An Apparatus and Method for Real Time In-Situ Targeted Virtual Biopsy

Field of the invention

The present invention relates to an intelligent apparatus and method for real time in-situ targeted virtual biopsy to recognize and localize the cancerous cells and tumors inside the patient organ and body.

Background of the Invention

To determine the presence or extent of a disease, a surgical procedure for removing some tissues or cells from a living subject for examination under a microscope is most commonly performed by a pathologist. The pathologist examines the histologic patterns and molecular characteristics for insight into possible cancerous and inflammatory conditions. When only a sample of tissue is removed with preservation of the histological architecture of the tissue's cells, the procedure is the incisional biopsy or core biopsy.

The detect accuracy and detect rate of an incisional biopsy is mainly dependent on the accuracy of localization of cancerous cells and the number of sampling of the cells. Because the organ is normally constructed by some soft tissues or cells and located inside the patient's body, the localization of the biopsy needle become difficult. The samples from wrong location can affect the detection results so the treatment procedure and may cause the serial results to patient. Although It may be improved by increasing the number of samples but limited by the damage on patient by too many samples taken and the cost on the longer time of surgical procedure and pathological examination. In additions, it is quite difficult to take the examination in-situ in real time, which is very important during the therapeutic procedure.

Recently, there are some new technologies being developing and testing for the detection of the changes on the physical characters and microstructures of

cancerous cells. The traditional stress and strain measurement on cancerous tissues finds the cancerous tissues are hardened than the surrounding ones. It is not suitable for all of cancerous, but suitable for most cancerous, such as breast and prostate cancers. The resolution of some medical image technologies, such as Optical Coherence Tomography (OCT), has been reaching a few of micron meter (10^{-6}m) scale and is quite closely to the microscope's resolution, so possible of providing the microstructure image pattern that is quite similar with the histological architecture. For some OCT technologies, a two dimensions image with about 1μm resolution can be, in-situ, taken in a few of micron seconds, so possible a real time operation. Furthermore, the OCT technology can form the three dimensions image with a few of mm penetration for the architecture of cancerous cells. It can help for surgeon not only on diagnoses but also on planning and executing therapeutic procedure.

The new technologies are possible of providing a biopsy procedure in-situ without any tissues or cells to be taken from the patient. The key issues are how to apply the related technologies to the targets inside the patient body and location them with enough accuracy for diagnosis and therapy and how to obtain and present the results in short time, say a few of micron seconds without the presence of a pathologist. It must rely on the robotic technology and artificial intelligence for quick characters recognition and identification.

Summary of the invention

The present invention aims to provide an intelligent in-situ targeted virtual biopsy apparatus and method by using needle-based mechanics measurement unit and needle-based OCT probe to identify the cancerous cells inside the patient body. The changes of cancerous cells both on physical characters such as hardness and on histologic patterns and molecular characteristics have been recorded and identified by the optical character recognition and knowledge based artificial intelligence technologies. It acts as incisional biopsy but taking

no cells or tissues from patient, so targeted virtual incisional biopsy or simple targeted virtual biopsy. It will arm a surgeon with a virtual pathologist and a specialist system to help on carrying out a surgical procedure on cancerous diagnosis and therapy more accurately, quickly and effectively.

In general, the present invention provides an intelligent apparatus and method for identifying and localizing the cancerous cells. The basic function is similar to the incisional biopsy, but without any cells and tissues to be taken from patient. The examination results are obtaining in-situ by an artificial intelligence system armed with the Optical Character Recognition (OCR) and Artificial Intelligence (AI) technologies, in which the pattern identification on the histological architecture pattern of the cancerous cells and the historical records on the physical characters or hardness of the cells have been executed automatically.

The present invention uses 3D ultrasound images to localize and visualize the targets or interesting area inside the patient body. The targets or interesting area will be digitalized in the image space by the computer. A robotic arm with a nine axes Inertial Measurement Unit (IMU) will carry a needle placement unit to manipulate a needle-based OCT probe integrating with a Mechanics Parameter Measurement Unit (MPMU) in the physical space to the targets and interesting area. Once the OCT probe and the MPMU sensor reaching the targets or entering the interesting area, the OCT images and physical parameters from MPMU sensor will be taken and then sent to the artificial intelligent system in the local or remote computer. In additions, the sonar character recognition system on cancerous identification, such as Histoscan™ system will be integrated into the invention apparatus directly to help recognition and boundary the cancerous cells and tumors.

