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(54) **ELECTROMAGNETIC NAVIGATION  
BRONCHOSCOPY USING ULTRASOUND**

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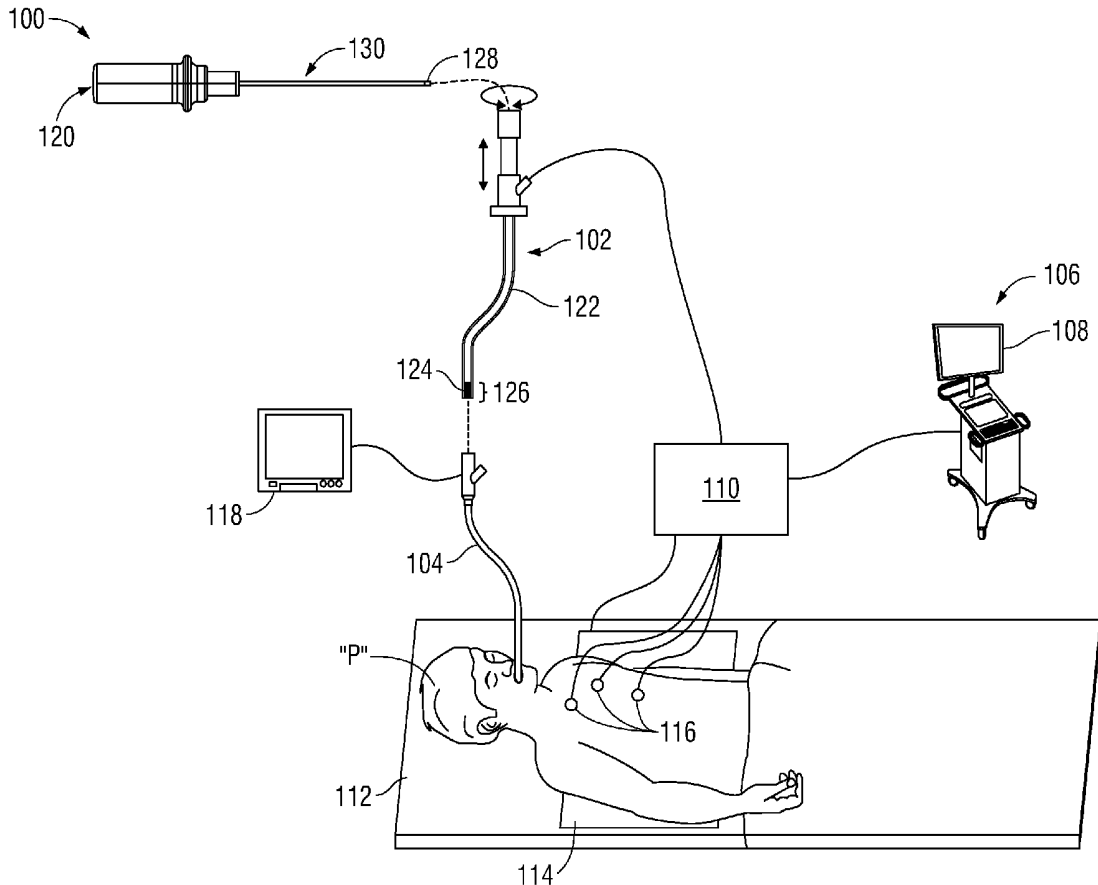
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(57) **ABSTRACT**

Methods and systems for facilitating electromagnetic navigation bronchoscopy using ultrasound are described. One such method includes receiving, from an electromagnetic sensor coupled to a distal portion of an extended working channel, an electromagnetic sensor signal value corresponding to a location of the distal portion of the extended working channel. Ultrasound image data is received from an ultrasound probe protruding from the distal portion of the extended working channel. Based on the ultrasound image data, an ultrasound image is displayed via a display device. An instruction is received to store location data corresponding to a location of target tissue, and, in response, the location data corresponding to the location of the target tissue is stored in a memory. The location data corresponding to the location of the target tissue is based on the received electromagnetic sensor signal value corresponding to the location of the distal portion of the extended working channel.



