An Intelligent Apparatus for Surgical Device Visualization and Localization

Field of the invention

The present invention relates to an intelligent surgical device visualization and localization apparatus to help surgeon manipulating the surgical device inside the patient organ and body accurately, safely and effectively.

Background of the Invention

Minimal invasive and non-invasive therapeutic procedures can minimize the damage on patients and cut short the recovery time, so reducing the cost. Normally, the minimal invasive and non-invasive therapeutic procedure is referring to insert a needle or a cannula into the patient organ or point a physical device to a point or area inside the patient body. Due to the organ is normally constructed by some soft tissues or cells and located inside the patient body, the visualization and localization of the surgical device becomes difficult. It results in the poor location accuracy and the longer time of operation. For some complex cases, the surgeon’s experience becomes very important and the training time could be very long for an experienced surgeon.

By means of advanced medical image technology, the visualization and localization of the unhealthy tissues and cells is possible. The information of the unhealthy tissues and cells has been transformed to digital information and possible to guide some device through digital control system or robotic control system. It seems no problems. The key issue is how to build a practical real-time visualization and location system to guide the operation of the surgical procedure, which can overcome the problems from the deformation and movement of the organ inside the patient body. In additions, real-time visualization of the whole device using the three dimensions medical images is not a practical way on both image quality and cost. For some image modalities such as CT, MRI and so on, the metal surgical device is not allowed such that

the real-time visualization on these devices is not possible. Therefore, the augmented virtual reality will be used to help the visualization and localization of the surgical devices.

Summary of the invention

The present invention aims to provide an intelligent surgical device visualization and localization apparatus to arm a surgeon with the eye viewing the surgical procedure carried out inside the patient and to help surgeon localizing the surgical device and exercising the surgical procedure more accurately, quickly and effectively.

In general, the present invention is an intelligent apparatus for surgical device visualization and localization, which comprises three functional components and a set of adaptors or templates for matching the different surgical device:

- An PC based digital processing unit. The unit will real-timely collect both visualization and localization information of the surgical device and then registered with the information of unhealthy organ and device to form a live visualization and localization system including both organ and device on the monitor. The graphic user interface (GUI) enables the surgeon to control the localization of device.
- A robotic manipulator with a nine axes Inertial Measurement Units (IMU) to measure the location and movement of whole apparatus and a robotic control unit with four servo-controllers of the movement of robotic arm that holds the surgical device.
- A floating table with two turning and one linear axes to hold the robotic manipulator and the display device with an on-board computer to process the relation images and location informations.
- A group of templates constructed a smart template system.

Three functional components supported by the artificial intelligent system build an intelligent device visualization and localization apparatus, enabling the complete information on both the device and the organ inside the patient body for exercising the surgical procedure accurately, safely and effectively.

The configuration of the robotic manipulator and the surgical device to be used is building into the system before the surgical procedure. The configuration and the location of the robotic manipulator and the surgical device as a whole system defined at the physical space will be changed real-timely during the surgical procedure. It will be registered with the three dimensions medical images of the patient defined in the image space and formed a complete visualization and localization system by means of augmented virtual reality technology.

The registration or fusion of images with the configuration and location of surgical device is also possible among the three dimensions images in image space on real-time base. The off-line images from MRI, PET, CT or others could be registered with the real-time image from any image system, such as ultrasound image system which is cheapest image tool with lowest risk on damage the patient.

The robotic manipulator component provides a physical system to handle the surgical device inside the patient body or organ. The embedded nine axes IMU enables a space independent localization system, which has been integrated into the whole system defined in both image space and physical space. A set of templates enable most effective and accuracy operation on the surgical devices.

The floating table with two turning and one linear axes provides a very flexible operation platform for surgeon to operate the apparatus near the patient and provides a safety structure for the system.

The apparatus could be installed on the top or side of surgical operating bed or put simple on a mobile table. For a patient with tight operation space such as urology therapy, a simple mobile cart as shown in Fig 19 could be used.

Brief Description of the Figures

An embodiment of the invention will now be illustrated for the sake of example only with reference to the following drawings, in which:

FIG 1 is an overall perspective view of the apparatus 100 according to an embodiment of the present invention.

FIG 2 is an overall perspective view of the apparatus 100 with a front view 205 and a side view 201. It composes three function components, i.e. an all-in-one PC 202 with a support arm 206 and a monitor 207, a robotic manipulator 203, and a floating table 204. A multi-turning adaptor 208 has been used for quick installation of the robotic manipulator on the floating table.

