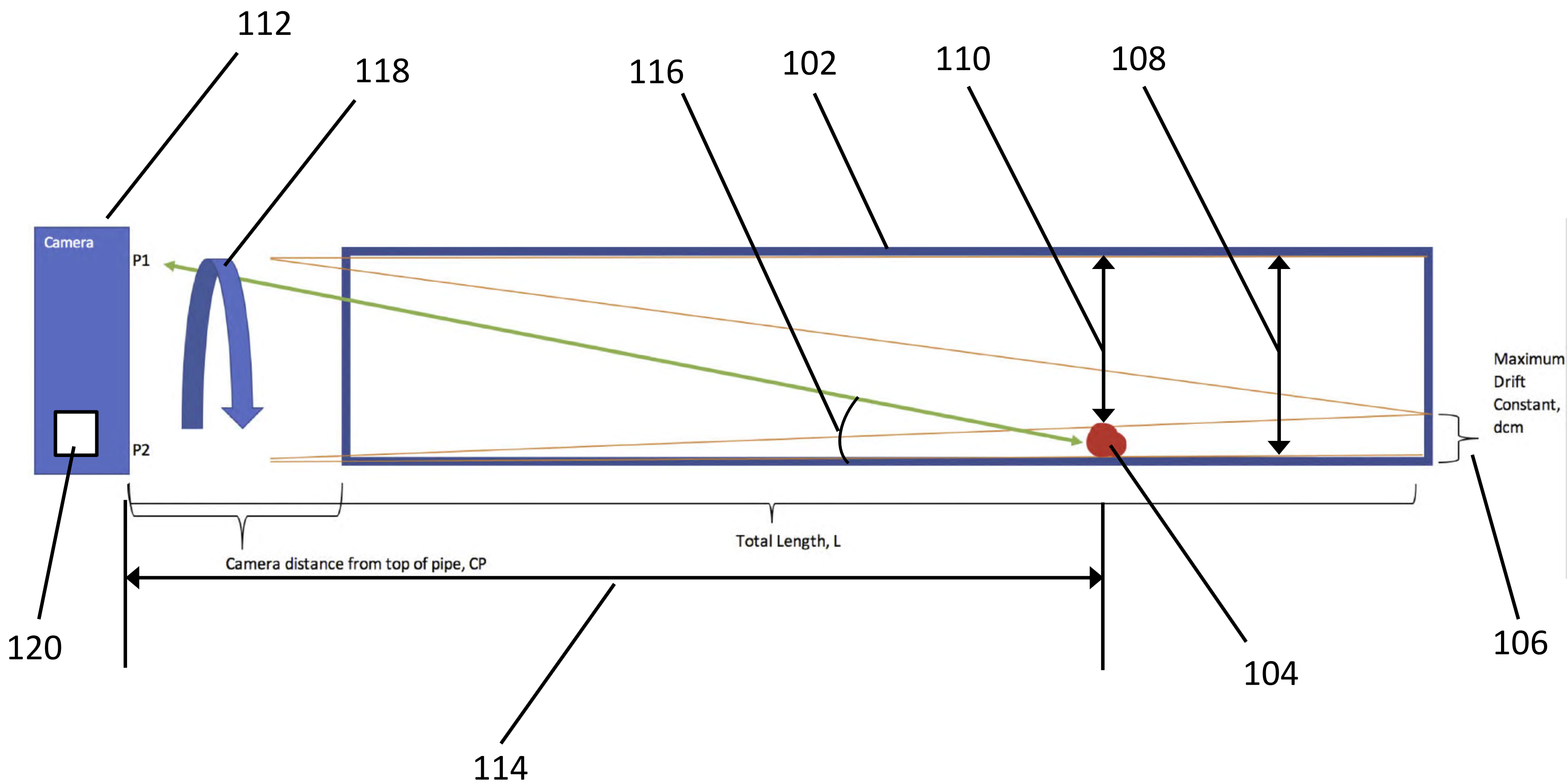
112
118
116
102
110
108
Camera
P1
P2
Maximum
Drift
Constant,
dcm
Total Length, L
Camera distance from top of pipe, CP
120
114
104
106

