

An Apparatus and Method for Percutaneous Access to Kidney

FIELD OF INVENTION

The field of the currently claimed embodiments of this invention relates to a multi-imaging alignment and robotic surgery system for percutaneous access to the kidney in the percutaneous nephrolithotomy (PCNL) surgery

BACKGROUND

Percutaneous access to the kidney (PAK) or renal access is a minimally invasive procedure for establishing a keyhole access in percutaneous nephrolithotomy (PCNL) to remove a kidney stone. In this procedure, a trocar is passed through a patient's skin through the body layers into the kidney to reach a stone target. Surgical instruments such as guidewire, ultrasonic probes and vacuum are then passed through the hole in the trocar to carry out the stone removal process.

Conventionally, a PAK procedure is carried out by a surgeon holding a trocar in his hand with one end of the trocar resting on a patient's skin. The other end of the trocar is tilted numerous times to establish an accurate alignment between the trocar and the stone target. The alignment of the trocar is determined with the help of a C-arm fluoroscope. Once the accurate alignment is confirmed, the surgeon has to maintain the alignment of the trocar by steadying his hand. The trocar is subsequently pushed into the patient's body to reach the stone target. There are three major drawbacks of the conventional PAK procedure: (1) The duration of the trocar insertion procedure typically ranges from 10 minutes to 1.5 hours and throughout the procedure, the C-arm fluoroscope has to be in operation. Consequently, both the patient and surgical crew are subjected to long exposure of X-ray and this could be a potential health hazard in the long run. (2) Due to the elaborate procedure, there may be instances when the trocar has to be withdrawn and the entire procedure needs to be repeated. This may aggravate the condition of the patient as multiple punctures of the kidney may increase the risks to the patient such as significant bleeding, haematoma formation and infection. (3) The procedure may have to be called off and rescheduled, thus causing much distress to the patient and loss of precious time of the healthcare professionals.

To address the problems above, robotic arms are used to perform the trocar insertion procedure. For example, current approaches utilise robotic arm surgical systems which mimic the standard manual percutaneous renal access. In other words, the systems are manually controlled by the surgeon, e.g. using a manipulator such as a joystick, to align the trocar with the kidney stone. Furthermore, some robotic arms automatic aligned the trocar and the stone

target. This greatly reduces the surgeon's operating time and surgical difficulty. However, all above systems cannot avoid the long exposure to the patient in X-ray. Therefore, these systems are bulky and slow in processing. It is also expensive to manufacture the systems and implement the trocar insertion procedure using the systems.

SUMMARY

This invention tries to overcome the drawbacks of conventional PAK systems. The field of the currently claimed embodiments of this invention relates to a multi-imaging alignment and robotic surgery system for percutaneous access to the kidney.

The system consists of seven parts: operating table, workstation, movable bracket, target tracker, robotic positioning module, B-probe and needle. In which the target tracker which includes optical tracking device and sterile skin markers detects surgical condition in vitro; The robotic positioning module performs the positioning of the B-probe and the puncture needle according to the predetermined plan; the B-probe scans to detect the puncture trajectory in real-time. This invention combines CT scanning images and optical tracking device real-time tracking images, to identify the surgical site accurately and intuitively. This invention uses a robotic positioning module to achieve a wide range of puncture angle, and the needle can puncture into the lesions in vertical or any cone angle in a certain range.

The current invention covers a wide range of different embodiments, sharing a tightly integrated common core of components and methods used for general local sensing, imaging and automation.

Some embodiments of the current invention described multi-imaging alignment system – enabling the process of imaging, tracking and sensing.

Some embodiments of the current invention have different number of mechanisms of rotational linkage with slider as actuator.

Some embodiments of the current invention are directly combining the multi-imaging and robotic positioning module by the calculation of the image analysis algorithms. Thus, the robotic positioning module can position to the best puncture position and angle automatically.

Some embodiments of the current invention allow the CT used only once before the operation to minimise the injury to the patients.

US 20170014193 A1 discloses a system and method for aligning an elongated tool to an occluded target. An adjustment mechanism configured to adjust an angular orientation of the

elongated tool relative to the image length of the elongated tool on an X-ray image. The adjustment mechanism is automatically controlled by the computer which is analysing and comparing the X-ray images. The imaging device is a C-arm fluoroscope configured to capture real-time X-ray images. The patient is exposed to an X-ray environment for a long time.

CN 100493471 C discloses a puncture guiding system of computer aided PCNL. Only one or two X-ray images need to be taken to positioning the insert point. Some of the points in the target cover which is attached to one end of the C-arm, are used to make the connection of the earth coordinate system and X-ray image coordinate system. The others are used to make the connection of the earth coordinate system and the positioning coordinate system which marks the needle position. The position of needle in the positioning system can be translated to the position in the kidney in the X-ray image coordinate system.