FIG 3 is an overall perspective view of the robotic manipulator 203. It composes three linear movement modules, 301 for Y-movement, 302 for Z-movement and 303 for X-movement.

FIG 4 is the overall perspective view of the robotic manipulator 203 with front view 401, top view 402 and side view 403.

FIG 5 is the main software structure of the apparatus invented.

FIG 6 is the perspective view of module 301 in FIG 3 for Y-movement of the robotic manipulator. It shows three views, the front view 605, side view 601 and section AG-AG view 603. The Y-movement is driven by a mini-motor 604 with a magnet encoder and a planetary gear head on it. It drives a spur gear 610 and a rack 608 along the linear guide 609. Two fixed pins 602 on the main body of 301 for connecting with a fixed device guide. Two pins 606 on the linear guide enable the device guide on it moving along the Y-movement axis. The module will be integrated with other module through two mounting holes 607.

FIG 7 is the perspective view of module 302 in FIG 3 for Z-movement of the robotic manipulator. It shows four views, the front view 706, side view 701 section AG-AG view 704 and section AH-AH view 710. The Z-movement is driven by a mini-motor 712 with a magnet encoder and a planetary gear head on it. It drives a spur gear 711 and a rack 703 along the linear guide 702. A micro-process based robotic controller 705 with a nine axes Inertial

Measurement Unit (IMU) on it. The robotic controller is installed in the box 709 and fixed on the Z-movement frame 708. A device adaptor 707 is also fixed on the frame 708 so moving along the Z-axis.

FIG 8 is the perspective view of module 303 for X-movement of the robotic manipulator. It shows three views, the front view 801, section AH-AH view 802 and section AI-AI view 805. The X-movement is driven by a mini-motor 806 with a magnet encoder and a planetary gear head on it. It drives a spur gear 807 and a rack 808 along the linear guide 803. Two holes at 804 are for installing the module 302 in FIG 3 and two holes at 809 for module 301.

FIG 9 is the functional block diagram of the micro-processor based robotic control unit 705 in FIG 7 inside the robotic manipulator. The nine axes IMU with a digital compass has been integrated in the unit and a Web Camera can help surgeon to record the procedure for review. The robotic controller can control up to four motors for X, Y, Z and Rotation movements.

FIG 10 shows the robotic manipulator of the apparatus invented with a moving template 1001 along XYZ-direction for guiding a surgical needle together with or without cannula. The template has five holes as shown at 1003. The needle tip can reach the patient body for a point at three dimensions space. For more details on the template, see FIG 21.

FIG 11 shows the robotic manipulator of the apparatus invented with a two hole moving template 1101 along XY-direction for guiding a surgical needle together with or without cannula and with a multi-holes template 1104 which can only moving along Z-direction. There are three views, front view 1102 side view 1105 and top view 1103. The holes on the template 1101 are opened such that the needle can move out from the side. It allows that the needle that has been inserted into patient body through the template 1104 leaves in there for other surgical operation such as injecting medicine later. For more details on the two templates, see FIG 20 and FIG 24.

FIG 12 shows the robotic manipulator of the apparatus invented with a moving template 1201 along XY-direction for guiding a surgical needle together with or without cannula and with another template 1204 which can only move along Z-direction. There are three views, front view 1202, side view 1203 and

back view 1205. The needle tip can reach the patient body for a point at three dimensions space through a pivot point on the template 1204. For more details on the template 1204, see FIG 24.

FIG. 13 shows the robotic manipulator of the apparatus invented carry a multi-function cannula 1305. There are three views, front view 1301, side view 1303 and back view 1304. A pivot point at 1302 is fixed on the front frame such that the tip of cannula can move within the cone volume space.

FIG 14 shows the robotic manipulator of the apparatus invented with a surgical cut 1403. There are two views, front view 1404 and side view 1402. The surgical cut through the pivot point 1401 moves in the corn volume space.

FIG 15 shows that the apparatus invented installed on a support frame with two T slots on 1503. There are two views, front view 1502 and side view 1504. The robotic manipulator integrated on 1501 can carry any surgical device such as those shown in FIGS 10-14. The two T slots are at the bottom the support frame such that the patient will be below the apparatus.