FIG. 1

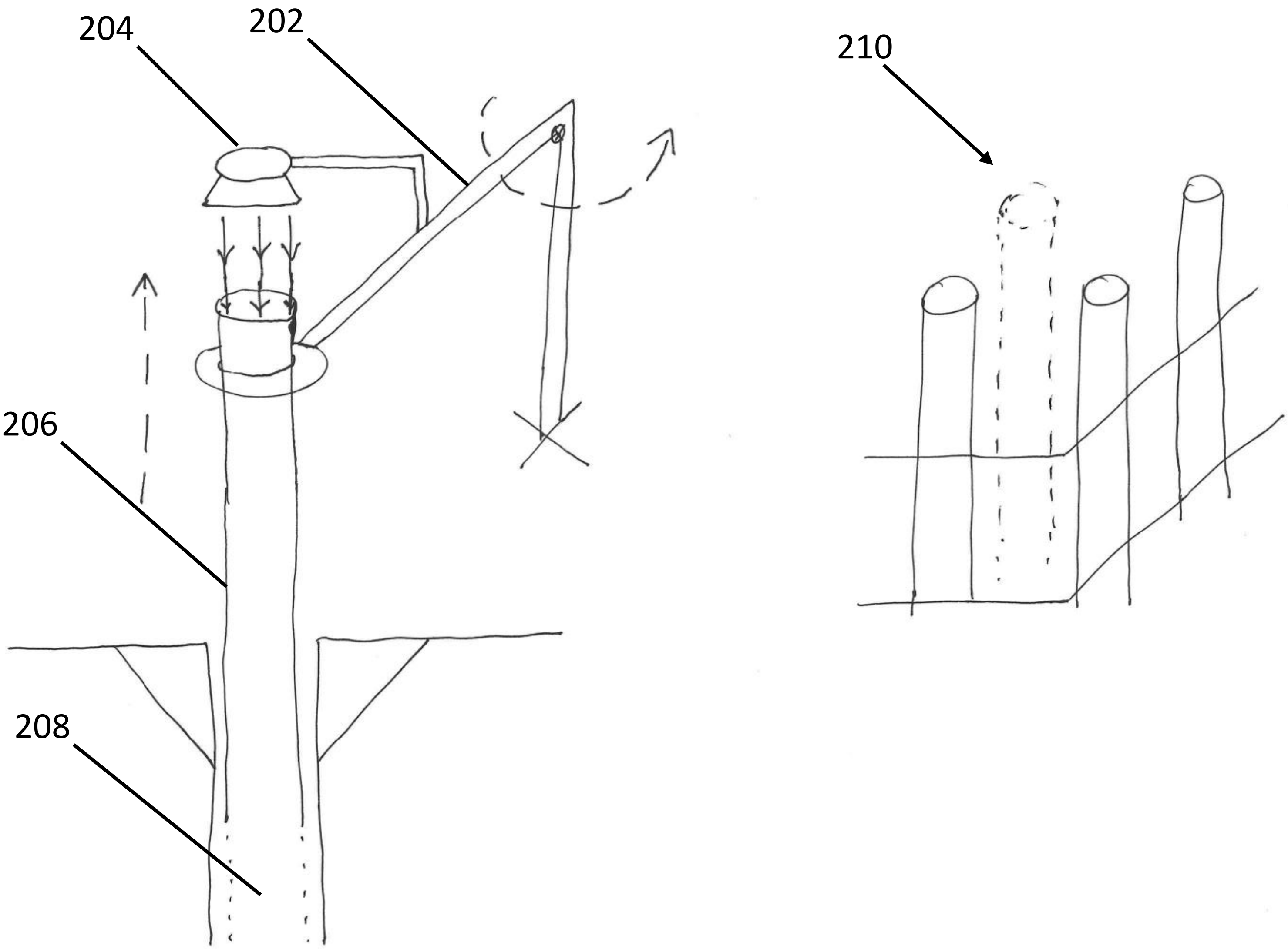

FIG. 2A

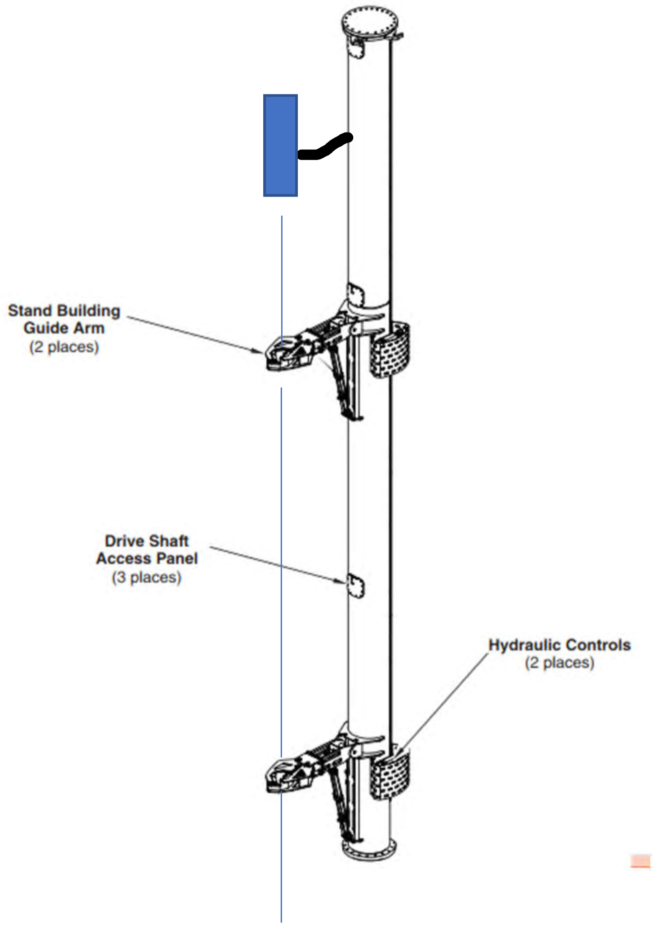
Stand Building
Guide Arm
(2 places)
Drive Shaft
Access Panel
(3 places)
Hydraulic Controls
(2 places)

FIG. 2B