The three dimensions volume ultrasound images are formed by a stack of two dimensions ultrasound images, taking from a two dimensions ultrasound probe by rotating the probe at specified angles or moving the probe linearly at specified distance by servo motor controlled by robotic controller. The 3D

volume ultrasound images will be reconstructed and the boundary of both organ and tumors will be identified by using the multi-gradient active contour method (snake searching algorithm). Reconstructed images are presented on monitor and located at the image space. The localization on both ultrasound images and robotic system which is defined at the physical space will be calibrated and integrated by means of augmented virtual reality technology, such that the visualization and localization on the whole system, including biopsy needle, needling trajectory, boundary of organ, needling plan and so on could be displayed and recorded in real time.

The present invention has built a unified platform enabling three newly developing cancerous diagnostic technologies based on OCT, sonar character recognition (ultrasound) and physical character recognition (hardness) integrated in one system to identify cancerous cells in-situ. The knowledge based artificial intelligence system has been used to enhance the recognition technology, which enables the cancerous identifying in real time, so could be used to guide the therapeutic procedure for cancer treatment and reduce the possibility on over or wrong treatment.

The apparatus and method could be installed on the top or side of surgical operating bed or put simple on a mobile table as shown in FIG 24 and FIG 25. For a patient with tight surgical operation space such as urology therapy, a simple mobile cart as shown in FIG 23 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 201 and a top view 202. It composes five function components, i.e. a virtual biopsy needle 205, a detachable three Degree Of Freedom (DOF) robotic manipulator 206, a two DOF robotic localizer 207, a trans-rectal ultrasound probe 204 and a sonar penetration kit 203.

FIG 3 is a perspective view of the virtual biopsy needle 205 with a side view 301 and a top view 302. The top cover 303, the side firing OCT sensor 304, front support adaptor 305 and the base 306 are shown in this figure.

FIG 4 is the perspective view of the virtual biopsy needle 205 with a section view 401 from the AK-AK plane of top view 405. A lead screw 403 driven by an encoded gear servo motor 406 moves the OCT needle 402 along a linear direction L1. The lead screw is supported by two bearings 404 and coupling with the motor by a coupling 407.

FIG 5 is the right view of the virtual biopsy needle 205 for more details on front support adaptor 305. There is a round guide slot 501 and slide stop 502 on it.

FIG 6 is the perspective view of the virtual biopsy needle 205 with the front view 603 without top cover 303. The front view of the top cover shows at 602. A section views from AK-AK plane of top cover 602 shows at 601. There are two separation plates 601 in the top cover, forming a container 604 and a guide slot 605.

FIG 7 is the top view of virtual biopsy needle 205, without top cover 302. There are two strain measurement sensors 701 insides the fibre OCT needle sensor base 702, which is moving by the motor 406 alone the L1 direction.

FIG 8 is the perspective view of two strain measurement sensor at 701. 801 is the front view and 802 is the top view. Two sliding adaptors 804 are inserting into the lead screw 403 and OCT fibre base 702 separately, which is vertical to the direction of L1 movement. There is a strain gauge on each strain sensor to monitor the deformation of the strain measurement sensor.

FIG 9 is an overall perspective view of the robotic manipulator 206. It composes five modules; base 901, robotic control system 902, rotation mechanisms for R1 rotation 903, two linear movement mechanisms 904 and the ultrasound probe adaptor 905.

FIG 10 shows the bottom view of robotic manipulator 206 with a section view 1001 along the plane AK-AK. An encoded gear servo motor 1005 will drive the ultrasound probe adaptor 905 together with two linear movement mechanisms 904 rotation along the R1 direction as shown in FIG 9. There is a pier of spur gear 1007 to transmit the rotation to the probe adaptor 905 through a pipe adaptor 1006. There are two bearings 1002 fixed on the base 1003 with the same centre line of the pipe adaptor 1006 to centralize the ultrasound probe with the R1 rotation mechanisms. A potentiometer 1108 is installed on the front of motor 1005 to detect the real positon of the ultrasound probe adaptor.

FIG 11 shows the right view of robotic manipulator 206. The module 904 is composed by two linear movement mechanisms 1101 and 1104. 1101 carries a U-shape handle 1102 moving along the L2 direction and 1104 carries an O-shape handle 1105 moving along the L3 direction. Two linear movement mechanisms connected on a plate 1106 with a hole at the centre of R1 rotation direction, so rotation along the centre 1103. There is a pipe connector 1107 enabling the water to the pipe adaptor 1006 in FIG 10.