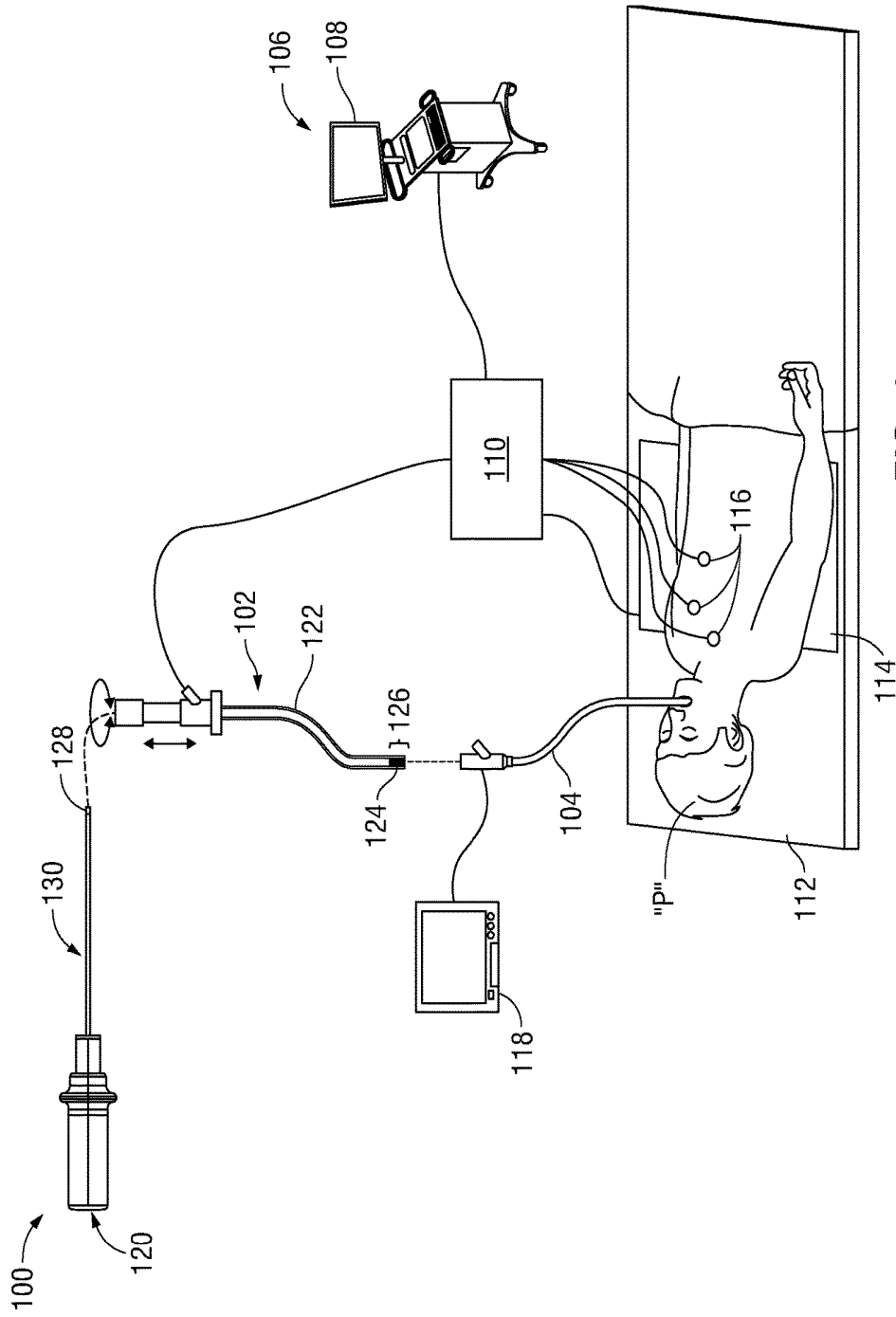


FIG. 1