US 20120069965 A1 disclosed a method of positioning a surgical instrument is provided which includes mapping a volume adjacent an operating table by taking mapping images from two orientations of a calibration object which includes a 3-dimensional array of radio opaque markers in a known configuration. A patient is positioned on the operating table with a patient target area within a mapped volume, and an instrument holder carrying a known configuration of radio opaque markers positioned adjacent the target area. Further fluoroscopic target images of the target area and instrument holder are obtained from the two orientations and the target area then reconstructed in 3-dimensions by comparing the target images to the mapping images. An instrument holder orientation is then calculated from the reconstruction.

US 20110263967 A1 describes methods and apparatus for detecting stones by ultrasound, in which the ultrasound reflections from a stone are preferentially selected and accentuated relative to the ultrasound reflections from blood or tissue. US 20110263967 A1 also describes methods and apparatus for applying pushing ultrasound to in vivo stones or other objects, to facilitate the removal of such in vivo objects.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will be described with respect to the figures, in which like reference numbers denote like elements and in which:

Figure 1 is a schematic diagram of one embodiment of a robotic surgery system according to the current invention.

Figure 2 is a schematic diagram of the essential positioning and surgery parts of the robotic system.

Figure 3 is a schematic diagram of the optical tracking device of the target tracker.

Figure 4 is a schematic diagram of the robotic positioning module.

Figure 5 is a schematic diagram of the internal structure of robotic positioning module.

Figure 6 shows a flow chart of the whole PAK procedure

DETAILED DESCRIPTION

Some embodiments of the current invention are discussed in detail below. In describing embodiments, specific terminology is employed for the sake of clarity. However, the invention is not intended to be limited to the specific terminology so selected. A person skilled in the relevant art will recognize that other equivalent components can be employed and other methods developed without departing from the broad concepts of the current invention.

Figure 1,2 shows a schematic diagram of the embodiment of a robotic surgery system according to the current invention. The robotic surgery system includes operating table 1, workstation 2, movable bracket 3, target tracker 4, robotic positioning module 5, needle 6 and B-probe 7.

A patient keeps the prone position on the operating table 1, the operating table 1 consists of table 11, support portion 12 and pulleys 13. Said pulleys 13 are under the support portion 12, and the said support portion 12 support the table 11. the pulleys 13 of the operating table 1 can be frozen or movable, this means the operating table 1 can be easily adjusted its position, and the support portion 12 of the operation table 1 can extend and shrank. As a result, the height of the operation table 1 can be changed.

Said workstation 2 consists of dual screens 21, work table 22, computer server 23 and pulleys 24. The pulleys 24 are installed in the legs of work table 22 and the dual screens 21 are on the work table 22 and the computer server 23 is fixed to the work table 22. The workstation 2 can move by active the pulleys 24 and the work table 22 can adjust its height. One of the dual screens 21 shows the fusion imaging of CT scanning images and optical tracking device images, the other one shows the ultrasound scanning images in real time.

One end of the movable bracket 3 is fixed on the corner of the work table 22, in another embodiment, it can be fixed on the operating table 1. The other end of the movable bracket 3 is supporting the optical tracking device 41 and robotic positioning module 5 keep above the skin of surgical site of patient. There is a knob 31 in the joint of the movable bracket 3 to freeze the bracket once the position of the far end is determined.

The optical tracking device 41 and robotic positioning module 5 keeps above the surgical site, the B-probe 7 and needle 6 are mounted on the robotic positioning module 5. The sterile skin markers 42 are fixed on the skin of the surgical site.

Figure 3 shows a schematic diagram of the optical tracking device 41 of the target tracker 4. On the bottom are the optical tracking device lens 411 for taking images of surgical situation. Figure 4 and 5 show a schematic diagram of the robotic positioning module. The robotic positioning module 5 consists of housing 51, motors 52, screw shafts 53, sliders 54, links 55, needle fixing module 56 and probe fixing module 57. The motors 52 drive the screw shafts 53 rotate and the sliders 54 move on the shafts 53, sliders 54 are connected to the links 55 and the links 55 can determine the position and orientation of the needle fixing module 56 and the probe fixing module 57. Positioning the needle fixing module 56 and probe fixing module 57 can finally translate to position eight sliders 54, which are controlled by the eight motors 52 respectively.

The needle fixing module 56 consists of the control centre 565, needle limiter 561, needle guide 562, hinge 563 and spherical hinge 564. The needle limiter 561 is controlled by the motor inside of the control centre 565 and can extend and shrink to adjust the puncture depth. The surgeon inserts the needle 6 to the lesions, passing through the limiter 561 and the needle guide 562. The hinge 563 and spherical hinge 564 connect the links 55 and the needle fixing part 56, and the same way, the hinge 573 and spherical hinge 574 connect the links 55 and the probe fixing part 57.

The probe fixing module 57 has a spring mechanism 571, which can help the scanning area of probe 7 always keep close to the skin.