FIG 16 shows that the apparatus invented installed on a support frame with two T slots on 1602. There are two views, front view 1603 and side view 1604. The robotic manipulator integrated on 1601 can carry any surgical device such as those shown in FIGS 10-14. The two T slots are at the top the support frame such that the patient will be at the same level of the apparatus for such as colorectal and urological surgical procedures.

FIG 17 shows that the module 301 in FIG 3 can be used alone. There are three views, front view 1702, left view 1704 and top view 1705. There is a moving template 1701 and multi-slots fixed template 1703.

FIG 18 shows that the module 301 in FIG 3 together with the templates shown in FIG 17, 1801, works together with cancer visualization and localization apparatus developed by Abacus Global Technology Pte Ltd in Singapore for imaged guided surgical diagnosis and therapy. There are three views, front view 1802, side view 1804 and top view 1803.

FIG 19 shows a layout of the apparatus together with an ultrasound cancer visualization and localization device. The surgical system 1901 as

shows in FIG 18 is mounted on the top of adaptor 1902. There are two views, front view 1903 and side view 1904 for this system.

FIG 20 shows that the details of multi-holes needle template. There are four views, front view 2002, left view 2001, right view 2005 and top view 2006. The template with two mounting pins on the bottom 2004 enables simple installation to the robotic manipulator. The multi-holes with the cut-edge as shown in 2003 enable the needle or device turning a certain angle. It can also insert parallel by means of another guiding template on the module 301 in FIG 3.

FIG 21 is a double five holes template. There are three views, front view 2101, side view 2104 and section AG-AG view 2102. The double five needle holes are at the same distance and same diameter. The needle can pass two holes on different sides. It can be parallel or non-parallel because the cut edges as shown at 2103. Two holes 2105 are for quick installation on the module 301 in FIG 3.

FIG 22 is a single line template. There are four views, front view 2203, side view 2207, top view 2201 and bottom view 2204. All of holes are open as shown at 2206 to allow the needle moving out from side. The cut-edge of the holes 2205 allows the needle inserting from a certain angle. There two mounting holes 2202 for integrating it onto module 301 in FIG 3.

FIG 23 is a fixed needle template. There are four views, front view 2301, right view 2306, top view 2307 and section AG-AG view 2303. Two pins 2304 are for mounting on the module 302 in FIG 3. The central hole 2305 with a cut-edge 2302 allows the needle inserting in parallel or a certain angle, depending on another guide on module 301 in FIG 3. Four holes around the central holes provide a flexible needling procedure.

FIG 24 is a template with double holes. There are four views, front view 2402, right view 2407, bottom view 2401 and section AG-AG view 2403. The two holes 2406 with the cut-edge 2404 are opened to allow the needle inserting from a certain angle. Two mounting holes 2405 provide a quick installment on module 301 in FIG 3.

Detailed Description of the Embodiments

An intelligent surgical device visualization and localization apparatus which is an embodiment of the invention will now be described with reference FIG 1 to FIG 24. The apparatus 100 as shown in FIG 1 comprises three functional components, i.e. Pc based digital process unit, robotic manipulator, and floating table. The whole apparatus could be installed on the surgical operation bed, on the top of patient as shown in FIG 15 and on the end of the bed for urology procedure as shown in FIG 16. It can also be installed on a mobile cart or ultrasound device as shown in FIG 19.

The PC based digital process unit will handle the transformation between the virtual image of the device and the real image of the device moving by the robotic manipulator and then display at the monitor 207 of FIG 2. The virtual images are defined at the image space and the physical surgical device and the robotic manipulator are defined art the physical space. All of images of the surgical device carried by the robotic manipulator are fused by the united by means of virtual-reality registration, so display at the physical space with accuracy localization. The images and device localization will be processing according to the main software structure as shown in FIG 5.

As shown in FIG 3, the robotic manipulator with a nine axes Inertial Measurement Units (IMU) to hold a surgical device composes three modules for three linear movements at XYZ-directions at the physical space. Three vertical movements, X-movement, Y-movement and Z-movement at three dimensions physical space is driven by three mini-motors as shown by 806 for X-movement, 604 for Y-movement and 712 for Z-movement. A micro-processor based robotic controller 705 has been integrated in the unit, which is working by following the block schematic diagram shown in FIG 9. The position information of the surgical device from the encoders on the three mini-motors will be sent to digital process unit and then transformed to device location information for

visualization and localization the surgical device. The nine axes IMU enables the measurement of both the location and movement of the robotic manipulator at the physical space, which can be transformed to image space directly by the image reconstruction system.