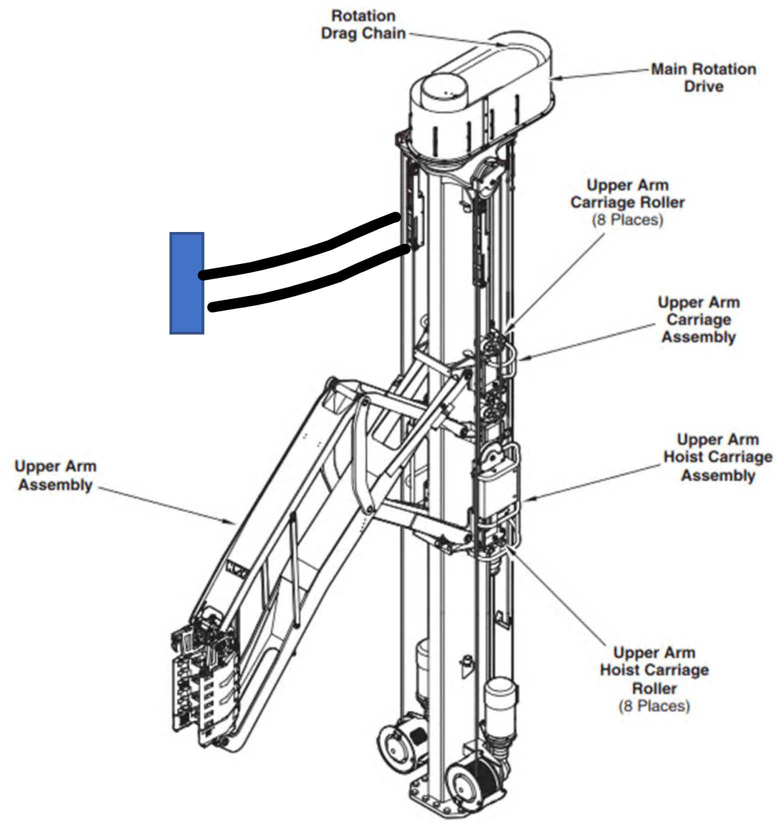
Rotation
Drag Chain
Main Rotation
Drive
Upper Arm
Carriage Roller
(8 Places)
Upper Arm
Carriage
Assembly
Upper Arm
Assembly
Upper Arm
Hoist Carriage
Assembly
Upper Arm
Hoist Carriage
Roller
(8 Places)