FIG 12 shows the left linear movement mechanisms 1101 for L2 movement without the cover. It is the same with the right one 1104 for L3 movement. An encoded gear servo motor 1203 through gear 1204 and rack 1201. There is a linear guide 1202 to make sure the U-shape handle moving along the L2 direction. Potentiometer 1205 by means of gear 1206 and rack 1201 is used to detect the real position of the U-shape handle.

FIG 13 is a perspective view of the robotic localizer 207 with front view 1301 and top view 1304. A shaft support 1307 is fixed on the base 1302, such that the whole localizer can rotate alone the axis the shaft. A round moving block 1306 carries a rotation mechanism 1305, which enables the robotic manipulator adaptor 1308 rotates along R2 direction at the center 1303. The block 1306 will move along the L4 direction.

FIG 14 shows more details on the robot localizer 207. 1401 is a section view along the plane AK-AK of the bottom view 1404. An encoded gear servo motor 1402 will drive a lead screw 1403 to move the block 1306 along the L4 direction. The lead screw is supported by two bearings 1406 and 1407. A linear guide 1405 is used to make the linear movement along the L4 direction.

FIG 15 shows more details on the rotation mechanism 1305 by means of a section view 1503 along the plane AM-AM of the bottom view 1501 of the robotic localizer 207. The R2 rotation is driven by an encoded gear servo motor 1502 through a worm gear 1505 and a worm wheel 1504. The worm gear is supported by two bearings 1507.

FIG 16 is an overall perspective view of four function components, i.e. an virtual biopsy needle 205, a detachable 3DOF robotic manipulator 206, a through rectal ultrasound probe 204 and a sonar penetration kit 203. It shows that the virtual biopsy needle 205 will rotate along the R3 direction, driven by L2 and L3 linear movement by means of U-shape handle 1102 moving along the L2 direction and O-shape handle 1105 moving along the L3 direction. The needle OCT probe is moving along the L1 direction with an angel between the robotic manipulator by R3 rotation.

FIG 17 shows that the virtual biopsy needle 205 together with two linear movement mechanisms 1101 and 1104 will rotate along the R1 direction at the center 1701. The ultrasound probe 204 will rotate together with the 1101 and 1104.

FIG 18 is also an overall perspective view of the apparatus 100 with a front view 1801 and a top view 1804. It shows that all of the components presented in FIG 16 are fixed on the adaptor 1308 by two screws at 1803 to the robot localizer 207, such that it will rotate along the R3 direction. 1804 is the top

view of the apparatus 100 and shows the components in FIG 16 will move alone the L4 direction by the block 1805.

FIG 19 the functional block diagram of the center processor based robotic control unit 1004 in FIG 10 inside the robotic manipulator. The nine axes IMU with a digital compass have been integrated in the unit to show the localization of apparatus 100 in physical space. The robotic controller can control six DC motors for L1, L2, L3 L4, R1 and R2 movements.

FIG 20 is a perspective view of the sonar penetration kit 203. 2001 is an ultrasound probe coupling with a window 2002 on it. The condom holds 2003 is inserted on the base of the sonar penetration kit 2004. A slot 2005 is for the tightness of the condom for filling water inside the condom.

FIG 21 shows the apparatus 100 enables the OCT needle working on the live ultrasound image window 2101 due to L2 and L3 movement do always on the plane of image. The side firing OCT probe could reach any point in the image window through any trajectories expected.

FIG 22 shows an alternative ultrasound probe to replace the trans-rectal ultrasound probe 204 and a sonar penetration kit 203. The new probe 2201 shown is commercial B&K 8553 probe. The apparatus with the OCT needle is now working at the vertical direction.

FIG 23 shows the apparatus 100 installed on a surgical cart with a surgical table on it to help surgeon operating the apparatus easily.

FIG 24 shows the apparatus with B&K 8553 ultrasound probe on the surgical cart with a surgical table on it to help surgeon operating the apparatus easily.

FIG 25 shows the apparatus with B&K 8553 ultrasound probe fixed on the operation bed. 2501 is front view and 2502 is the left side view. Two T-shape slots will be used to fix the apparatus on the surgical operation bed.

Detailed Description of the Embodiments

An intelligent in-situ targeted virtual biopsy apparatus and method which is an embodiment of the invention will now be described with reference FIG 1 to FIG 25. The apparatus 100 as shown in FIG 1 comprises six functional components, i.e. a virtual biopsy needle 205, a detachable 3DOF robotic manipulator 206, a 2DOF robotic localizer 207, a trans-rectal ultrasound probe 204, a sonar penetration kit 203 and a PC based digital processing unit. The whole apparatus could be installed on the surgical operation bed, on the top of patient as shown in FIG 25. It can also be installed on a mobile cart as shown in FIG 23 and FIG 24.