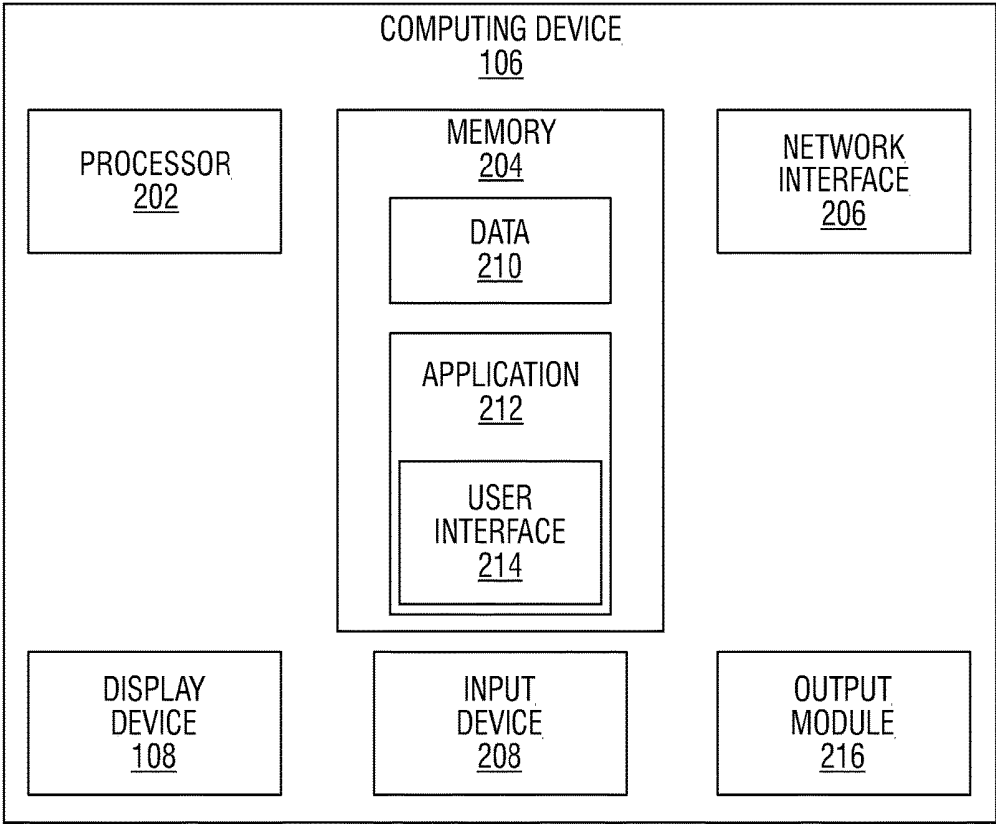
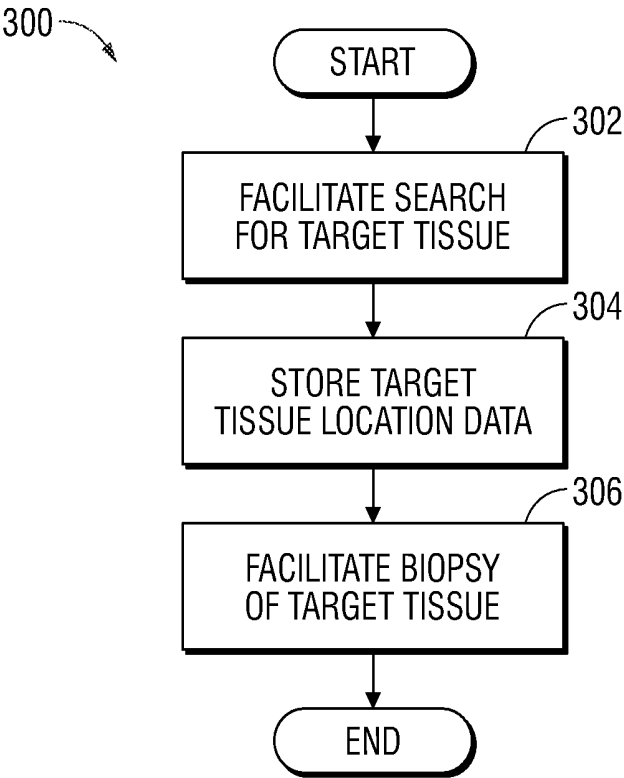