FIG. 2C

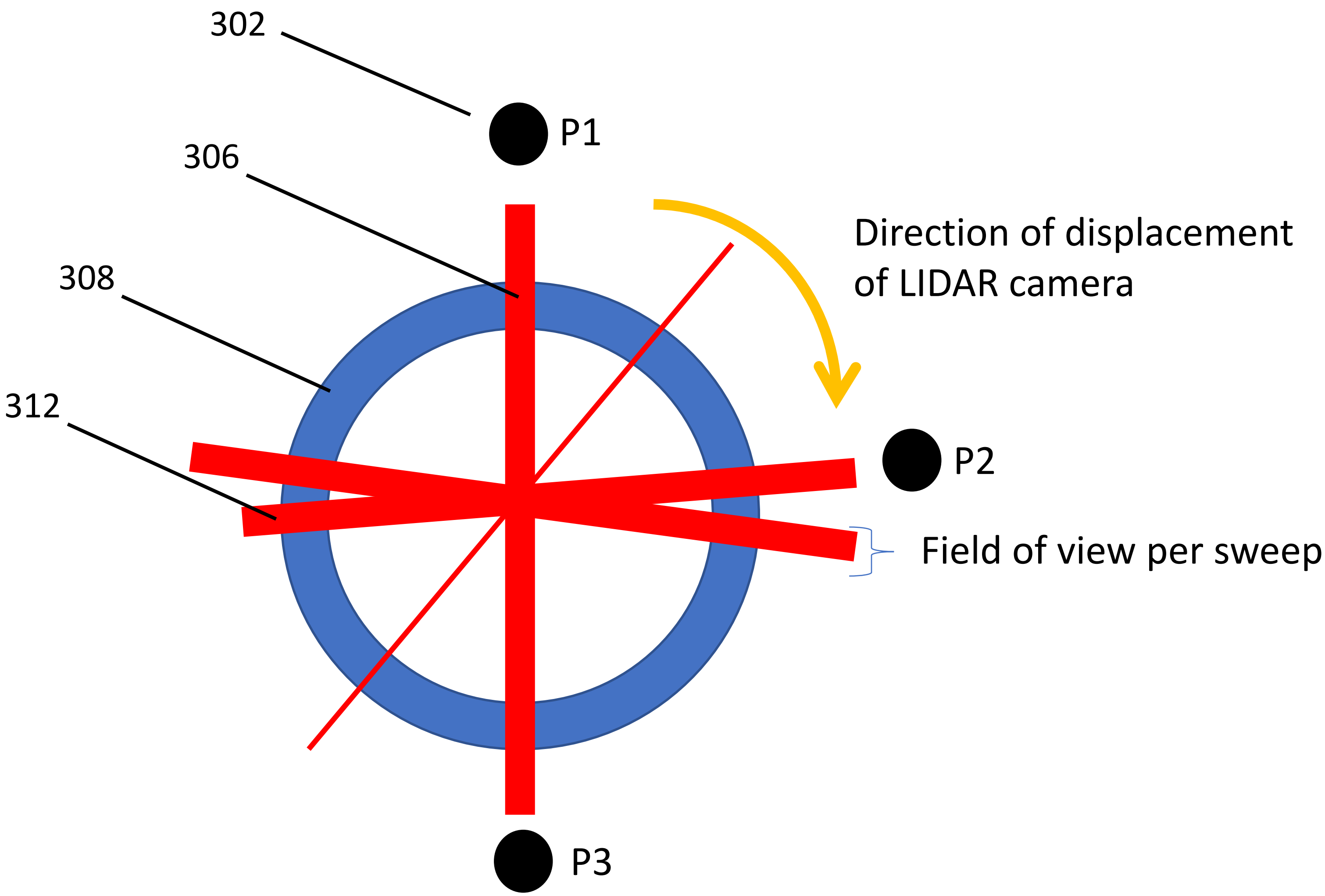
302
P1
306
308
312
Direction of displacement
of LIDAR camera
P2
Field of view per sweep
P3