The virtual biopsy needle component 205 is composed by a linear feeding mechanism to carry an OCT fiber sensor integrated in a 14g cannula. A precision force measuring unit has been installed at the end of the cannula, which is driven by an encoded gear servo motor by means of a lead screw at a constant speed and driven force. Two force sensors are installed on two sliding bars which will transform the push forces to deformation only. The Wheatstone strain bridge has been used to compensate other possible parameters, such as temperature change, to affect the force and deformation measurement.

The virtual needle component will move forward automatically into the organ to be detected at specified interval of time. At each time interval, the two dimensions (2D) OCT image and force needed to move the needle through the site with the 2D image will be output to the center processor of the apparatus invented. The center processor will process the OCT images in-situ by means of both optical character recognition and knowledge base artificial intelligence technologies. The tissue physical characters such as changes on hardness during the navigation of needle tip, measured by the force sensors are also input to the center processer in-situ to help identifying the cancerous tissue cells.

A 3DOF robotic manipulator 206 has been invented to localize both the virtual needle component 205 and ultrasound probe, such as 204.

Ultrasound system is used to view the target inside the patient body at real-time. A stack of 2D ultrasound images taking by rotating the probe by servo motor 1005 will be reconstructed into a 3D volume image and display on the monitor for visualization of the target and the surroundings for planning the trajectory of needling. The stack of 2D ultrasound images, depending on the probe used can also be taken by the linear movement by the servo motor 1402. Furthermore, the sonar character recognition system is used to identify the cancerous cells and tumors and to detect the boundaries of the cancerous cells and tumors.

There are two linear movement mechanisms 904 driven by two servo motors to move the virtual biopsy needle component 205 through a round pin 1105 at the position 305 and a U-shape handle 1105. The round pin allows the virtual biopsy needle component rotating along the axis and U-shape handle allows the virtual biopsy needle component moving up and done at different angles. Two linear movement mechanisms have been fixed on the rotation adaptor 905, such that will rotate together with the ultrasound probe by the servo motor 1005. It makes sure of the needling trajectory on the same plane with the real-time ultrasound image always. During the needling, two servo motors for the two linear movement mechanisms could still be operating, such that the needling trajectory may not be straight line. It enables that the needle tips together with the OCT sensor could reach some target behind some bone.

All of three servo motors in the robotic manipulator are operating by means of both magnetic encodes and potentiometers. The robotic controller knows the accuracy movement of the needle tip and the absolute position at any time during the operation. The active position of virtual biopsy needle tip inside the patient body that is defined in the physical space will be transformed into the image space for the real-time ultrasound image. A nine-axis Inertial Measurement Units (IMU) has been built in the manipulator to monitor the

active movement of the robotic manipulator. The whole procedure will be visualized on the monitor and recorded for active surveillance or guide the therapeutic procedure in real time.

The robotic localizer 207 is a 2DOF localizer. One servo motor 1403 provides linear movement L4 and another provides rotation R2 as shown in FIG 13. The robotic manipulator 206 is fixed on the robotic localizer by two screws at 1308. It enables that the robotic manipulator together with the virtual biopsy needle and the ultrasound probe is operating automatically at the physical space.

To enhance the ultrasound image quality of trans-rectal ultrasound system, a sonar penetration kit has been invented as show in FIG 20. The normal condom to be fixed on the adaptor 2003 will be filling with de-gas water to enable the better contact between the probe and rectal wall. A windowed sheath is used to confine the enlarge direction of the condom once the water is filled in.

The integrated system of all of five functions components are shown in FIG 1 and FIG 18. It is a 6DOF robotic system, which enables the virtual needle tip moving at a 6DOF physical space automatically. It could be installed on a mobile cart with a PC and monitor on it as shown in FIG 23 and FIG 24. I could also be installed on a mobile frame to fix on the operation bed as shown in FIG 25.

The apparatus invented refers to a surgical diagnosis system. It could perform the biopsy procedure without taking any tissues from patient, so the virtual biopsy in-situ in real time. The real time diagnostic results will help surgeon to perform the therapeutic procedure more accurately, safely and effectively. It does also help surgeon to perform the active surveillance procedure easily.

