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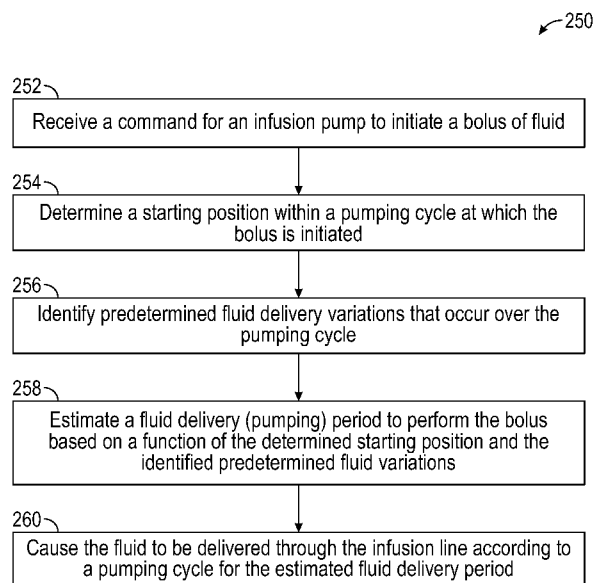


FIG. 8

(57) Abstract: An infusion pump control system determines, responsive to receiving a command to initiate a bolus, a starting position within the pump's fluid delivery cycle at which the bolus will be initiated, and estimates a fluid delivery period to perform the bolus based on a function of the bolus starting position within a fluid delivery cycle and predetermined fluid delivery variations throughout the cycle. The pump control system delivers the bolus by causing the fluid to be delivered through the infusion line for the estimated fluid delivery period according to a fluid delivery cycle.

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SYSTEM AND METHOD FOR IMPROVING FLUID DELIVERY ACCURACY OF AN INFUSION DEVICE

BACKGROUND

[0001] Large volume pumps (LVPs) are capable of delivering large fluid volumes (e.g., 100 mL or more of fluid from a single container) and usually operate through peristalsis, where a rotor turning across a section of tubing causes fluid to move through the tubing through positive displacement. LVP boluses programmed at low volumes have been known to have a very high amount of variability in performance. High variability and poor performance increase patient risk, especially during the administration of life sustaining drugs and sensitive patient populations.

SUMMARY

[0002] There is a need to increase the overall accuracy of LVPs, particularly in the administration of low volumes. Accordingly, the subject technology provides an apparatus and method for improving bolus accuracy. The subject technology adjusts bolus delivery based on the point within the fluid delivery cycle of an LVP at which the bolus delivery is initiated and predetermined fluid delivery variations.

[0003] According to various implementations, a system for improving fluid delivery accuracy of an infusion device, comprises: an infusion pump configured to deliver a fluid through an infusion line loaded into the infusion pump by causing an amount of the fluid to be delivered through an infusion line according to a fluid delivery cycle; and a control unit configured to: receive a command for the infusion pump to initiate a bolus of the fluid; determine, responsive to receiving the command and before initiating the bolus, a starting position within the fluid delivery cycle at which the bolus is initiated; identify predetermined fluid delivery variations that occur over the fluid delivery cycle; estimate, based on a function of the starting position and the identified predetermined fluid delivery variations, a fluid delivery period (e.g., a cycle length or time) to perform the bolus, the estimate of the fluid delivery period being different than an estimate based on the function absent the predetermined fluid delivery variations; and deliver the bolus by causing the fluid to be delivered, according to the fluid delivery cycle, through the infusion line for the estimated fluid delivery period. Other aspects include corresponding apparatus (e.g., an infusion device), methods and computer program products for implementation of the corresponding system and its features.

[0004] According to various implementations, a method for improving fluid delivery accuracy of an infusion device comprises: operating an infusion pump configured to deliver a fluid through an infusion line loaded into the infusion pump by causing an amount of the fluid to be delivered through an infusion line according to a fluid delivery cycle; receiving a command for the infusion pump to initiate a bolus of the fluid; determining, responsive to receiving the command and before initiating the bolus, a starting position within the fluid delivery cycle at which the bolus is initiated; identifying predetermined fluid delivery variations that occur over the fluid delivery cycle; estimating, based on a function of the starting position and the identified predetermined fluid delivery variations, a fluid delivery period to perform the bolus, the estimate of the fluid delivery period being different than an estimate based on the function absent the predetermined fluid delivery variations; and delivering the bolus by causing the fluid to be delivered, according to the fluid delivery cycle, through the infusion line for the estimated fluid delivery period. Other aspects include corresponding apparatus (e.g., an infusion device), systems and computer program products for implementation of the corresponding method and its features.

[0005] It is understood that other configurations of the subject technology will become readily apparent to those skilled in the art from the following detailed description, wherein various configurations of the subject technology are shown and described by way of illustration. As will be realized, the subject technology is capable of other and different configurations and its several details are capable of modification in various other respects, all without departing from the scope of the subject technology. Accordingly, the drawings and detailed description are to be regarded as illustrative in nature and not as restrictive.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] For a better understanding of the various described implementations, reference should be made to the Description of Implementations below, in conjunction with the following drawings. Like reference numerals refer to corresponding parts throughout the figures and description.

[0007] FIG. 1A depicts a perspective view of an example infusion device showing an infusion set in place within the infusion device, according to various aspects of the subject technology.

[0008] FIG. 1B depicts an example patient care unit shown, according to various aspects of the subject technology.

[0009] FIG. 2 depicts an example pumping mechanism of an infusion pump, according to various aspects of the subject technology.

[0010] FIG. 3 depicts an example occluder valve, according to various aspects of the subject technology.

[0011] FIG. 4 depicts an example camshaft of an infusion pump, according to various aspects of the subject technology.

[0012] FIG. 5 depicts an example cam phase diagram corresponding to a fluid delivery cycle of an infusion pump, according to various aspects of the subject technology.

[0013] FIG. 6 depicts example fill and delivery phases, according to various aspects of the subject technology.

[0014] FIG. 7A depicts a first example profile of delivery variations over a given fluid delivery cycle of an infusion pump, according to various aspects of the subject technology.

[0015] FIG. 7B depicts a second example profile of delivery variations over a given fluid delivery cycle of an infusion pump, according to various aspects of the subject technology.

[0016] FIG. 8 depicts a second example process for improving fluid delivery accuracy of an infusion device, according to aspects of the subject technology.

[0017] FIG. 9 is a conceptual diagram illustrating an example electronic system for improving fluid delivery accuracy of an infusion device, according to aspects of the subject technology.

DESCRIPTION

[0018] Reference will now be made to implementations, examples of which are illustrated in the accompanying drawings. In the following description, numerous specific details are set forth, in order to provide an understanding of the various described implementations. However, it will be apparent to one of ordinary skill in the art that the various described implementations may be practiced without these specific details. In other instances, well-

known methods, procedures, components, circuits, and networks have not been described in detail so as not to unnecessarily obscure aspects of the implementations.

[0019] According to various implementations of the subject technology, a fluid tubing is loaded in an infusion pump and primed with a fluid. During fluid delivery, upper and lower occluder elements of an infusion pump are activated to press against the fluid tubing to block and isolate the fluid in an upstream portion of the tubing from a downstream portion of the tubing. While flow within the fluid tubing is blocked by the occluder elements, a pumping element of the infusion pump is activated to compress an intermediate portion of the tubing, between the downstream portion and the upstream portion, to cause a pressure increase within the fluid tubing. The lower occluder is opened and the fluid flows downstream. The foregoing cycle repeats to continuously pump a fluid through the fluid tubing.

[0020] It has been found that, as a volume of fluid delivered by a large volume pump (LVP) decreases, the potential for error increases and, conversely, as a volume of fluid delivered by the LVP increases the potential for error decreases, and that these variances are due, at least in part, to the current state of the pump's pumping mechanism. That is, where the delivery phase correlates to a given cycle (e.g., a cam rotation), the variance may be dependent on the point in the cycle at which the delivery begins and/or ends (including, e.g., how many rotations or partial rotations of the cam are involved in the bolus delivery).

[0021] As will be described further, the subject technology adjusts the duration (e.g., the number or rotations or partial rotations of the cam are involved in the bolus delivery) and/or length of a predetermined fluid delivery period (pumping period) to account for discrepancies in fluid delivery over a given cycle. A pump control system may monitor delivery and, depending on at what point in the fluid delivery (pumping) cycle that the fluid delivery is initiated, the duration of the fluid delivery period may be adjusted to account for known non-linearities of the pump system. Based on the starting point within the cycle and identified fluid delivery variations that occur throughout the pump's fluid delivery cycle, the pump estimates a fluid delivery period to perform the bolus and performs the bolus delivery over the course of the estimated fluid delivery period. According to various implementations, the estimated fluid delivery period is different than an estimate based on a function absent the identified variations. In some implementations, the number of rotations per minute (RPM) may also be adjusted so that the duration of the bolus remains unchanged despite the adjustment in the delivery period.

FIG. 1A depicts a perspective view of an example infusion device showing an infusion set in place within the infusion device, according to various aspects of the subject technology. An infusion system for parenteral infusion of a medical fluid to a patient comprises a pump unit, a major part of which comprises a housing which accommodates, in manner known per se, a cam system (not shown) controlling a plurality of fingers of a pumping mechanism, an electric motor and associated gearing, driving said cam mechanism, and further accommodates electronic control and processing circuitry for controlling such motor and processing signals from pressure sensors etc. provided on the unit. The pump unit, as shown, may also comprise an electronically operated display, an alarm light, an input keyboard or other manually operated controls, all in manner known per se.

[0022] As shown in FIG. 1A, an infusion pump 10 is shown in perspective view with the front door 50 open, showing the upstream fluid line 30 (e.g., portion between fluid container and the infusion pump 30) and downstream fluid line 31 (e.g., portion between the infusion pump 31 and a patient) in operative engagement with the infusion pump 10. The infusion pump 10 directly acts on a tube 66 that connects the upstream fluid line 30 to the downstream fluid line 31 to form a continuous fluid conduit, extending from a respective fluid supply to a patient, through which fluid is acted upon by the pump to move fluid downstream to the patient. Specifically, a pumping mechanism 70 acts as the flow control device of the pump to move fluid through the conduit. The depicted references 30, 31, 66 may be used to describe herein portions of one continuous fluid line or, in some implementations, may individually describe portions that are fluidly connected together to form a continuous fluid line. The upstream and downstream fluid lines and/or tube 30, 31, 66 may also be coupled to a pump cassette or cartridge that is configured to be coupled to the pump 10.

[0023] As shown in FIG. 1A, the face plate 50 which may be opened to reveal the internal loading mechanism for an infusion set. Within the housing of the infusion device (e.g., behind the door or face plate), the infusion device includes a pumping segment including a group of serially-aligned pumping elements configured to compress an elongated compressible channel of an infusion set 66, when loaded within the pumping segment. The pumping segment includes a group of serially-aligned pumping elements (e.g., occluders and/or pumping finger(s)) configured to compress the elongated compressible channel (e.g., an IV tubing segment) loaded within the pumping segment.

[0024] The infusion set includes an intermediate section of the resiliently compressible tubing 66, for example of silicone rubber and, in some implementations, upper and/or lower fittings which each tubing section may be connected respectively with a respective upper line 30 and with the lower line 31. In use, each upper line 30 extends upwardly to a source of the medical fluid to be administered whilst the lower line 31 extends from the infusion pump to an infusion needle or the like inserted into the patient. In use, the infusion set 66 is extended across the face or deck of the pump unit so that its fittings (not labeled) are received in respective brackets respectively and so that the tubing segment extends over a pumping mechanism. In the depicted example, the pumping mechanism includes a four finger pump assembly 72, 74, 76, 78. In the depicted example, the infusion set is fitted in place in this fashion whilst the door 50 is in the open position. After the infusion line has been so fitted, the door 50 may be moved to the closed position and is secured by a catch 52 which may include a lever mounted on the outer edge of the door.

[0025] The four finger pump assembly 72, 74, 76, 78 includes respective fingers that are moveable by a cam system (See FIGS. 4 and 5) inwards and outwards from the face or deck of the pump to compress a respective tubing segment against a counter surface or anvil to propel fluid within the infusion line. In order to make it easier to maintain sterile conditions, these fingers may be covered by a thin flexible membrane, (not shown), sealed at its edges with respect to the deck. The fingers of the pump assembly periodically press the flexible resilient tubing against the counter surface which may be configured on an opposite side, for example, on an inner portion of the door 50.

[0026] The type of pumping mechanism may vary and may be for example, a multiple finger pumping mechanism. In the depicted example, the pumping mechanism includes an upstream occluding element or finger 72, a primary pumping element or finger 74, a downstream occluding element or finger 76, and a secondary pumping element or finger 78. The pumping mechanism (and mechanisms used in other linear peristaltic pumps) operate by sequentially pressing on a segment of the fluid conduit by means of the cam-following pumping elements (e.g., pumping fingers and valve fingers) 72, 74, 76, and 78, which in the depicted example make a four finger pump assembly. Each element may be sequentially activated by a respective cam lobe on a camshaft to apply a downward compression against tubing 66, to move the fluid in the tubing 66 downstream. Intermediate pumping mechanism 74 may include multiple intermediate elements or fingers (not shown) that sequentially activate according to

positioning of the cam lobes. In some implementations, the pressure is applied in sequential locations of the conduit, beginning at the upstream end of the pumping mechanism, and working toward the downstream end. At least one finger is always pressing hard enough to occlude the conduit. As a practical matter, one finger does not retract from occluding the tubing until the next one in sequence has already occluded the tubing; thus, at no time is there a direct fluid path from the fluid supply to the patient. The operation of peristaltic pumps including four finger pumps is well known to those skilled in the art and no further operational details are provided here.