FIG. 2



**FIG. 3**

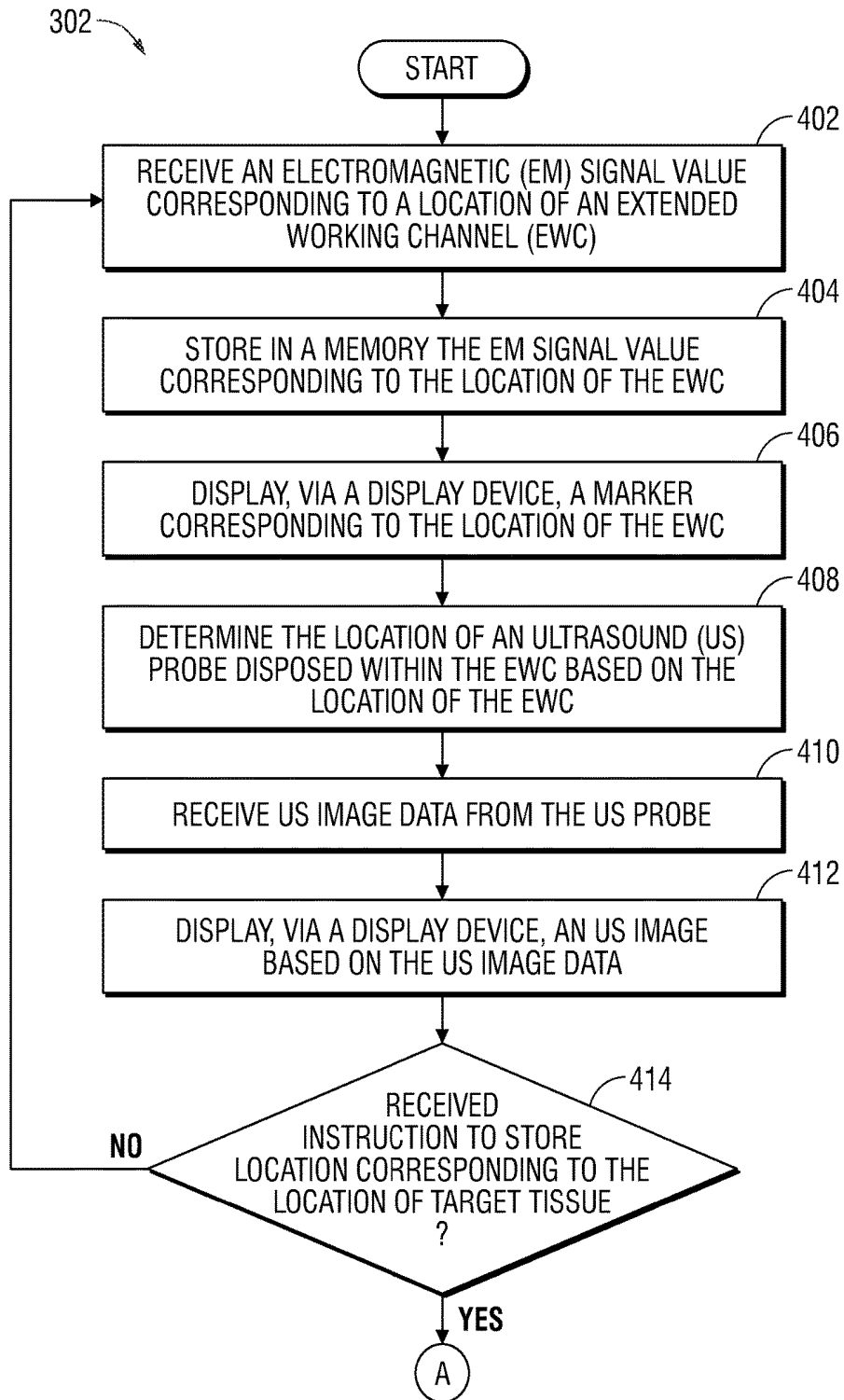
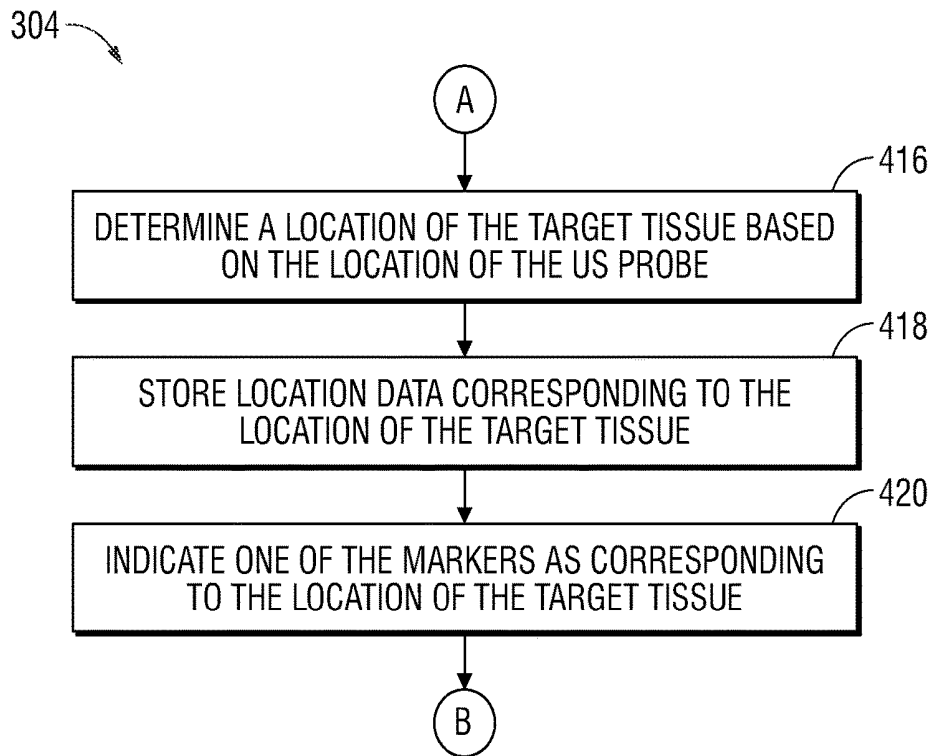