The apparatus invented is a general visualization and localization system for surgical device. The location of the surgical device carried by the robotic manipulator or robotic arm could be decided at physical space with the accuracy up to 10^{-3} mm. The location information will be transformed into the image space by means of augmented virtual reality technology such that the surgeons can visualization the surgical procedure carried inside the patient body. In generally, any surgical device that can be held by the hand of surgeon can also be held by the apparatus to perform the surgical procedures. FIGS 11 to 14 show some typical devices in the daily surgical operations.

FIG 10 shows an application of the apparatus for the robotic manipulator 203 together with a double line template of five holes 1001. The template can be simple moving alone the three coordinates of Cartesian coordinates. As shown at 2103 of FIG 21, there are two lines of holes with cut-edge holes. Therefore, the needle can be inserting into the patient body through any two holes at different line, parallel of non-parallel because the cut-edge design. The needle with a cannula can perform many operations such as taking out the needle and then inserting a laser fiber to perform a thermal therapy or inserting an optical coherence tomography (OCT) for diagnostic cancer or simple taking out a sample for pathology examination.

FIG 11 shows a multi needle therapy platform. The multi-holes template 1104 is fixed on the module with Z-movement and another two holes template 1101 is fixed on the module with Y-movement. The template 1101 can move at the XY plane, so can carry any needle that inserting in any holes on the template 1104 moving within the corn shape volume. It allows multi-needle insertion because the two holes on the template 1101, seen FIG 24, are opened such that the

needles can be moved from side and leave it in the patient body through any holes on the template 1101, see FIG 20. All of holes on the templates 1104 and 1101 are cut-edge design so that the needles can be paralleled or non-paralleled with some certain angles. The typical application for the layout is for Brachytherapy procedure of prostate cancer. It provides accuracy operation and can avoid the problem of touching the born.

FIG 13 shows an application of needle or surgical device inserting into the patient body through one pivot point. As shown in FIG 23, there are four holes around the pivot point for flexible purpose such as inserting a temperature sensor.

For different sized surgical device, the hole of the pivot point can be simple changed. It allows many different surgical devices operating by the robot manipulator are possible, such as a multi-purpose cannula for laparoscope surgery as shown in FIG 13. It can also carry a surgical cut as shown in FIG 14 to remove some unhealthy tissues inside the patient body. All of operation will be performed through a hole only, so minimal the invasion and short the recovery time.

The robotic manipulator 203 is integrated on the floating table 204 as shown at in FIG 2 by means a multi-turning adaptor 208. It can be very easily to take out from the floating table for hand operation. It can also be installed on a support frame and fixed on the top of surgical operating bed with two T-slots on two sides, as shown in FIG 15. If the T-slots convert to the top, the apparatus will be at the same level of the surgical operating bed as shown in FIG 16, so suitable for the colorectal and urology surgical procedures.

In additions, the module 301 can be easily taken out as a simple mobile template if installed a simple template 1703 in FIG 17, together with the template 1701 with the details in FIG 22 and FIG 24. FIG 18 shows its application for a hand-hold ultrasound based prostate biopsy device, which can

also be integrated with a three dimensions ultrasound system as shown in FIG 19 for more complex diagnosis and therapy.

The apparatus invented refers to a general visualization and localization system for surgical device. It has been built by means of advanced image process and robotic control technologies and formed a unified transformation platform for augmented virtual reality in healthcare industry. The visualization and localization of surgical device in both image and physical spaces can be registered with any medical image system with DICOM format, such as cancer visualization and localization system developed by Abacus Global Technology Pte Ltd in Singapore. The apparatus invented integrated with the cancer visualization and localization system can provide a complete system to enable the surgeon viewing the details both on the surgical device and the unhealthy cells and tissues inside the patient body and performing the surgical procedure accurately, safely and effectively.

Claims

1. An apparatus for visualization and localization of surgical device inside the patient organ or body, the apparatus comprising:

- A PC based digital image processing unit running by means of a robotic controller to control the surgical device visualization and localization;
- A robotic manipulator with a nine axes Inertial Measurement Units (IMU) to measure the location and movement of whole apparatus and a robotic control unit with four servo-controllers of the movement of robotic arm that holds the surgical device.
- A group of templates constructed a template system;
- A table with two turning and one linear axes to hold the robot manipulator and the computer display device with an on-board computer to process the surgical images and information and to make sure of the safety of patient.