[0027] An upstream pressure sensor 80 may also be included in the pump 10. The upstream pressure sensor may be mounted to pumping mechanism 70 or located adjacent and upstream in relation to the pumping mechanism 70 between a fluid supply and the pumping mechanism 70, so that the connection of the correct fluid supply with the correct pump may be verified before any fluid is pumped to the patient. A downstream pressure sensor 82 is also included in the example infusion pump 10 at a downstream location with respect to the pumping mechanism, that is, at a location between the patient and the flow control device, so that the connection of the correct fluid supply with the correct pump may be verified before any fluid is pumped to the patient. Downstream pressure sensor 82 may be used to detect a pressure change adjacent to occluder 76 and/or downstream finger 78, to determine whether these elements are functioning properly.

[0028] FIG. 1B depicts an example patient care unit 12 shown, according to various aspects of the subject technology. FIG. 1B shows two functional infusion pumps 10 (e.g., “infusion pump modules”) mounted at either side of a main frame infusion controller 14, and the displays and control keys of each, with the main frame infusion controller 14 being capable of programming both infusion pumps. The infusion device includes a door 5a and a handle 5b that operates to lock the door in a closed position for operation and to unlock and open the door for access to the internal pumping and sensing mechanisms and to load administration sets for the pump. When the door 5a is open, the tube can be connected with the pump 10. When the door 5a is closed, the tube is brought into operating engagement with the pumping mechanism, the upstream and downstream pressure sensors, and the other equipment of the pump. A display 5c, such as an LED display, is located in plain view on the door in this embodiment and may be used to visually communicate various information relevant to the pump 10, such as alert indications (e.g., alarm messages). Control keys 5e-h may exist for programming and

controlling operations of the infusion pump as desired. In some implementations, the control keys may be presented as interactive elements on the display 5c (e.g., touchscreen display). The main frame and/or functional module may also include audio alert equipment in the form of a speaker (not shown).

[0029] The main frame infusion controller 14 of the patient care unit 12 includes a display 6a for visually communicating various information, such as the operating parameters of a connected pump and alert indications and alert messages, and control keys 6b and 6c for selecting and/or setting control parameters and/or options for controlling the patient care unit 12 and connected modules. The main frame infusion controller 14 may also include a speaker to provide audible alerts. In some implementations, the display 6a may be implemented as a touchscreen display. In such implementations, the control keys 6b may be omitted or reduced in number by providing corresponding interactive elements via a graphical user interface presented via the display 6a. In some implementations, each control key 6b (or 6c) may select a corresponding option displayed in display 6b.

[0030] The main frame infusion controller 14 may include a communications system (not shown) with which the main frame infusion controller 14 may communicate with external equipment such as a medical facility server or other computer and with a portable processor, such as a handheld communication device or a laptop-type of computer, or other information device that a clinician may have to transfer information as well as to download drug libraries to a functional module 10. The communication module may be used to transfer access and interaction information for clinicians encountering the main frame infusion controller or device coupled therewith (e.g., pump 10 or bar code scanner). The communications system may include one or more of a radio frequency (RF) system, an optical system such as infrared, a BLUETOOTH™ system, or other wired or wireless system. The bar code scanner and communications system may alternatively be included integrally with the infusion pump 10, such as in cases where a main frame infusion controller is not used, or in addition to one with the main frame infusion controller 14. Further, information input devices need not be hard-wired to medical instruments, information may be transferred through a wireless connection as well. Additionally, other types of modules may be connected to the pump modules or to the main frame infusion controller such as a syringe pump module, patient controlled analgesic module, end tidal CO₂ monitoring module, oximeter monitoring module, or the like.

[0031] FIG. 2 depicts an example pumping mechanism 120 of an infusion device 10 including two occluder valves 100, 110 (e.g., pumping elements 72, 76), according to various aspects of the subject technology. A typical medical pump for IV infusion delivery has two occluders, a first occluder 100 located upstream and a second occluder 110 located downstream, with a plunger 120 (e.g., pumping element 74) in between. The occluders and plunger coordinate with each other in programmable, sequential steps, controlled by a cam shaft to have two phases: 1) a filling phase, and 2) a delivery phase. The occluders move fluid in a tubing 103 by sequentially compressing the tubing, thereby causing a flow in a direction 104 according to the particular compression sequence of the occluders.

[0032] During the medication infusion process, in the filling phase, the upstream occluder 100 lifts to suck the medication into the tubing segment, which creates a pause, followed by the delivery phase to push the fluid out. These sequences can repeat through multiple cycles. To specify, when the plunger of a single plunger/tubing design is lifted from the tubing segment during the filling phase, there will be a disruption in the continuous infusion process.

[0033] FIG. 3 depicts an example occluder valve 120, according to various aspects of the subject technology. According to various implementations, there are two occluder elements 130; one for the upper occluder 72, and one for the lower occluder 76 of FIG. 1A. Occluder element 130 is configured to move according to a cam motion of a cam 132 to apply a periodic compression to a flexible infusion line 134 when the flexible infusion line is placed between the occluder element 130 and a plate assembly 136, also termed “platen”. In this regard, the cam motion oscillates the occluder element 130 to occlude a fluid within the flexible infusion line by periodically compressing the flexible infusion line. Compression springs 139 apply a constant force to the occluder element 130, forcing it against the plate assembly 136, while the cam 132 applies a force at predetermined intervals in an opposite direction, moving the lower portion of the occluder element responsible for compressing the infusion line 134 away from the plate assembly. Each cam 132 may be elliptical in shape and may rotate on an axis off center of the ellipse.

[0034] In the example of FIG. 3, the occluder element 130 is shown in the top dead center position (top position) with the stroke of the cam is fully upward and with the occluder element furthest apart from the plate assembly 136. A normal occluder element 130 compresses a tubing with a predetermined tolerance. That is, the occluder valve has a certain gap tolerance, or threshold distance between the platen 136 and the occluder element 130 when it is fully

extended whereby the occluder element 130 will still fully compress the tubing 134. The platen 136 may be capable of moving towards and away with respect to the valve structure, and may be mechanically connected to the door mechanism of the door 50 shown in FIG. 1A. In this regard, the platen 136 may move away from the occluder element and an upper frame 139 of the valve 120 when the door 30 is opened, and move to lock in place as depicted in FIG. 3 when the door 50 is closed.

[0035] FIG. 4 depicts an example camshaft of an infusion pump 10, according to various aspects of the subject technology. As described previously, upper and lower occluders 72, 76, and intermediate finger(s) 74 may each be movable by a cam 140. Integrally connected onto camshaft 140 at predetermined locations along the axis of the camshaft 140 may be a series of cam lobes 150. As will be appreciated by those skilled in the pertinent art, cam lobes 150 are eccentrically mounted on camshaft 140 in a pattern along the axis of camshaft 140 and are engaged with a respective pump element in a manner which, in some implementations, may create a wave-like movement of pumping elements when the camshaft 140 is rotated.

[0036] Once the fluid tubing of an infusion set 66 is loaded in infusion pump 10 and engaged with the four finger pump assembly, the door 50 is closed. The closure of door 50 causes the platen to contact a section of the tubing and enclose the section between the platen and a tube support (not shown) for supporting the tube in substantially a flat linear orientation. Activation of a stepper motor rotates a drive shaft causing a drive pulley to rotate the camshaft. The actual positioning of camshaft 140 may be represented by respective camshaft rotation angles θ , as depicted in FIG. 5. Revolution of camshaft 140 will cause the series of cam lobes 150 to reciprocate the pumping elements in a direction substantially perpendicular to the axis of, for example, the intermediate section of resiliently compressible tubing. Due to the configuration of cam lobes 150 on camshaft 140, the pumping elements may be sequentially urged against the tubing to create a moving zone of occlusion along the length the tubing during revolution of camshaft 140.

[0037] According to various implementations, the stepper motor assembly (not shown) and/or cam 140 of infusion pump 10 may be coupled to an encoder. In this manner, the encoder may encode the turns and/or steps of the motor and/or the cam 140 for use in determining the current rotation angle of the cam 140. The encoder may transmit a single to the infusion pump's control unit (e.g., within main frame controller 14) which may, as described in further detail below, associate the current angle of the cam 140 with a pressure value.

[0038] FIG. 5 depicts an example cam phase diagram corresponding to a fluid delivery cycle of an infusion pump, according to various aspects of the subject technology. Each row depicted in FIG. 5 corresponds to a pumping element 72, 74, 76, 78, and illustrates an example pumping function of the element according to a complete cam rotation (360°). That is which pumping elements are closing (compressing the tube) and which elements are opening, thereby creating an aspiration phase and a dispensing phase.

[0039] In the depicted example, initially, from 0° to 90°, the upper occluder 72 is open, while the lower occluder remains closed. The upper occluder 72 completes closing at about 120°; however, the fluid tubing may be sufficiently compressed to stop aspiration of the fluid at about 110°. The lower occluder remains closed until the cam reaches 140°. While the upper occluder 72 is open—until it begins to close at about 90°—the upper finger 74 is aspirating. The upper occluder closes between 90-120°, and the lower occluder begins to open at 140°. At this point, the lower finger will begin to deliver the fluid. In the depicted example, delivery begins at about 145°, with about 5° rotation accounting for the time to decompress the tubing.

[0040] FIG. 6 depicts example fill and delivery phases, according to various aspects of the subject technology. In the depicted example, the infusion pump 10 is designed such that one occluder is always closed to prevent uncontrolled flow. With reference to FIGS. 4 and 5, the rotation of the cam 140 determines whether the pump is in the fill phase (206) or the delivery phase (208). During the fill phase (e.g., between a cam rotation angles of 312° and 112°) the lower occluder is closed and the upper occluder is open, letting the fluid from the bag into the pumping chamber. The secondary pumping finger pushes the fluid toward the patient. At the end of the fill phase (e.g., between the cam rotation angles of 112° and 312°), the upper occluder gets closed (i.e., both occluders are closed).

[0041] During the delivery phase (e.g., between cam rotation angles of 132° and 292°), the lower occluder gets opened and the primary pumping finger pushes the fluid toward the patient. At the end of the delivery phase (e.g., between the cam rotation angles of 292° and 132°), the lower occluder gets closed (i.e., both occluders are closed). Afterward, the upper occluder gets opened and the process repeats. Under normal conditions, free flow is not possible because one of the occluders is always engaged.

[0042] FIG. 7A depicts a first example profile of delivery variations over a given fluid delivery cycle of an infusion pump, according to various aspects of the subject technology.

According to various implementations, the amount of fluid delivered during a pump's fluid delivery cycle is not linear. The depicted chart graphs a weight w of fluid delivery 210 over time t . Delivery of the fluid increases 212 and decreases 214 depending on the point in the delivery cycle; e.g., depending on the current angle of rotation. While a sinusoidal delivery profile 210 is visualized, it is understood that increases or decreases in fluid delivery may appear to be randomized throughout any given cycle, or be based on a different predetermined pattern.

[0043] The subject technology characterizes a pump (or type of pump) over its fluid delivery cycle, to identify variations in delivery from a linear delivery. As an example, under-delivery may occur during a refill phase and over-delivery may occur during a delivery phase, or vice versa. Characterization of the pump may occur during manufacturing (e.g., for the type of pump generally) or may occur in real-time based on flow monitoring and machine learning principles. In some implementations, characterization (or profiling) the pump identifies an increase in fluid delivery for a range of positions within a fluid delivery cycle and identifies a decrease in fluid delivery for another range of positions.

[0044] Typically, a pump may deliver a relatively small amount of fluid per cycle (or cam rotation). For example, in a linear model 216, a full rotation of a LVP's cam may, on average, deliver about 0.17 mL of fluid, depending on calibration. If a pump is programmed to deliver a 0.5 mL bolus, the pump may perform 2.92 rotations, starting at a starting position (e.g., given cam angle), to complete the bolus. A 0.1 mL bolus may require 0.58 rotations, or 210°. According to various implementations, at a starting position of a_0 (e.g., 75° cam rotation), delivery may be accurate and stable (within an acceptable tolerance), while at a_2 (e.g., 175°) the delivery may be at a maximum over-delivery. Using the subject technology, if the pump starts at a position of over-delivery then the pump may determine that 0.45 rotations, or 162°, would complete the delivery of the same amount (0.1 mL). The pump may then proceed to deliver the 0.1 mL bolus by rotating the cam 162° from the starting position.

[0045] In some implementations, the pump software keeps track of the number of steps the motor has traveled and adds a correction based on the pump's delivery profile (and variations). In some implementations, the software determines a motor duration (e.g., in degrees or time) to perform the bolus based on the delivery variations following the starting position. In some implementations, the number of cycles or sub-cycles (measured in, e.g., degrees or steps) may

be determined by integrating an area under the variations of a given curve, such as the fluid delivery profile 210 of FIG. 7A. Accordingly, the amount delivered may resolve to:

$$b = \int_{a-start}^{a-end} f(x) \quad (\text{eq. 1})$$

where b is the bolus amount and f(x) is the fluid delivery profile. In some implementations, the number of cycles and/or sub-cycles may be determined based on summation of known variations following the starting position. In this manner, the estimation of the total fluid delivery period for the bolus (and ending position) may occur in real time during the bolus.