FIG. 4A



**FIG. 4B**

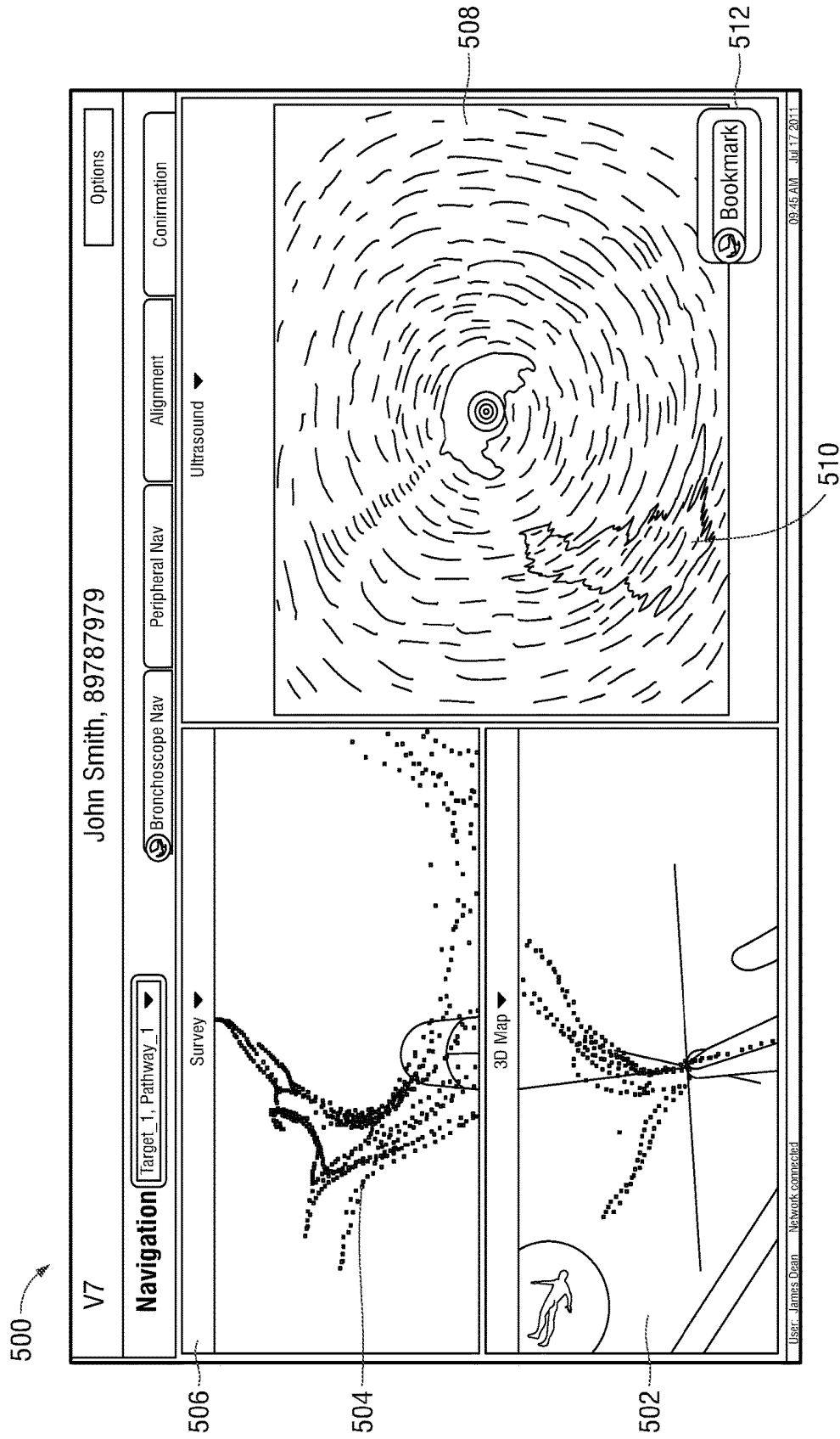