2. An apparatus according to claim 1, wherein the surgical device to be carried is presented by means of virtual images defined in the image space.

3. An apparatus according to claims 1 and 2, wherein the robotic manipulator that carries the surgical device is presented at the physical space with the real movement measured by the encoders in the digital format.

4. An apparatus according to claims 1 to 3, wherein the localization of the surgical device is presented at the physical space and the visualization of the device are displayed by means of augmented virtual reality at the monitor.

5. An apparatus according to claim 1, wherein there is a four axes driving mechanism to carry and localize a surgical device by means of four axes robotic controlling unit.

6. An apparatus according to claims 1 and 5, wherein the robotic manipulator embedded with a nine axes Inertial Measurement Unit (IMU) together with a digital compass to measure and monitor the position and movement of the robotic manipulator and the surgical device carried.

7. An apparatus according to claims 1, 5 and 6, wherein the surgical device carried by the robotic manipulator is controlled by the electronic unit together with a nine axes IMU and digital compass.

8. An apparatus according to claims 1, 5 to 7, wherein the surgical device is controlled by means of both high accuracy encoder and high accuracy potentiometer for fast response and accuracy localization.

9. An apparatus according to claim 1, wherein a table is invented to hold all of components of the apparatus invented.

10. An apparatus according to claims 1 and 9, wherein there are three turning axes for locating the robotic manipulator, three dimensions image reconstruction unit and the table itself, which will be aligned on the same plane and paralleled each other.

11. An apparatus according to claims 1, 9 and 10, wherein the table has been carried a linear movement mechanism such that the robotic manipulator can move along the linear line and turning on the turning axis.

12. An apparatus according to claims 1, 9 to 11, wherein a multi-turning adaptor enables the quick installation of the robotic manipulator on the table.

13. An apparatus according to claims 1 to 12, wherein the apparatus can carry a double line template to enable the surgical needle used for surgical procedure at a specified angle.

14. An apparatus according to claim 13, wherein the double line template is on the same plane and with cut-edge holes to allow the needle or device inserting parallel or non-parallel with a certain angle

15. An apparatus according to claims 1 to 12, wherein the apparatus will carry a multi-hole template (say 13x13 holes) to perform a complex procedure.

16. An apparatus according to claim 15, wherein the holes on the multi-hole template are cut-edged to allow the surgical needle or device used for surgical procedure at a certain angle.

17. An apparatus according to claims 1 to 12, wherein the apparatus will carry an adaptor with a pivot point at the template center or two pivot points at a specified distance.

18. An apparatus according to claim 17, wherein the surgical needle or device used for surgical procedure will be guided into the patient organ and body through a pivot point and the needle tip can be inserted into the patient body within a corn shape volume.

19. An apparatus according to claims 1 to 12, wherein the apparatus can carry a multi-purpose cannula for laparoscope surgery work inside the patient body and move within a corn sharp volume through a pivot point on the skin of patient body.

20. An apparatus according to claims 1 to 12, wherein the apparatus will carry a surgical tool that can cut the tissue by a sharp tip to remove the tissue inside the patient body through a pivot point on the skin of patient.

21. An apparatus according to claims 1 to 20, wherein the apparatus will be installed on any mobile vehicle or any medical image device for real-time operation of a surgical procedure.

22. An apparatus according to claims 1 to 20, wherein the apparatus will be installed on the top of surgical operating bed by using a clipping frame.

23. An apparatus according to claims 1 to 20, wherein the apparatus will be installed on the end of surgical operating bed by using the clipping frame to perform the rectal, urological and vaginitis surgical procedure.

Below abstract has been put at a separated file.

Abstract

An Intelligent Apparatus for Surgical Device Visualization and Localization

The present invention relates to an intelligent surgical device visualization and localization apparatus to enable the surgeon viewing the surgical procedure inside the patient organ or body and localizing the surgical device more accuracy. The apparatus comprises three functional components, augmented virtual-reality based visualization unit, robotic manipulator and floating table, together with a set of templates for different surgical procedures. The apparatus can carry a surgical device performing parallel shape, corn shape and parallel-corn shape hybrid operation for surgical procedure inside the patient organ and body. The apparatus is possible to work with any medical image system such as cancer visualization and localization system to perform therapeutic procedure more accurately, safely and effectively. In additions, all of the information can also be saved in digital format to review later, which can perform an effective procedure for active surveillance on the healthcare and perform the best procedure for the therapy.

[FIG1]