[0046] In some implementations, the pump software may determine cumulative fluid delivery variations from a linear delivery based on a fixed amount (e.g., 0.17 mL) per cycle for an estimated number of cycles, beginning at the starting position, and then adjust the number of cycles to perform the bolus based on a function identified delivery variations over each cycle. In this regard, based on a linear determination, an ending position at which the bolus is completed can be estimated. The ending position may be within a given fluid delivery cycle. The ending position may be adjusted before the bolus is initialized or during the bolus. For example, the software may estimate a number of cam rotations to perform the bolus based on a linear delivery of fluid throughout the bolus, absent the predetermined fluid delivery variations. The software may then determine an adjustment by indexing a table based on the starting position and bolus amount, and increase or decrease the number of cam rotations by the adjustment returned from the table. In some implementations, the software may identify delivery variations subsequent to the starting position and then determine the number of cycles and/or sub-cycles based on a cumulative estimation of the fluid delivery (including the variations) from the starting position, for example, in real time.

[0047] FIG. 7B depicts a second example profile of delivery variations over a given fluid delivery cycle of an infusion pump, according to various aspects of the subject technology. In the depicted example, a delivery profile is characterized for one or more pumps 218 over a full 360° cam rotation, e.g., to determine a relative bolus error. Under-infusion is determined in a zone (or range) between about 275° and 360°, and between 0° and 75°, and over-infusion between about 100° and 260°. In this regard, the pump software may characterize the cycle into two or more zones (or ranges). As will be described further, an adjustment to the infusion may then be made based on in which zone the bolus begins.

[0048] Accordingly, the pump software may identify an increase in fluid delivery for a first range 220 of positions within a respective fluid delivery cycle, and identify a decrease in fluid delivery for a second range 222 of positions within the respective fluid delivery cycle. A third range 224 may be assigned to period in which the fluid delivery is relatively stable (e.g., within a tolerance). Given this information, the pump software may then adjust the fluid delivery period based on whether the starting position is within the first range or the second range. A predetermined adjustment may be assigned to each range (or zone). For example, a -10% adjustment may be assigned to the zone(s) or cycle range(s) corresponding to under-infusion; a +10% adjustment may be assigned to zone(s) or cycle range(s) corresponding to under-infusion, and no adjustment may be assigned to the remaining zones (e.g., between under-infusion and over-infusion zones). Accordingly, the pump software is preprogrammed with a number of fluid delivery cycles to perform a given bolus based on a linear delivery of fluid. This number may then be adjusted by applying the adjustment for the given zone associated with the starting position.

[0049] According to various implementations, the pump software adjusts a predetermined fluid delivery period (e.g., based on a linear delivery). If the starting position falls within a zone having a +10% adjustment then the duration of the fluid delivery period may be adjusted by +10%. Accordingly, based on a linear delivery of 0.17 mL per cycle and a 0.5 mL bolus, the default fluid delivery period of 2.94 cycles/rotations may be increased to 3.24 rotations. In some implementations, the adjustment may be further adjusted based on the size of the bolus. As the bolus volume increases the potential error decreases due to the starting cam position. Accordingly, the adjustment (e.g., for the zone) may be decreased a predetermined amount according to an increase in the bolus size. For example, a bolus of 0.5 mL may not include a further adjustment, while a bolus of 2 mL may include a bolus adjust adjustment of 50%, e.g., further modifying a 10% adjustment to 5%. In some implementations, the adjustment may only be applied to the first delivery cycle of multiple delivery cycles.

[0050] It is understood that, while the depicted example includes three zones, more than three zones (or ranges) may be identified for a fluid delivery cycle of an infusion device, each with a different adjustment. The adjustment may be increased according to the magnitude of under-infusion, or increased according to the magnitude of under-infusion. Moreover, since a cycle typically traverses a single direction (e.g., increasing degrees), the zones may be offset of actual under or over infusion determinations. That is, if an over-infusion begins primarily at

100° then a starting position may be considered to be in the zone earlier than 100° to ensure the over-infusion adjustment is properly applied regardless of how far within the zone is the starting position.

[0051] FIG. 8 depicts a second example process 250 for testing a pumping element, according to aspects of the subject technology. For explanatory purposes, the various blocks of example process 250 are described herein with reference to FIGS. 1 through 7, and the components and/or processes described herein. The one or more of the blocks of process 250 may be implemented, for example, by one or more computing devices including, for example, within infusion device 12. In some implementations, one or more of the blocks may be implemented based on one or more machine learning algorithms. In some implementations, one or more of the blocks may be implemented apart from other blocks, and by one or more different processors or devices. Further for explanatory purposes, the blocks of example process 250 are described as occurring in serial, or linearly. However, multiple blocks of example process 250 may occur in parallel. In addition, the blocks of example process 250 need not be performed in the order shown and/or one or more of the blocks of example process 250 need not be performed.

[0052] In the depicted example, the infusion pump 10 is configured to deliver a fluid through an infusion line loaded into the infusion pump by causing an amount of the fluid to be delivered through an infusion line according to a fluid delivery cycle. At least one occluder element of an infusion pump 10 is activated to compress the fluid tubing filled with a fluid, to move the fluid in an upstream portion of the fluid tubing (e.g., in a fluid container upstream of the pump) to a downstream portion of the tubing, downstream of the infusion pump 10. As described previously, the infusion pump 10 includes or is associated with a control unit. The control unit may be part of a patient care unit 12 or may be implemented as a processing component within the infusion pump 10.

[0053] The control unit receives a command for the infusion pump to initiate a bolus of the fluid (252). The bolus may be any amount, including less than 1 mL or more than 100 mL. According to various implementations, the pump software is programmed delivery a fixed amount of fluid during each cycle. For example, the pump may be configured to delivery 0.17 mL per fluid delivery cycle (e.g., each rotation of the cam). This amount may be adjusted based on the type of fluid or type of tubing used to delivery the fluid. For example, heavier fluids and/or heavier tubing may require a longer fluid delivery period to deliver the same

amount, and the predetermined amount delivered each cycle may be stored in a memory, indexed by the fluid type and/or tubing type.

[0054] The control unit, responsive to receiving the command and before initiating the bolus, determines a starting position within the fluid delivery cycle at which the bolus is initiated (254). According to various implementations, the starting position is a position within the current cycle at which the bolus will start. That is, if the pump is currently operating (e.g., cycling), the starting position will be the point in a respective cycle wherein the bolus will start. If the pump is currently stopped or paused then the starting position may be the point in the cycle where the pump is currently stopped and will begin again with the bolus is initiated.

[0055] A cycle may be synonymous with a degree of cam rotation. However, in some implementations, each fluid delivery cycle may include a predetermined number of motor steps and the starting position may be a particular number of motor steps into a given cycle. In some implementations, the starting position may be represented by a percentage or fraction of the cycle (e.g., 0.54 of a cycle). Accordingly, the control unit may determine an end of a fluid delivery period (e.g., including an ending position) by dividing the bolus amount by the fixed delivery amount per cycle and adding the result to the starting position.

[0056] The control unit identifies predetermined fluid delivery variations that occur over the fluid delivery cycle (256). With brief reference to FIGS. 7A and 7B, fluid variations are variations from a fixed linear delivery over a cycle. As the cycle progresses (e.g., the cam rotates), the pump will fluctuate in its delivery and will vary. The control unit may, in some implementations, identify variations by indexing a lookup table based on the starting position. The table may include a variation from the pump's linear delivery profile 216 for each zone, or for each degree of the cycle (e.g., cam angle), or for each motor step of the cycle. In some implementations, identifying the variation may return an amount of fluid delivered for a particular portion of the cycle. In some implementation, the variation will be identified apart from the total amount of fluid delivered. According to various implementations, the sum of fluctuations over a cycle may equate to zero; that is, the over-infusion events may equal the under-infusion events; however, the over and under infusion events may vary throughout the cycle.

[0057] In some implementations, identifying the fluid variations includes determining a zone and/or adjustment for the zone based on the starting position. In this regard, the control

unit may identify an increase in fluid delivery for a first range of positions within a respective fluid delivery cycle and a decrease in fluid delivery for a second range of positions within the respective fluid delivery cycle. In some implementations, an increase or decrease in motor duration or number of motor steps for the bolus (from a default duration or number) may be identified based on the zone. In some implementations, an increase or decrease in cam rotations may be identified (e.g., based on the zone in which the cam angle of the starting position falls). In some implementations, identifying the fluid variations occurs in real time together with the next step of estimating the fluid delivery period.

[0058] The control unit estimates a fluid delivery period to perform the bolus based on a function of the determined starting position and the identified predetermined fluid variations (258). The estimate of the fluid delivery period is different than an estimate based on the function absent the predetermined fluid delivery variations. As described previously, the control unit may first determine a default fluid delivery period for the bolus based on a linear delivery model, and then modify that fluid delivery period based on the identified variations to determine the estimated (revised) fluid delivery period for the bolus.

[0059] In some implementations, the control unit may index the table by the starting position and (in some implementations) the volume of the bolus, and the table may return the number of fluid delivery cycles (which may be less than a whole number) to perform the bolus. The control unit may then determine the ending position in the current cycle or future cycle at which the bolus will be completed. As an example, the control unit may estimate a number of cam rotations to perform the bolus, where the estimated number of cam rotations includes at least one partial rotation (e.g., 1.02 cam rotations), which may then be added to the current cam angle to determine the cam angle at which the bolus will be completed. In some implementations, the control unit determines a number of default motor steps to complete the bolus, and increases or reduces that number based on the starting position.

[0060] In some implementations, the fluid delivery period is determined based on integration of fluid delivery variations over the fluid delivery cycle. In this regard, the function of the estimation may involve an integral of fluid delivery over the fluid delivery cycle, accounting for the identified predetermined fluid variations, and determining the bounds of the integral. For example, an integral of a predetermined fluid delivery curve 210 for the pump, as shown in FIG. 7A. In some implementations, an integral equation such as in eq. 1 may be solved for the ending position α_{end} .

[0061] In some implementations, the estimation is further based on a function of the size of the bolus. During the setup of the infusion therapy, a clinician may cause the pump to receive the size (e.g., volume) of the bolus. Entry of the bolus parameters such as volume may be received via input control keys 5e-h or 6b or 6c, or via a touch screen input 6a. In some implementations, bolus parameters are received from a remote device or computing system. For example, the clinician may use a terminal to cause an information server to send an automated programming request directly to the pump to program the pump with the bolus parameters, or may use a mobile device or other terminal operably connected to the pump to enter the parameters. In implementations where the previously described lookup table is indexed by the size of the bolus, the control unit may provide the bolus size to the lookup table. In some implementations, the size may be provided to a separate table (or database), and a modification of the previously described adjustment may be determined based on the size.

[0062] The control unit delivers the bolus by causing the fluid to be delivered through the infusion line according to a fluid delivery cycle for the estimated fluid delivery period (260). The pump begins to pump the fluid for the estimated fluid delivery period, which may be a number of cam cycles, motor steps, or a motor duration and ends at an ending positioned determined by the previously described estimation.

[0063] In some implementations, the control unit may determine a predetermined ending position within a fluid delivery cycle at which the bolus will be completed and adjust the ending position based on the starting position and the identified predetermined fluid delivery variations. The pump may then deliver the fluid up until the determined ending position.

[0064] Many of the above-described devices, systems and methods, may also be implemented as software processes that are specified as a set of instructions recorded on a computer readable storage medium (also referred to as computer readable medium), and may be executed automatically (e.g., without user intervention). When these instructions are executed by one or more processing unit(s) (e.g., one or more processors, cores of processors, or other processing units), they cause the processing unit(s) to perform the actions indicated in the instructions. Examples of computer readable media include, but are not limited to, CD-ROMs, flash drives, RAM chips, hard drives, EPROMs, etc. The computer readable media does not include carrier waves and electronic signals passing wirelessly or over wired connections.

[0065] The term “software” is meant to include, where appropriate, firmware residing in read-only memory or applications stored in magnetic storage, which can be read into memory for processing by a processor. Also, in some implementations, multiple software aspects of the subject disclosure can be implemented as sub-parts of a larger program while remaining distinct software aspects of the subject disclosure. In some implementations, multiple software aspects can also be implemented as separate programs. Finally, any combination of separate programs that together implement a software aspect described here is within the scope of the subject disclosure. In some implementations, the software programs, when installed to operate on one or more electronic systems, define one or more specific machine implementations that execute and perform the operations of the software programs.

[0066] A computer program (also known as a program, software, software application, script, or code) can be written in any form of programming language, including compiled or interpreted languages, declarative or procedural languages, and it can be deployed in any form, including as a stand-alone program or as a module, component, subroutine, object, or other unit suitable for use in a computing environment. A computer program may, but need not, correspond to a file in a file system. A program can be stored in a portion of a file that holds other programs or data (e.g., one or more scripts stored in a markup language document), in a single file dedicated to the program in question, or in multiple coordinated files (e.g., files that store one or more modules, sub programs, or portions of code). A computer program can be deployed to be executed on one computer or on multiple computers that are located at one site or distributed across multiple sites and interconnected by a communication network.

[0067] FIG. 9 is a conceptual diagram illustrating an example electronic system 600 for improving fluid delivery accuracy of an infusion device, according to aspects of the subject technology. Electronic system 600 may be representative of a control unit and/or computing device for execution of software associated with one or more components and processes provided by FIGS. 1 through 8 (e.g., pump software), including but not limited to infusion pump 10 (e.g., a processing system of controller 14 or within infusion pump 10). Electronic system 600 may be representative of a device used in connection or combination with the disclosure regarding FIGS. 1 through 8. In this regard, electronic system 600 may be a device connected to the infusion device 10, for example, to activate the occluders and/or pumping fingers, the cam 142, or to monitor or control same. For example, system 600 may be representative of a personal computer or a mobile device such as a smartphone, tablet

computer, laptop, personal digital assistant (PDA), an augmented reality device, a wearable such as a watch or band or glasses, or combination thereof, or other touch screen or television with one or more processors embedded therein or coupled thereto, or any other sort of computer-related electronic device having network connectivity specifically configured to implement one or more of the features described.