Figure 6 shows a flow chart of the whole procedure of percutaneous access to the kidney using the robotic system. The day before surgery, patient was kept the prone position on the operating table 1. Five sterile skin markers 42 were fixed on the skin of surgical area, CT scanned to acquire images. Then the sterile skin markers 42 were removed and surgeon made marks on the markers location with a waterproof pen. The CT images focus on the imaging of ribs, bladder, ureter, renal tissue, kidney stones, liver, spleen, colon and skin markers. Surgeon made optimal puncture angle and trajectory plan based on 3D CT images, and archived. The day of surgery, patient keeps the prone position on the operating table 1, the sterile skin markers 42 are fixed again on the position where marked as the target position on the back of the patient the day before surgery, using the optical tracking device 41 to take pictures of markers region, the pictures are transferred to the computer server 23 to calculate, and the computer server 23 merges images. Once the optical tracking device 23 scans the

image of sterile skin markers 42, the dual screens 21 displays the 3D CT images and puncture plan. According to the optimize puncture plan, the robotic positioning module 5 follows the instructions of computer server 23 and sets the pre-determined position and direction to let the surgeon insert the needle 6. During the puncture process, the anesthesiologist ensures the air circulation of operating room. Pelvis is the final location of the puncture, during puncture using real-time ultrasound scanning of B probe 7 to locate and inspect the puncture needle 6, when the needle 6 arrives the pelvis, taking follow-up surgical procedures.

In order to meet the needs of different treatments, the robotic system can be used for percutaneous renal biopsy, percutaneous nephrostomy drainage and percutaneous nephrolithotomy lithotripsy. Another puncture needle or drainage catheter or gravel scalpel can be inserted into the hollow puncture needle of the robotic positioning module. If inserting the needle, the lesions can be sampled and analysed; If inserting drainage catheter, urine can be discharged from the calyx or pelvis; If inserting rushed scalpel, kidney stones can be crushed accurately.

CLAIMS

1. A multi-imaging alignment and robotic surgery system for multi-imaging alignment and robotic surgery system for percutaneous access to the kidney in the percutaneous nephrolithotomy (PCNL) surgery, the robotic surgery system includes operating table, workstation, movable bracket, target tracker, robotic positioning module, needle and B-probe.

A patient keeps the prone position on the operating table. One end of the movable bracket is fixed on the corner of the workstation or on the operating table. The other end of the movable bracket supports the optical tracking device and robotic positioning module keep above the skin of surgical site of patient. the B-probe and needle are mounted on the robotic positioning module.

2. The system as claimed in claim 1, the operating table consists of table, support portion and pulleys. The pulleys are under the support portion, and the support portion supports the table.
3. The system as claimed in claim 1, the workstation consists of dual screens, work table, computer server and pulleys. The pulleys are installed in the work table legs and the dual screens are on the work table and the computer server is fixed to the work table.
4. The system as claimed in claim 1, the target tracker consists of the optical tracking device and the sterile skin makers.
5. The system as claimed in claim 1, The robotic positioning module consists of housing, motors, screw shafts, sliders, links, needle fixing module and probe fixing module.
6. The system as claimed in claim 2, wherein the pulleys of the operating table can be frozen or movable, this means the operating table can be easily adjusted its position. The support portion of the operation table can extend and shrank. As a result, the height of the operation table can be changed.
7. The system as claimed in claim 3, wherein the workstation can move by active the pulleys and the work table can be adjusted its height.
8. The system as claimed in claim 3, wherein the workstation has dual screens, one shows the fusion imaging of CT scanning images and optical tracking device images, the other one shows the ultrasound scanning images in real time.
9. The system as claimed in claim 1, wherein the movable bracket can be frozen or movable by rotating the knob in the joint. When the movable bracket is unfrozen, the position of the target tracker and the robotic positioning module are adjusted according

to the patient's prone position and height. When the movable bracket is frozen, the position of the target tracker and the robotic positioning module is fixed.

10. The system as claimed in claim 4, wherein the optical tracking device of the target tracker catches the sterile skin markers and takes images in real time.
11. The system as claimed in claim 4, wherein the sterile skin markers of the target tracker are made of a material that can be captured by the optical tracking device.
12. The system as claimed in claim 1 and 5, wherein the robotic positioning module uses several mechanical structures of rotational linkage with slider, the motor rotates to drive the slider move along the screw shaft, adjusting the puncture needle and the B-probe position through the rotational linkage with slider mechanism.
13. The system as claimed in claim 1 and 5, within the needle fixing module, motor drives the screw shaft and lead to the depth limiter move in the direction of the puncture guide, thereby limiting the puncture depth of the needle.
14. The system as claimed in claim 1 and 5, wherein the probe fixing module has a spring mechanism to ensure the B-probe fit close into the skin.
15. The system as claimed in claim 1 and 5, wherein rotational linkage with slider mechanism for controlling the puncture needle and the one for controlling the B-probe are two separate mechanical structures. Although the mechanical structures are the same, the two independent mechanical structures work together under the control of computer server.
16. A method for percutaneous access to the kidney, the method comprising: on surgical skin, five sterile skin markers are fixed, the system starts CT scanning, and obtains the best puncture angle and the trajectory after analysing all these CT images by the computer server. The best puncture angle and the trajectory are tracked by the optical tracking device of target tracker. The computer server will fusion CT images and optical tracking device images, guiding the robotic positioning module automatically position to the best puncture point and the best puncture direction. Surgeon inset the hollow puncture needle to perform next step.