FIG. 3A

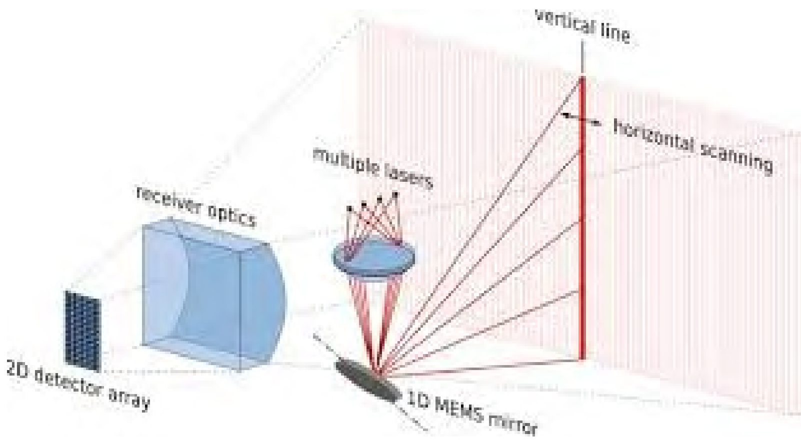
vertical line
horizontal scanning
multiple lasers
receiver optics
2D detector array
1D MEMS mirror