[0068] Electronic system 600 may include various types of computer readable media and interfaces for various other types of computer readable media. In the depicted example, electronic system 600 includes a bus 608, processing unit(s) 612, a system memory 604, a read-only memory (ROM) 610, a permanent storage device 602, an input device interface 614, an output device interface 606, and one or more network interfaces 616. In some implementations, electronic system 600 may include or be integrated with other computing devices or circuitry for operation of the various components and processes previously described.

[0069] Bus 608 collectively represents all system, peripheral, and chipset buses that communicatively connect the numerous internal devices of electronic system 600. For instance, bus 608 communicatively connects processing unit(s) 612 with ROM 610, system memory 604, and permanent storage device 602.

[0070] From these various memory units, processing unit(s) 612 retrieves specific instructions to execute and data to process, in order to execute the processes of the subject disclosure. The processing unit(s) can be a single processor or a multi-core processor in different implementations.

[0071] ROM 610 stores static data and instructions that are needed by processing unit(s) 612 and other modules of the electronic system. Permanent storage device 602, on the other hand, is a read-and-write memory device. This device is a non-volatile memory unit that stores instructions and data even when electronic system 600 is off. Some implementations of the subject disclosure use a mass-storage device (such as a magnetic or optical disk and its corresponding disk drive) as permanent storage device 602.

[0072] Other implementations use a removable storage device (such as a floppy disk, flash drive, and its corresponding disk drive) as permanent storage device 602. Like permanent storage device 602, system memory 604 is a read-and-write memory device. However, unlike storage device 602, system memory 604 is a volatile read-and-write memory, such as random access memory. System memory 604 stores some of the instructions and data that the processor

needs at runtime. In some implementations, the processes of the subject disclosure are stored in system memory 604, permanent storage device 602, and/or ROM 610. From these various memory units, processing unit(s) 612 retrieves instructions to execute and data to process, in order to execute the processes of some implementations.

[0073] Bus 608 also connects to input and output device interfaces 614 and 606. Input device interface 614 enables the user to communicate information and select commands to the electronic system. Input devices used with input device interface 614 include, e.g., alphanumeric keyboards and pointing devices (also called “cursor control devices”). Output device interfaces 606 enables, e.g., the display of images generated by the electronic system 600. Output devices used with output device interface 606 include, e.g., printers and display devices, such as cathode ray tubes (CRT) or liquid crystal displays (LCD). Some implementations include devices such as a touchscreen that functions as both input and output devices.

[0074] Also, as shown in FIG. 9, bus 608 also couples electronic system 600 to a network (not shown) through network interfaces 616. Network interfaces 616 may include, e.g., a wireless access point (e.g., Bluetooth or WiFi) or radio circuitry for connecting to a wireless access point. Network interfaces 616 may also include hardware (e.g., Ethernet hardware) for connecting the computer to a part of a network of computers such as a local area network (“LAN”), a wide area network (“WAN”), wireless LAN, a personal area network (“PAN”), or an Intranet, or a network of networks, such as the Internet. Any or all components of electronic system 600 can be used in conjunction with the subject disclosure.

[0075] These functions described above can be implemented in computer software, firmware, or hardware. The techniques can be implemented using one or more computer program products. Programmable processors and computers can be included in or packaged as mobile devices. The processes and logic flows can be performed by one or more programmable processors and by one or more programmable logic circuitry. General and special purpose computing devices and storage devices can be interconnected through communication networks.

[0076] Some implementations include electronic components, such as microprocessors, storage and memory that store computer program instructions in a machine-readable or computer-readable medium (also referred to as computer-readable storage media, machine-

readable media, or machine-readable storage media). Some examples of such computer-readable media include RAM, ROM, read-only compact discs (CD-ROM), recordable compact discs (CD-R), rewritable compact discs (CD-RW), read-only digital versatile discs (e.g., DVD-ROM, dual-layer DVD-ROM), a variety of recordable/rewritable DVDs (e.g., DVD-RAM, DVD-RW, DVD+RW, etc.), flash memory (e.g., SD cards, mini-SD cards, micro-SD cards, etc.), magnetic and/or solid state hard drives, read-only and recordable Blu-Ray® discs, ultra density optical discs, any other optical or magnetic media, and floppy disks. The computer-readable media can store a computer program that is executable by at least one processing unit and includes sets of specific instructions for performing various operations described herein. Examples of computer programs or computer code include machine code, such as is produced by a compiler, and files including higher-level code that are executed by a computer, an electronic component, or a microprocessor using an interpreter.

[0077] While the above discussion primarily refers to microprocessor or multi-core processors that execute software, some implementations are performed by one or more integrated circuits, such as application specific integrated circuits (ASICs) or field programmable gate arrays (FPGAs) specifically configured with one or more of the features described. In some implementations, such integrated circuits execute instructions that are stored on the circuit itself.

[0078] As used in this specification and any claims of this application, the terms “computer”, “server”, “processor”, and “memory” all refer to electronic or other technological devices. These terms exclude people or groups of people. For the purposes of the specification, the terms display or displaying means displaying on an electronic device. As used in this specification and any claims of this application, the terms “computer readable medium” and “computer readable media” are entirely restricted to tangible, physical objects that store information in a form that is readable by a computer. These terms exclude any wireless signals, wired download signals, and any other ephemeral signals.

[0079] To provide for interaction with a user, implementations of the subject matter described in this specification can be implemented on a specifically configured computer having a display device, e.g., a CRT (cathode ray tube) or LCD (liquid crystal display) monitor, for displaying information to the user and a keyboard and a pointing device, e.g., a mouse or a trackball, by which the user can provide input to the computer. Other kinds of specifically configured devices can be used to provide for interaction with a user as well; e.g., feedback

provided to the user can be any form of sensory feedback, e.g., visual feedback, auditory feedback, or tactile feedback; and input from the user can be received in any form, including acoustic, speech, or tactile input. In addition, a computer can interact with a user by sending documents to and receiving documents from a device that is used by the user; e.g., by sending web pages to a web browser on a user's client device in response to requests received from the web browser.

[0080] Implementations of the subject matter described in this specification can be implemented in a specifically configured computing system that includes a back end component, e.g., as a data server, or that includes a middleware component, e.g., an application server, or that includes a front end component, e.g., a client computer having a graphical user interface or a Web browser through which a user can interact with an implementation of the subject matter described in this specification, or any combination of one or more such back end, middleware, or front end components. The components of the system can be interconnected by any form or medium of digital data communication, e.g., a communication network. Examples of communication networks include a local area network ("LAN") and a wide area network ("WAN"), an inter-network (e.g., the Internet), and peer-to-peer networks (e.g., ad hoc peer-to-peer networks).

[0081] The computing system can include clients and servers. A client and server are generally remote from each other (e.g., physically separated) and may interact through a communication network. The relationship of client and server arises by virtue of computer programs running on the respective computers and having a client-server relationship to each other. In some implementations, a server transmits data (e.g., an HTML page) to a client device (e.g., for purposes of displaying data to and receiving user input from a user interacting with the client device). Data generated at the client device (e.g., a result of the user interaction) can be received from the client device at the server.

[0082] Those of skill in the art would appreciate that the various illustrative blocks, modules, elements, components, methods, and algorithms described herein may be implemented as electronic hardware, computer software, or combinations of both. To illustrate this interchangeability of hardware and software, various illustrative blocks, modules, elements, components, methods, and algorithms have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system.

The described functionality may be implemented in varying ways for each particular application. Various components and blocks may be arranged differently (e.g., arranged in a different order, or partitioned in a different way) all without departing from the scope of the subject technology.

[0083] It is understood that the specific order or hierarchy of steps in the processes disclosed is an illustration of example approaches. Based upon design preferences, it is understood that the specific order or hierarchy of steps in the processes may be rearranged. Some of the steps may be performed simultaneously. The accompanying method claims present elements of the various steps in a sample order, and are not meant to be limited to the specific order or hierarchy presented.

[0084] Illustration of Subject Technology as Clauses:

[0085] Various examples of aspects of the disclosure are described as numbered clauses (1, 2, 3, etc.) for convenience. These are provided as examples, and do not limit the subject technology. Identifications of the figures and reference numbers are provided below merely as examples and for illustrative purposes, and the clauses are not limited by those identifications.

[0086] Clause 1. A system for improving fluid delivery accuracy of an infusion device, comprising: an infusion pump configured to deliver a fluid through an infusion line loaded into the infusion pump by causing an amount of the fluid to be delivered through an infusion line according to a fluid delivery cycle; and a control unit configured to: receive a command for the infusion pump to initiate a bolus of the fluid; determine, responsive to receiving the command and before initiating the bolus, a starting position within the fluid delivery cycle at which the bolus is initiated; identify predetermined fluid delivery variations that occur over the fluid delivery cycle; estimate, based on a function of the starting position and the identified predetermined fluid delivery variations, a fluid delivery period to perform the bolus, the estimate of the fluid delivery period being different than an estimate based on the function absent the predetermined fluid delivery variations; and deliver the bolus by causing the fluid to be delivered, according to the fluid delivery cycle, through the infusion line for the estimated fluid delivery period.

[0087] Clause 2. The system of Clause 1, wherein identifying the predetermined fluid delivery variations comprises: identifying an increase in fluid delivery for a first range of positions within a respective fluid delivery cycle; and identifying a decrease in fluid delivery

for a second range of positions within the respective fluid delivery cycle, and wherein estimating the fluid delivery period comprises adjusting a predetermined fluid delivery period for the bolus based on whether the starting position is within the first range or the second range.

[0088] Clause 3. The system of Clause 1, wherein estimating the fluid delivery period comprises: adjusting a predetermined motor duration for the bolus by a first duration when the starting position is within a first range of positions in the fluid delivery cycle, and by a second duration when the starting position is within a second range of positions in the fluid delivery cycle.

[0089] Clause 4. The system of any one of Clauses 1 to 3, wherein the fluid delivery cycle comprises a complete rotation of a cam responsible for operating a peristaltic pumping mechanism; wherein determining the starting position comprises determining a starting cam position; wherein estimating the fluid delivery period to perform the bolus comprises estimating a number of cam rotations to perform the bolus, wherein the estimated number of cam rotations includes at least one partial rotation; and wherein causing the fluid to be delivered for the estimated fluid delivery period comprises performing the estimated number of cam rotations.

[0090] Clause 5. The system of Clause 4, wherein estimating the number of cam rotations comprises: cumulating the predetermined fluid delivery variations beginning at the starting position up until the bolus is satisfied; and adjusting a predetermined number of cam rotations for the bolus based on the cumulated predetermined fluid delivery variations.

[0091] Clause 6. The system of Clause 4, wherein adjusting the number of cam rotations comprises: reducing a predetermined number of cam rotations for the bolus when the starting cam position is between a first range of cam angles, and increasing the predetermined number of cam rotations for the bolus when the starting cam position is between a second range of cam angles.

[0092] Clause 7. The system of Clause 1, wherein estimating the fluid delivery period based on a function of the starting position and the identified predetermined fluid delivery variations comprises integrating fluid delivery over at least a portion of the fluid delivery cycle while accounting for the identified predetermined fluid delivery variations.

[0093] Clause 8. The system of Clause 1, wherein the control unit is further configured to: identify predetermined fluid delivery variations and estimate the fluid delivery period based on indexing a database based on the starting position of the bolus and adjusting a predetermined fluid delivery period for the bolus based on an adjustment obtained from the database responsive to the indexing.

[0094] Clause 9. The system of Clause 1, wherein the fluid delivery cycle comprises a predetermined number of motor steps, wherein estimating the fluid delivery period comprises: estimating a number of motor steps within a respective cycle to complete the bolus; increasing or reducing the estimated number of motor steps based on the starting position and the identified predetermined fluid delivery variations; and wherein delivering the bolus for the estimated fluid delivery period comprises performing the increased or reduced number of motor steps within the respective cycle.

[0095] Clause 10. The system of any one of Clauses 1 to 9, wherein the control unit is further configured to: receive a size of the bolus; and estimate the fluid delivery period to perform the bolus based on a function of the starting position and the identified predetermined fluid delivery variations and the size of the bolus.

[0096] Clause 11. A method comprising: operating an infusion pump configured to deliver a fluid through an infusion line loaded into the infusion pump by causing an amount of the fluid to be delivered through an infusion line according to a fluid delivery cycle; receiving a command for the infusion pump to initiate a bolus of the fluid; determining, responsive to receiving the command and before initiating the bolus, a starting position within the fluid delivery cycle at which the bolus is initiated; identifying predetermined fluid delivery variations that occur over the fluid delivery cycle; estimating, based on a function of the starting position and the identified predetermined fluid delivery variations, a fluid delivery period to perform the bolus, the estimate of the fluid delivery period being different than an estimate based on the function absent the predetermined fluid delivery variations; and delivering the bolus by causing the fluid to be delivered, according to the fluid delivery cycle, through the infusion line for the estimated fluid delivery period.

[0097] Clause 12. The method of Clause 11, wherein identifying the predetermined fluid delivery variations comprises: identifying an increase in fluid delivery for a first range of positions within a respective fluid delivery cycle; and identifying a decrease in fluid delivery

for a second range of positions within the respective fluid delivery cycle, and wherein estimating the fluid delivery period comprises adjusting a predetermined fluid delivery period for the bolus based on whether the starting position is within the first range or the second range.