Claims

1. An apparatus for virtual biopsy in-situ at the real time, the apparatus comprising:

- A virtual biopsy needle integrated with optical coherence tomography (OCT) fiber sensor and precision mechanics measurement unit to detect the cancerous cells and tumors in-situ by means of the history pathology features comparing technology;
- A detachable 3DOF robotic manipulator integrated with 9-axis Inertial Measurement Unit (IMU) to handle and localize the virtual biopsy needle unit;
- A 2 Dimension Of Freedom (DOF) robotic localizer to provide additional DOF on operating the virtual biopsy needle;
- An ultrasound system to provide real time view of human organ and tissues inside the patient body and to detect the cancerous cells by means of sonar character recognition technology;
- A sonar penetration improvement device to enhance the ultrasound image quality for trans-rectal ultrasound system only.
- A PC based processer integrated with a knowledge based artificial intelligent system to process the history pathology graphics for real time identification of cancerous cells and tumors;

2. An apparatus and method according to claim 1, wherein the virtual biopsy needle is integrated together with the knowledge based intelligent system enables the virtual biopsy without take any tissues.

3. An apparatus according to claims 1 and 2, wherein the OCT fiber sensor is installed in a cannula which is driven by a servo motor controlled by both encoder and potentiometer through the computer based controlling unit.

4. An apparatus and method according to claim 3, wherein the insertion force of the cannula together with the OCT fiber sensor has been measured by two precision force sensors at two sides of needle insertion direction.

5. An apparatus and method according to claim 1, wherein the robotic manipulator is to be handle both the virtual biopsy needle and the ultrasound probe, in which the manipulator is driven by three servo motors integrated with both encoders and potentiometers for accuracy positioning and controlling.

6. An apparatus and method according to claim 1, wherein the nine axes Inertial Measurement Unit (IMU) together with a digital compass to measure and monitor the position and movement of the robotic manipulator, the virtual biopsy needle and the ultrasound probe carried.

7. An apparatus and method according to claims 1, 5 and 6, wherein the two linear movement mechanisms to carry the needle and cannula are moving at the same plane; a round pin inserted in front of the virtual biopsy needle enables the virtual biopsy needle rotating freely and moving along the L3 direction driven by servo motor; and a U-shape handle enables the virtual biopsy needle sliding in it freely and moving along L2 direction driven by servo motor.

8. An apparatus and method according to claims 1, 5 to 7, wherein the virtual biopsy needle tip is inserting into the patient organ at the same plane with the real-time ultrasound image with the linear or curved trajectories inside the patient body.

9. An apparatus and method according to claim 1, wherein the 2DOF robotic localizer is composed by a linear movement mechanism and a rotation mechanism, which enables the ultrasound probe moving forward and backward to collect the 2D images at specified intervals.

10. An apparatus and method according to claim 9, wherein the servo motor for the 2DOF robotic localizer is localized and controlled by both encoders and potentiometers, so known the position at any time quickly.

11. An apparatus and method according to claims 1, 9 and 10, wherein the rotation mechanisms are composed by a pier of worm gear such that the rotation R2 could be locked by the mechanisms once the power to the motor being cut-off.

12. An apparatus and method according to claim 1, wherein the sonar penetration improvement kit is composed by a windowed sheath, a condom fixture and water seal base.

13. An apparatus and method according to claims 1 and 11, wherein the windowed sheath is made by the TPX material with the sonar penetration feature similar with the human tissue.

14. An apparatus and method according to claims 1 to 13, wherein the apparatus can carry the biopsy in-situ in real time without taking any tissues from patient.

15. An apparatus and method according to claims 1 to 14, wherein the histologic patterns and molecular characteristics for cancer cells are identified by both the optical character recognition and physical character identification technologies through the knowledge based artificial intelligence system.

16. An apparatus and method according to claims 1 to 15, wherein the virtual biopsy needle could be taken off by simple sliding a stopper at the back of biopsy needle holder.

17. An apparatus and method according to claims 1 to 16, wherein the sonar characters on cancerous cells and tumors from the ultrasound system are recorded and recognized by the knowledge based artificial intelligent system.

18. An apparatus and method according to claims 1 to 17, wherein three recognition technologies including optical character recognition, sonar character recognition and physical character recognition have been integrated for cancerous cell identification.

19. An apparatus and method according to claims 1 to 18, wherein the knowledge based artificial intelligence system for cancerous identification is based on any two or three recognition technologies of optical character recognition, sonar character recognition and physical character recognition for real time identification of cancerous cells and tumors.

20. An apparatus and method according to claims 1 to 19, wherein the apparatus can be installed on a surgical cart to perform the virtual biopsy for any organs inside the patient body.

21. An apparatus and method according to claims 1 to 20, wherein the apparatus can be installed on the top of surgical operating bed by using the frame, which can be clipped on the patient bed for virtual biopsy in-situ.