FIG. 3B

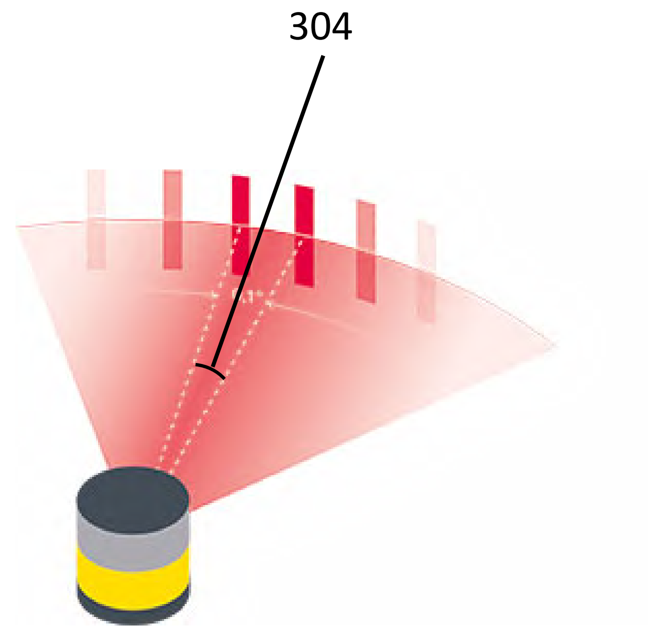
304

FIG. 3C

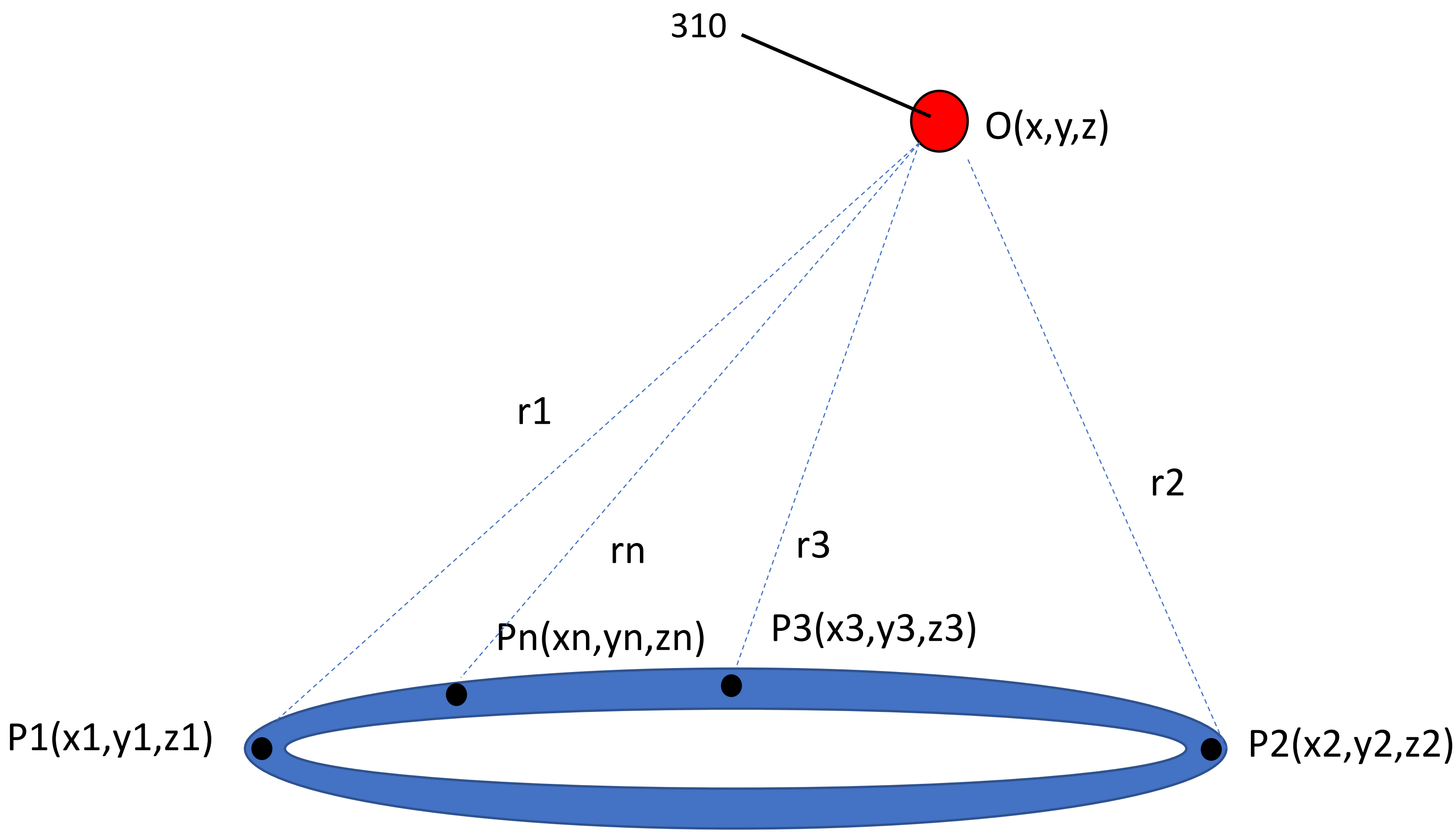

FIG. 3D

Velodyne UltraPuck Lidar			
Lidar Range OS-1 Lidar		120.00 m	
Range Accuracy +/-		120.00 mm	depends on range, temperature and target reflectivity
Angle Accuracy (Horizontal)	ARH	0.01 ∘	0.04 ∘
Angle Accuracy (Vertical)	ARV	0.01 ∘	
Pipe Length		**37000.00 mm**	
Camera distance to top of Pipe	CP	500.00 mm	
Camera to end of Pipe Length	L	**37500.00 mm**	
Maximum Lidar resolution at pipe length	MLR	6.54 mm	26.18 mm
Expected improvement with Super-Resolution (2x)		3.27 mm	2.91%
Tube Label1 3.5" Diameter (Table C.3 API 5CT)	D	88.90 mm	
Wall Thickness Label1 3.5" Diameter (Table C.3 API 5CT)	t	5.49 mm	
Outside Diameter Tolerance per API 5CT 8.11.1	ΔD	+/- 0.031 in	
Thickness Tolerance per API 5CT 8.11.1	Δt	12.50%	
Standard Drift mandrel clearance (drift constant) per API 5CT Table C.31, Label 1	dcm	**3.18 mm**	
Required angle accuracy		0.005 ∘	
Number of Sweep Required Angle Accuracy for pipe (180 degrees)		37,047	
Lidar FOV per sweep, OS-1		45.00 ∘	
Time to perform 180 at 20Hz		20.58 s	

		Inner Diameter d			Field of View Angle		
		D-ΔD	D	D+ΔD	D-ΔD	D	D+ΔD
		88.87 mm	88.90 mm	88.93 mm			
t+Δt	6.18 mm	82.69 mm	82.72 mm	82.75 mm	0.126 ∘	0.126 ∘	0.126 ∘
t	5.49 mm	83.38 mm	83.41 mm	83.44 mm	0.127 ∘	0.127 ∘	0.127 ∘
t-Δt	4.80 mm	84.07 mm	84.10 mm	84.13 mm	0.128 ∘	0.128 ∘	0.129 ∘

FIG. 4