[0098] Clause 13. The method of Clause 11, wherein estimating the fluid delivery period comprises: adjusting a predetermined motor duration for the bolus by a first duration when the starting position is within a first range of positions in the fluid delivery cycle, and by a second duration when the starting position is within a second range of positions in the fluid delivery cycle.

[0099] Clause 14. The method of any one of Claims 11 to 13, wherein the fluid delivery cycle comprises a complete rotation of a cam responsible for operating a peristaltic pumping mechanism; wherein determining the starting position comprises determining a starting cam position; wherein estimating the fluid delivery period to perform the bolus comprises estimating a number of cam rotations to perform the bolus, wherein the estimated number of cam rotations includes at least one partial rotation; and wherein causing the fluid to be delivered for the estimated fluid delivery period comprises performing the estimated number of cam rotations.

[0100] Clause 15. The method of Claim 14, wherein estimating the number of cam rotations comprises: cumulating the predetermined fluid delivery variations beginning at the starting position up until the bolus is satisfied; and adjusting a predetermined number of cam rotations for the bolus based on the cumulated predetermined fluid delivery variations.

[0101] Clause 16. The method of Claim 14, wherein adjusting the number of cam rotations comprises: reducing a predetermined number of cam rotations for the bolus when the starting cam position is between a first range of cam angles, and increasing the predetermined number of cam rotations for the bolus when the starting cam position is between a second range of cam angles.

[0102] Clause 17. The method of Claim 11, wherein estimating the fluid delivery period based on a function of the starting position and the identified predetermined fluid delivery variations comprises integrating fluid delivery over at least a portion of the fluid delivery cycle while accounting for the identified predetermined fluid delivery variations.

[0103] Clause 18. The method of Clause 11, further comprising: wherein identifying predetermined fluid delivery variations and estimating the fluid delivery period comprises indexing a database based on the starting position of the bolus and adjusting a predetermined fluid delivery period for the bolus based on an adjustment obtained from the database responsive to the indexing.

[0104] Clause 19. The method of Clause 11, wherein the fluid delivery cycle comprises a predetermined number of motor steps, wherein estimating the fluid delivery period comprises: estimating a number of motor steps within a respective cycle to complete the bolus; increasing or reducing the estimated number of motor steps based on the starting position and the identified predetermined fluid delivery variations; and wherein delivering the bolus for the estimated fluid delivery period comprises performing the increased or reduced number of motor steps within the respective cycle.

[0105] Clause 20. A non-transitory computer-readable medium having instructions stored thereon that, when executed by a computing device, cause the computing device to perform a method according to any one of Clauses 11 to 19.

[0106] Further Consideration:

[0107] In some embodiments, any of the clauses herein may depend from any one of the independent clauses or any one of the dependent clauses. In one aspect, any of the clauses (e.g., dependent or independent clauses) may be combined with any other one or more clauses (e.g., dependent or independent clauses). In one aspect, a claim may include some or all of the words (e.g., steps, operations, means or components) recited in a clause, a sentence, a phrase or a paragraph. In one aspect, a claim may include some or all of the words recited in one or more clauses, sentences, phrases or paragraphs. In one aspect, some of the words in each of the clauses, sentences, phrases or paragraphs may be removed. In one aspect, additional words or elements may be added to a clause, a sentence, a phrase or a paragraph. In one aspect, the subject technology may be implemented without utilizing some of the components, elements, functions or operations described herein. In one aspect, the subject technology may be implemented utilizing additional components, elements, functions or operations.

[0108] The previous description is provided to enable any person skilled in the art to practice the various aspects described herein. The previous description provides various examples of the subject technology, and the subject technology is not limited to these examples.

Various modifications to these aspects will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other aspects. Thus, the claims are not intended to be limited to the aspects shown herein, but is to be accorded the full scope consistent with the language claims, wherein reference to an element in the singular is not intended to mean “one and only one” unless specifically so stated, but rather “one or more.” Unless specifically stated otherwise, the term “some” refers to one or more. Pronouns in the masculine (e.g., his) include the feminine and neuter gender (e.g., her and its) and vice versa. Headings and subheadings, if any, are used for convenience only and do not limit the invention described herein.

[0109] The term website, as used herein, may include any aspect of a website, including one or more web pages, one or more servers used to host or store web related content, etc. Accordingly, the term website may be used interchangeably with the terms, web page and server. As used herein a “user interface” (also referred to as an interactive user interface, a graphical user interface or a UI) may refer to a network based interface including data fields and/or other control elements for receiving input signals or providing electronic information and/or for providing information to the user in response to any received input signals. Control elements may include dials, buttons, icons, selectable areas, or other perceivable indicia presented via the UI that, when interacted with (e.g., clicked, touched, selected, etc.), initiates an exchange of data for the device presenting the UI. A UI may be implemented in whole or in part using technologies such as hyper-text mark-up language (HTML), FLASH™, JAVA™, .NET™, web services, or rich site summary (RSS). In some implementations, a UI may be included in a stand-alone client (for example, thick client, fat client) configured to communicate (e.g., send or receive data) in accordance with one or more of the aspects described. The communication may be to or from a medical device, diagnostic device, monitoring device, or server in communication therewith.

[0110] The predicate words “configured to”, “operable to”, and “programmed to” do not imply any particular tangible or intangible modification of a subject, but, rather, are intended to be used interchangeably. For example, a processor configured to monitor and control an operation or a component, may also mean the processor being programmed to monitor and control the operation or the processor being operable to monitor and control the operation. Likewise, a processor configured to execute code can be construed as a processor programmed to execute code or operable to execute code.

[0111] The term automatic, as used herein, may include performance by a computer or machine without user intervention; for example, by instructions responsive to a predicate action by the computer or machine or other initiation mechanism. The word “example” is used herein to mean “serving as an example or illustration.” Any aspect or design described herein as “example” is not necessarily to be construed as preferred or advantageous over other aspects or designs.

[0112] As used herein, the terms “correspond” or “corresponding” encompasses a structural, functional, quantitative and/or qualitative correlation or relationship between two or more objects, data sets, information and/or the like, preferably where the correspondence or relationship may be used to translate one or more of the two or more objects, data sets, information and/or the like so to appear to be the same or equal. Correspondence may be assessed using one or more of a threshold, a value range, fuzzy logic, pattern matching, a machine learning assessment model, or combinations thereof.

[0113] A phrase such as an “aspect” does not imply that such aspect is essential to the subject technology or that such aspect applies to all configurations of the subject technology. A disclosure relating to an aspect may apply to all configurations, or one or more configurations. An aspect may provide one or more examples. A phrase such as an aspect may refer to one or more aspects and vice versa. A phrase such as an “implementation” does not imply that such implementation is essential to the subject technology or that such implementation applies to all configurations of the subject technology. A disclosure relating to an implementation may apply to all implementations, or one or more implementations. An implementation may provide one or more examples. A phrase such as an “implementation” may refer to one or more implementations and vice versa. A phrase such as a “configuration” does not imply that such configuration is essential to the subject technology or that such configuration applies to all configurations of the subject technology. A disclosure relating to a configuration may apply to all configurations, or one or more configurations. A configuration may provide one or more examples. A phrase such as a “configuration” may refer to one or more configurations and vice versa.

WHAT IS CLAIMED IS:

1. A system for improving fluid delivery accuracy of an infusion device, comprising:
an infusion pump configured to deliver a fluid through an infusion line loaded into the infusion pump by causing an amount of the fluid to be delivered through an infusion line according to a fluid delivery cycle; and
a control unit configured to:
receive a command for the infusion pump to initiate a bolus of the fluid;
determine, responsive to receiving the command and before initiating the bolus, a starting position within the fluid delivery cycle at which the bolus is initiated;
identify predetermined fluid delivery variations that occur over the fluid delivery cycle;
estimate, based on a function of the starting position and the identified predetermined fluid delivery variations, a fluid delivery period to perform the bolus, the estimate of the fluid delivery period being different than an estimate based on the function absent the predetermined fluid delivery variations; and
deliver the bolus by causing the fluid to be delivered, according to the fluid delivery cycle, through the infusion line for the estimated fluid delivery period.
2. The system of Claim 1,
wherein identifying the predetermined fluid delivery variations comprises:
identifying an increase in fluid delivery for a first range of positions within a respective fluid delivery cycle; and
identifying a decrease in fluid delivery for a second range of positions within the respective fluid delivery cycle, and
wherein estimating the fluid delivery period comprises adjusting a predetermined fluid delivery period for the bolus based on whether the starting position is within the first range or the second range.
3. The system of Claim 1, wherein estimating the fluid delivery period comprises:
adjusting a predetermined motor duration for the bolus by a first duration when the starting position is within a first range of positions in the fluid delivery cycle, and by a second

duration when the starting position is within a second range of positions in the fluid delivery cycle.

4. The system of any one of Claims 1 to 3,
wherein the fluid delivery cycle comprises a complete rotation of a cam responsible for operating a peristaltic pumping mechanism;
wherein determining the starting position comprises determining a starting cam position;
wherein estimating the fluid delivery period to perform the bolus comprises estimating a number of cam rotations to perform the bolus, wherein the estimated number of cam rotations includes at least one partial rotation; and
wherein causing the fluid to be delivered for the estimated fluid delivery period comprises performing the estimated number of cam rotations.

5. The system of Claim 4, wherein estimating the number of cam rotations comprises:
cumulating the predetermined fluid delivery variations beginning at the starting position up until the bolus is satisfied; and
adjusting a predetermined number of cam rotations for the bolus based on the cumulated predetermined fluid delivery variations.

6. The system of Claim 4, wherein adjusting the number of cam rotations comprises:
reducing a predetermined number of cam rotations for the bolus when the starting cam position is between a first range of cam angles, and
increasing the predetermined number of cam rotations for the bolus when the starting cam position is between a second range of cam angles.

7. The system of Claim 1, wherein estimating the fluid delivery period based on a function of the starting position and the identified predetermined fluid delivery variations comprises integrating fluid delivery over at least a portion of the fluid delivery cycle while accounting for the identified predetermined fluid delivery variations.

8. The system of Claim 1, wherein the control unit is further configured to:

identify predetermined fluid delivery variations and estimate the fluid delivery period based on indexing a database based on the starting position of the bolus and adjusting a predetermined fluid delivery period for the bolus based on an adjustment obtained from the database responsive to the indexing.

9. The system of Claim 1, wherein the fluid delivery cycle comprises a predetermined number of motor steps, wherein estimating the fluid delivery period comprises:

estimating a number of motor steps within a respective cycle to complete the bolus;
increasing or reducing the estimated number of motor steps based on the starting position and the identified predetermined fluid delivery variations; and
wherein delivering the bolus for the estimated fluid delivery period comprises performing the increased or reduced number of motor steps within the respective cycle.

10. The system of any one of Claims 1 to 9, wherein the control unit is further configured to:

receive a size of the bolus; and
estimate the fluid delivery period to perform the bolus based on a function of the starting position and the identified predetermined fluid delivery variations and the size of the bolus.

11. A method comprising:

operating an infusion pump configured to deliver a fluid through an infusion line loaded into the infusion pump by causing an amount of the fluid to be delivered through an infusion line according to a fluid delivery cycle;

receiving a command for the infusion pump to initiate a bolus of the fluid;
determining, responsive to receiving the command and before initiating the bolus, a starting position within the fluid delivery cycle at which the bolus is initiated;

identifying predetermined fluid delivery variations that occur over the fluid delivery cycle;

estimating, based on a function of the starting position and the identified predetermined fluid delivery variations, a fluid delivery period to perform the bolus, the estimate of the fluid delivery period being different than an estimate based on the function absent the predetermined fluid delivery variations; and

delivering the bolus by causing the fluid to be delivered, according to the fluid delivery cycle, through the infusion line for the estimated fluid delivery period.

12. The method of Claim 11,
wherein identifying the predetermined fluid delivery variations comprises:
 identifying an increase in fluid delivery for a first range of positions within a respective fluid delivery cycle; and
 identifying a decrease in fluid delivery for a second range of positions within the respective fluid delivery cycle, and
wherein estimating the fluid delivery period comprises adjusting a predetermined fluid delivery period for the bolus based on whether the starting position is within the first range or the second range.

13. The method of Claim 11, wherein estimating the fluid delivery period comprises:
 adjusting a predetermined motor duration for the bolus by a first duration when the starting position is within a first range of positions in the fluid delivery cycle, and by a second duration when the starting position is within a second range of positions in the fluid delivery cycle.

14. The method of any one of Claims 11 to 13,
wherein the fluid delivery cycle comprises a complete rotation of a cam responsible for operating a peristaltic pumping mechanism;
 wherein determining the starting position comprises determining a starting cam position;
 wherein estimating the fluid delivery period to perform the bolus comprises estimating a number of cam rotations to perform the bolus, wherein the estimated number of cam rotations includes at least one partial rotation; and
 wherein causing the fluid to be delivered for the estimated fluid delivery period comprises performing the estimated number of cam rotations.

15. The method of Claim 14, wherein estimating the number of cam rotations comprises:

cumulating the predetermined fluid delivery variations beginning at the starting position up until the bolus is satisfied; and

adjusting a predetermined number of cam rotations for the bolus based on the cumulated predetermined fluid delivery variations.

16. The method of Claim 14, wherein adjusting the number of cam rotations comprises:

reducing a predetermined number of cam rotations for the bolus when the starting cam position is between a first range of cam angles, and

increasing the predetermined number of cam rotations for the bolus when the starting cam position is between a second range of cam angles.

17. The method of Claim 11, wherein estimating the fluid delivery period based on a function of the starting position and the identified predetermined fluid delivery variations comprises integrating fluid delivery over at least a portion of the fluid delivery cycle while accounting for the identified predetermined fluid delivery variations.

18. The method of Claim 11, further comprising:

wherein identifying predetermined fluid delivery variations and estimating the fluid delivery period comprises indexing a database based on the starting position of the bolus and adjusting a predetermined fluid delivery period for the bolus based on an adjustment obtained from the database responsive to the indexing.

19. The method of Claim 11, wherein the fluid delivery cycle comprises a predetermined number of motor steps, wherein estimating the fluid delivery period comprises:

estimating a number of motor steps within a respective cycle to complete the bolus;

increasing or reducing the estimated number of motor steps based on the starting position and the identified predetermined fluid delivery variations; and

wherein delivering the bolus for the estimated fluid delivery period comprises performing the increased or reduced number of motor steps within the respective cycle.

20. A non-transitory computer-readable medium having instructions stored thereon that, when executed by a computing device, cause the computing device to perform a method according to any one of Claims 11 to 19.

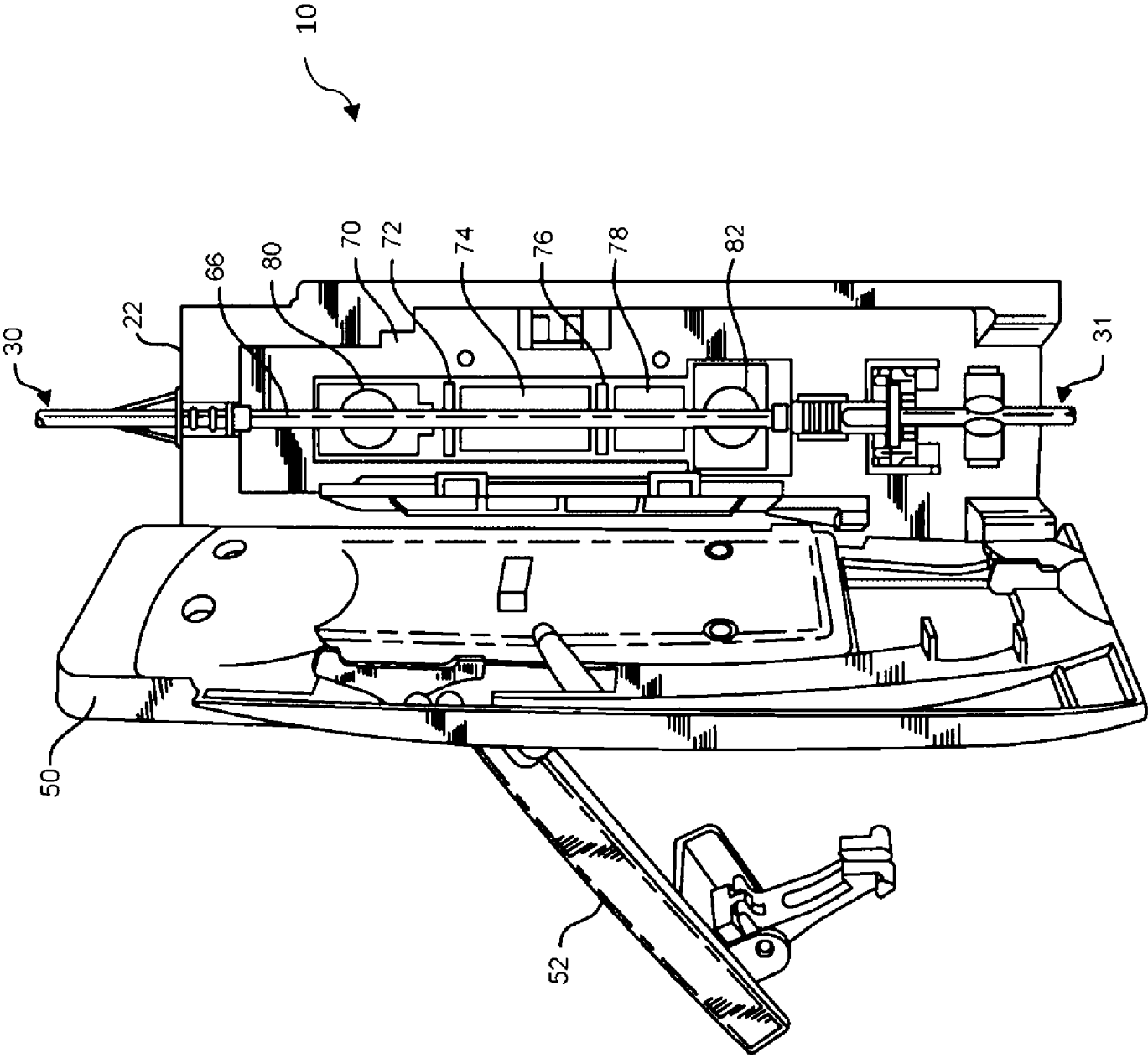


FIG. 1A

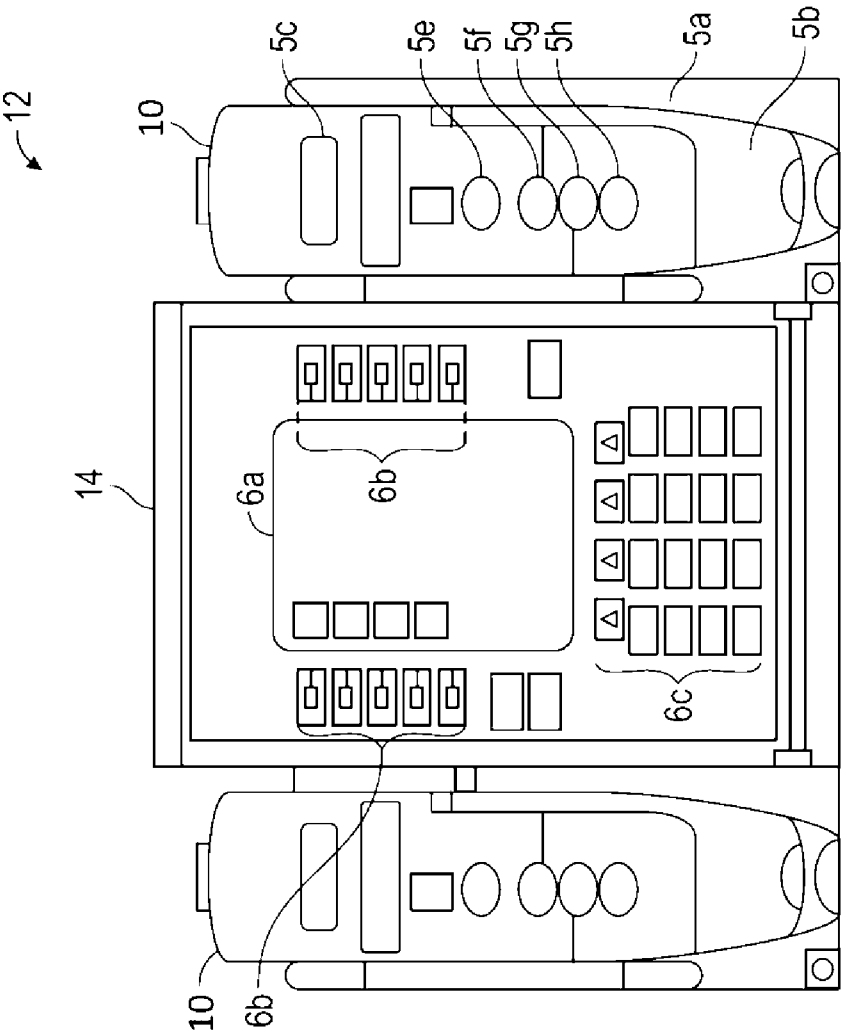


FIG. 1B

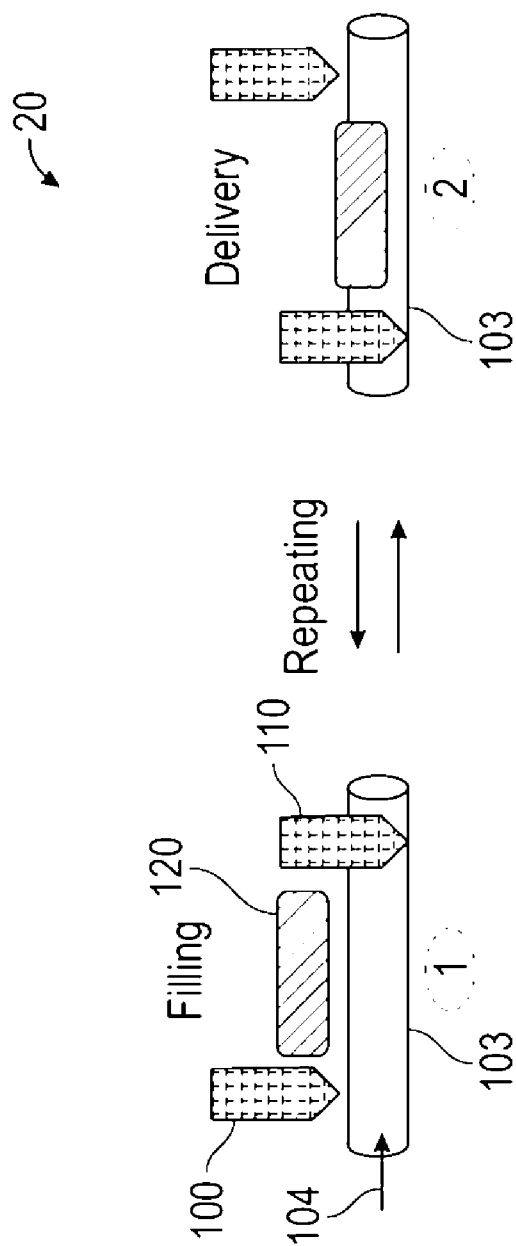


FIG. 2

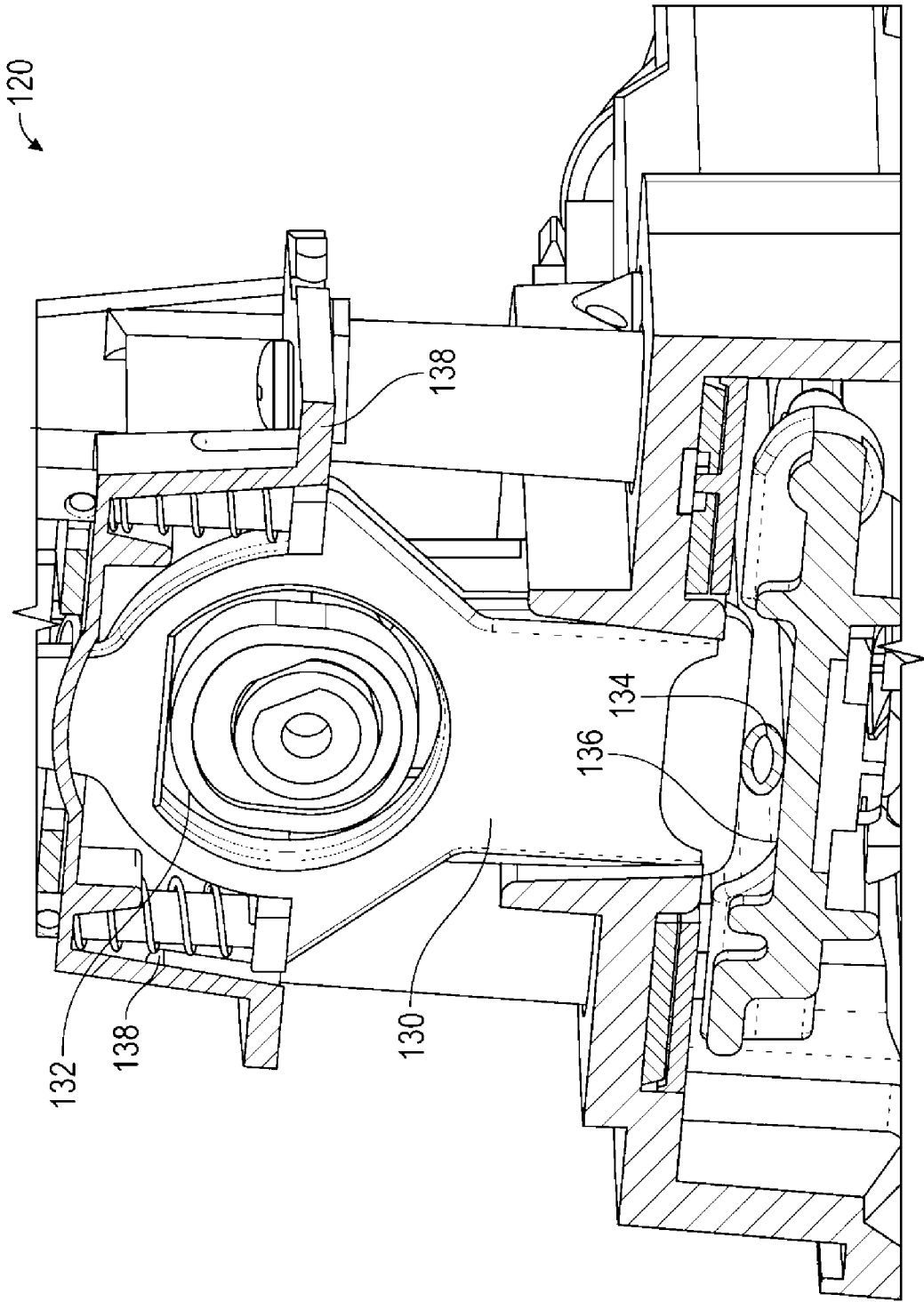


FIG. 3

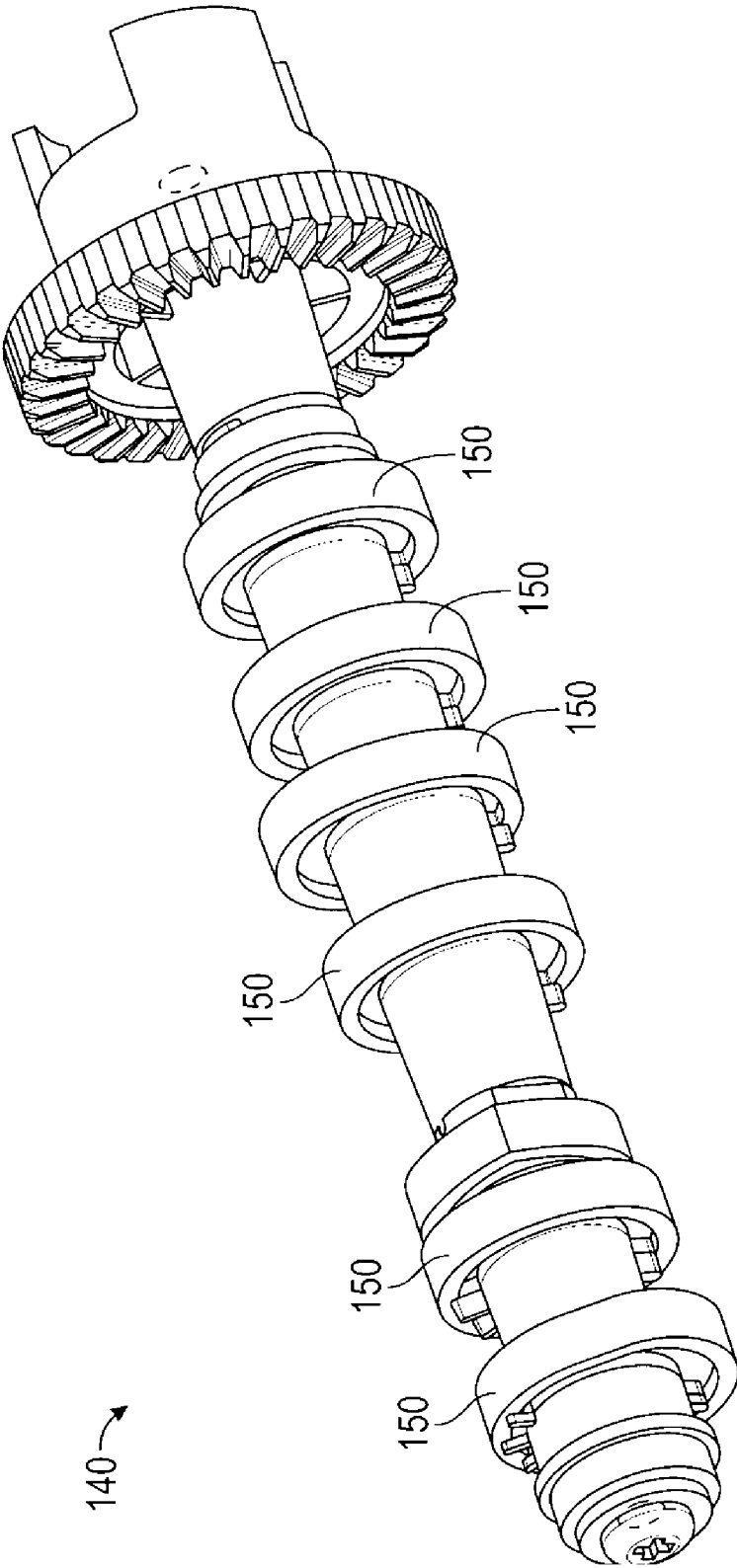


FIG. 4

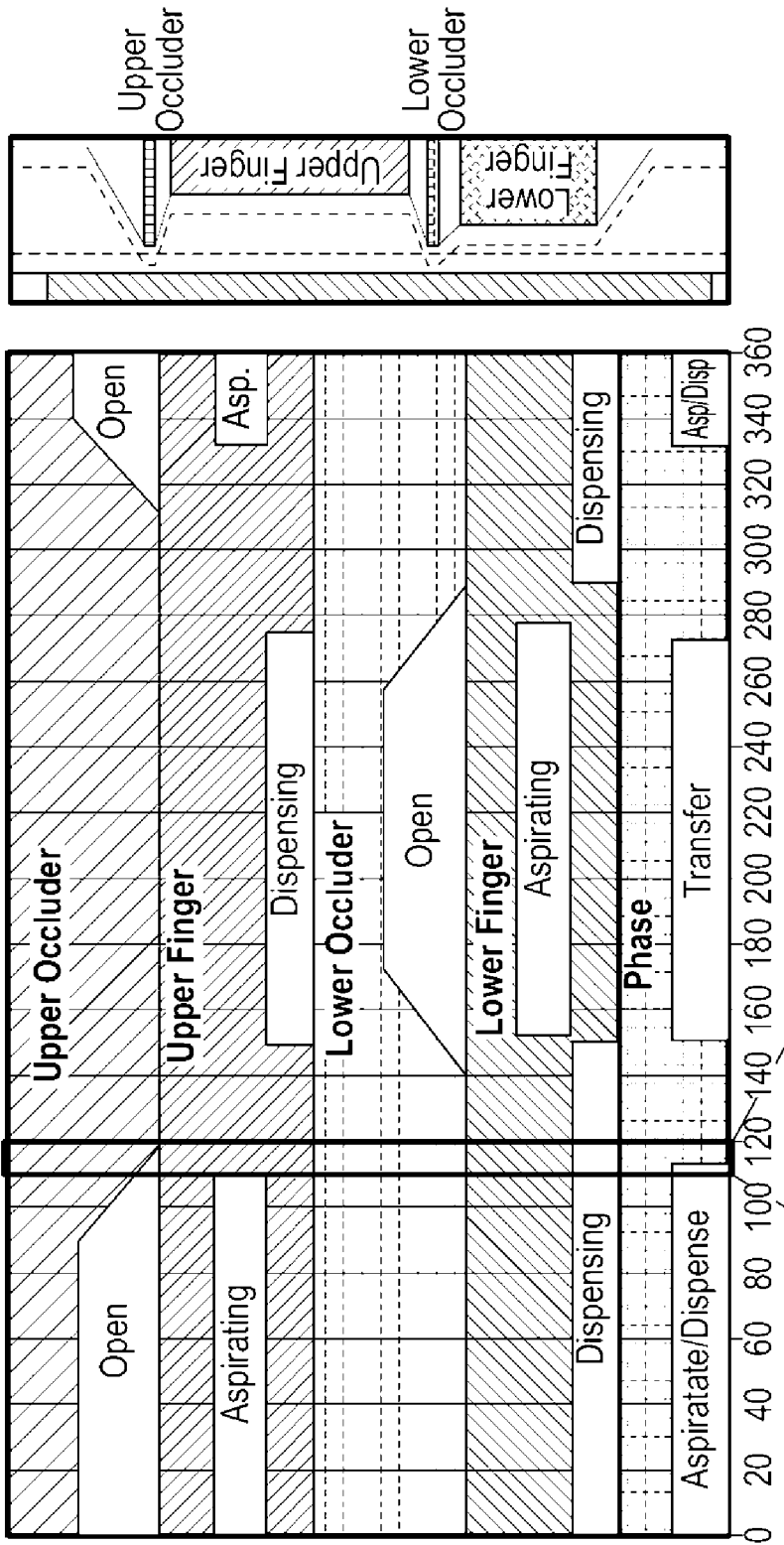


FIG. 5

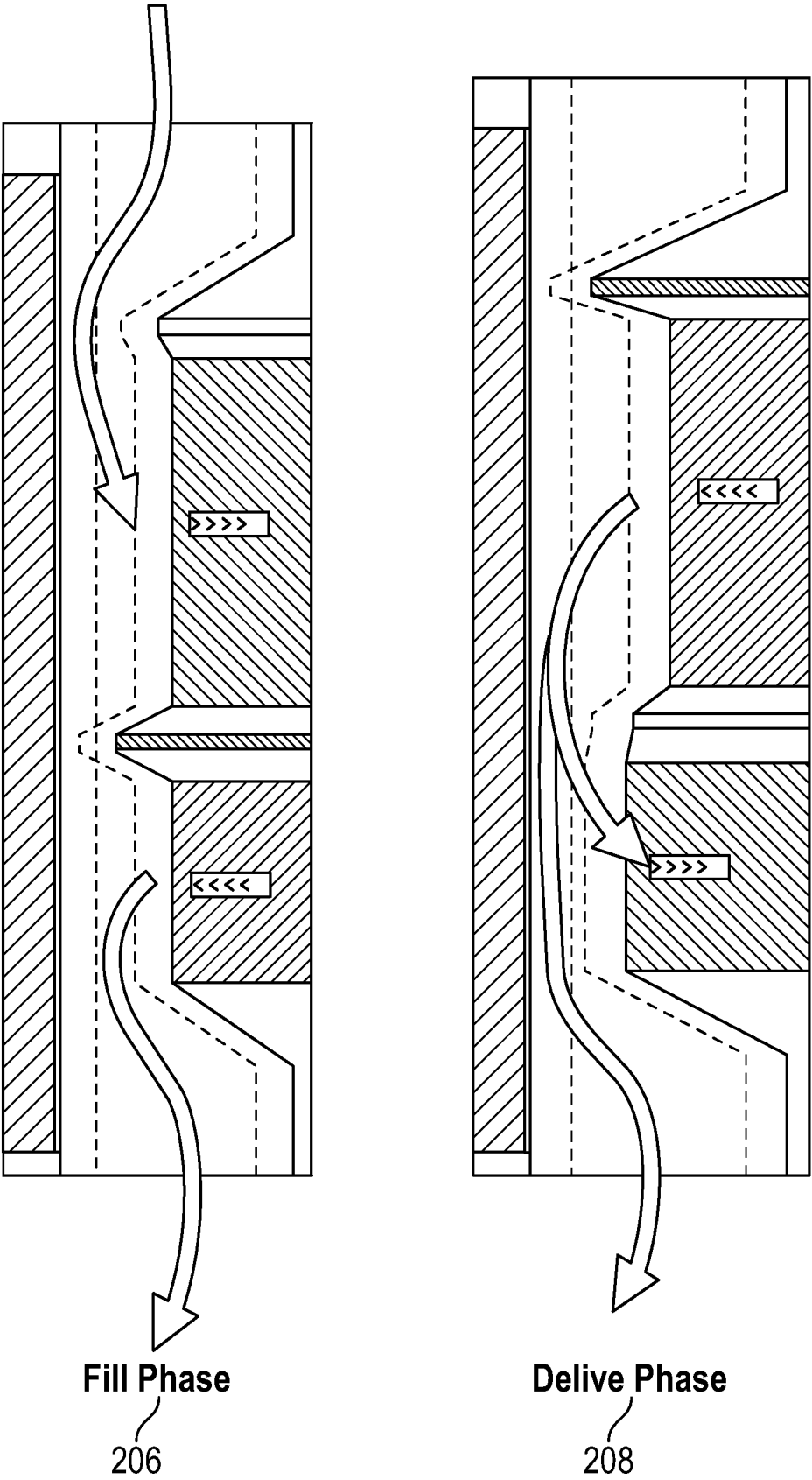


FIG. 6

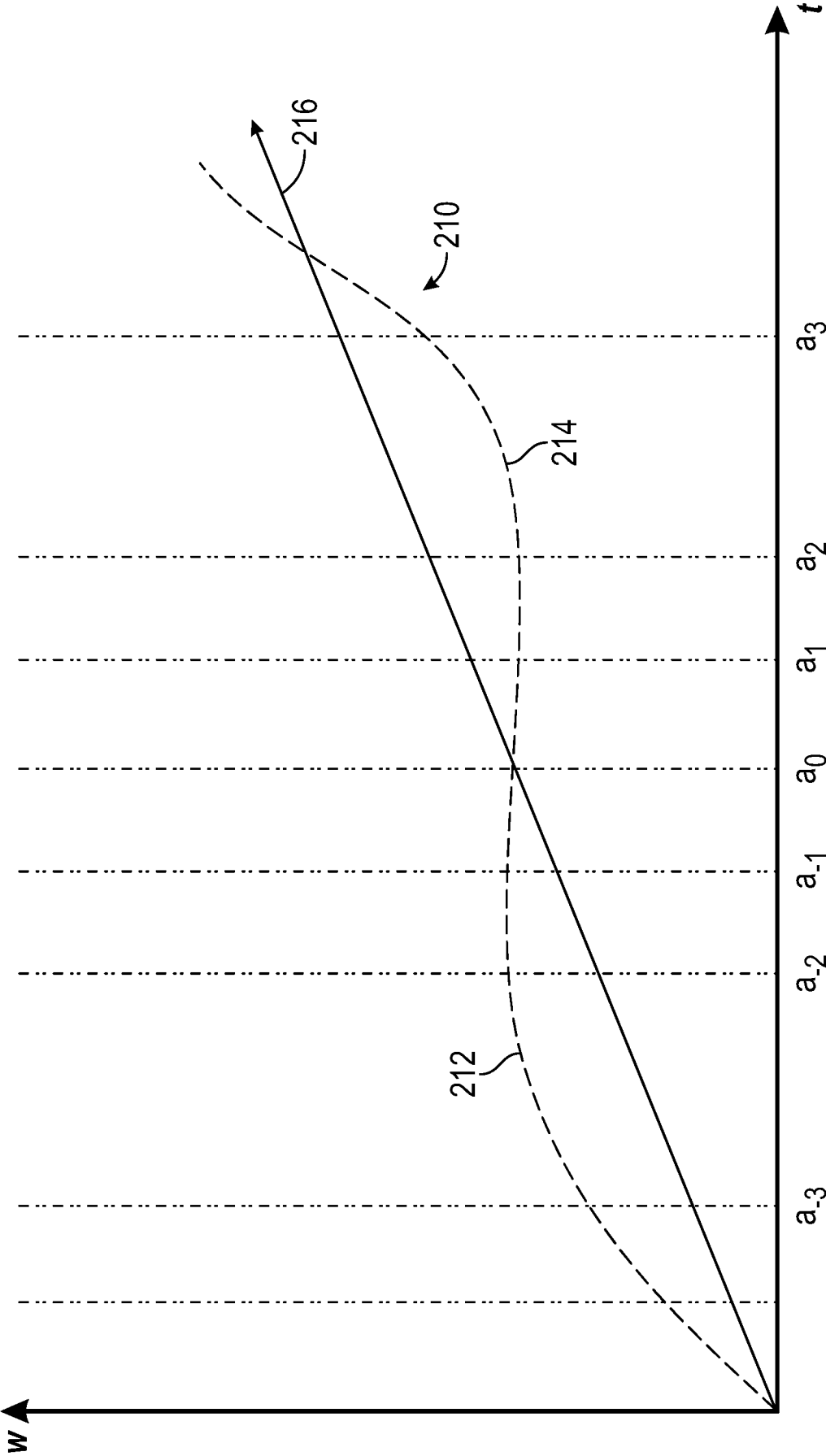


FIG. 7A

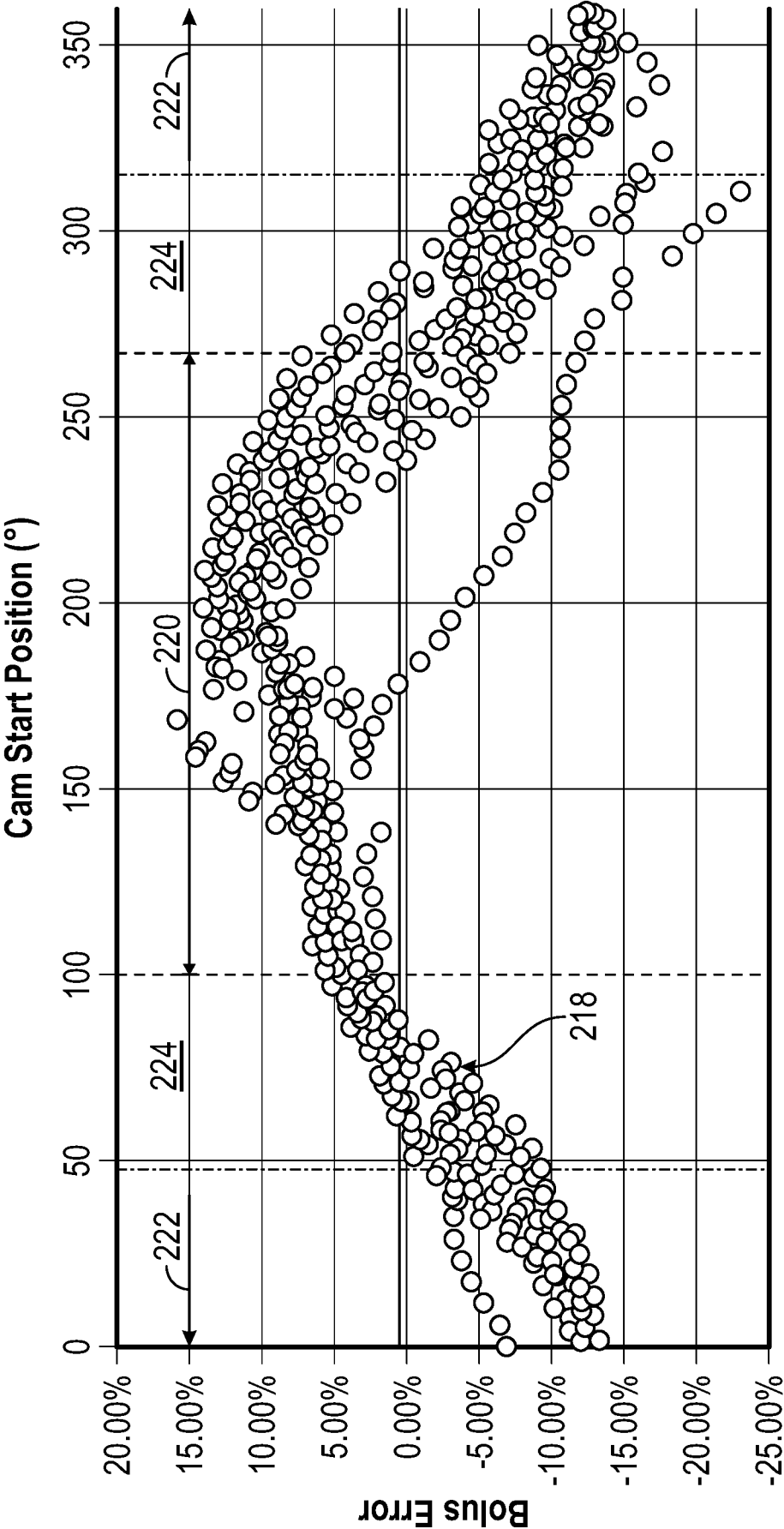
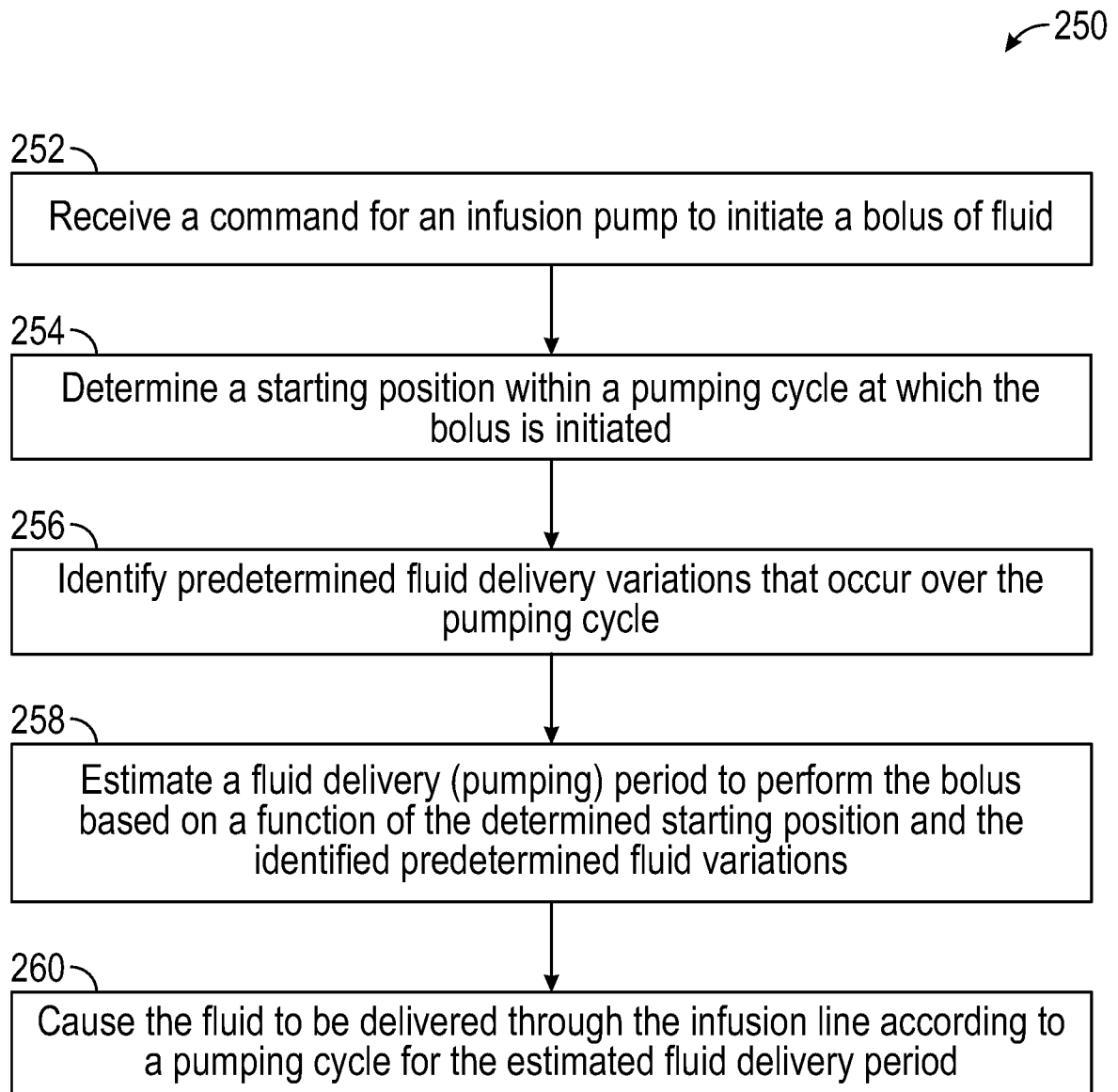


FIG. 7B

**FIG. 8**

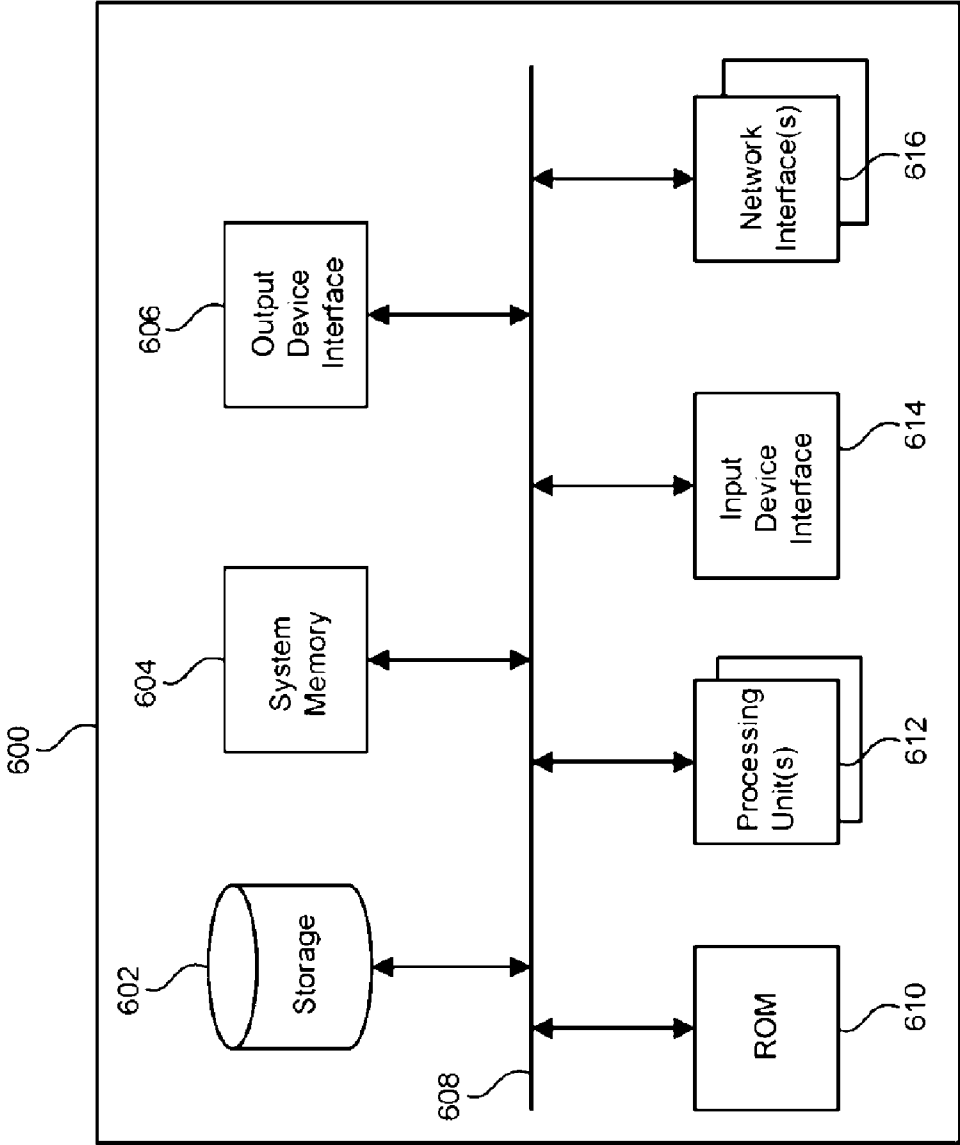


FIG. 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2023/025453

A. CLASSIFICATION OF SUBJECT MATTER INV. A61M5/142 A61M5/168 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols) A61M		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2023/043744 A1 (CAREFUSION 303 INC [US]) 23 March 2023 (2023-03-23) paragraph [0023] - paragraph [0023]; figures 1-3 -----	1-20
A	US 2017/268497 A1 (KAMEN DEAN [US] ET AL) 21 September 2017 (2017-09-21) the whole document -----	1-20
A	EP 4 147 736 A1 (CAREFUSION 303 INC [US]) 15 March 2023 (2023-03-15) paragraph [0009] - paragraph [0061]; figures 1-8 -----	1-20
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 19 December 2023		Date of mailing of the international search report 04/01/2024
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Feber, Laurent

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2023/025453

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