FIG. 5

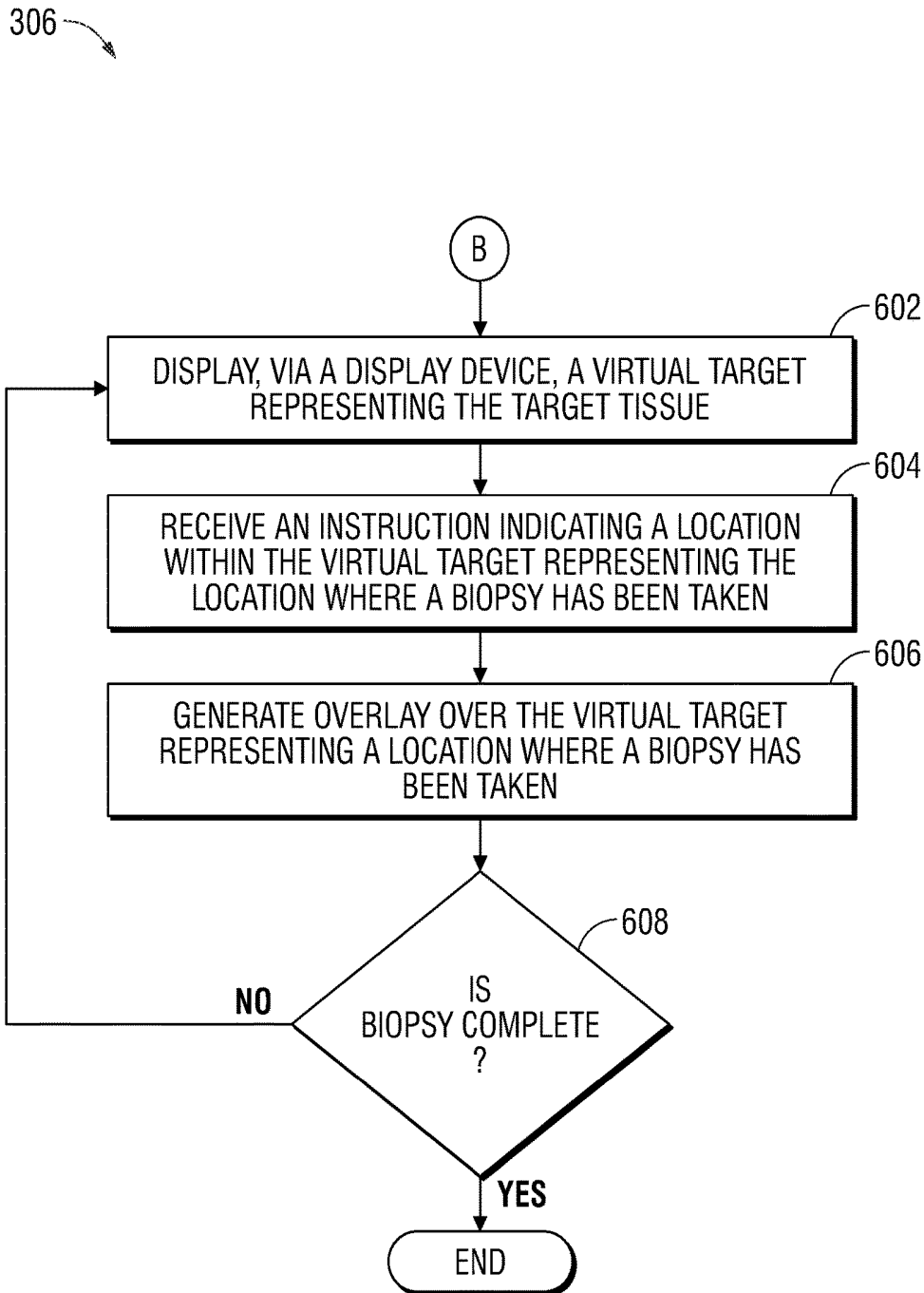


FIG. 6

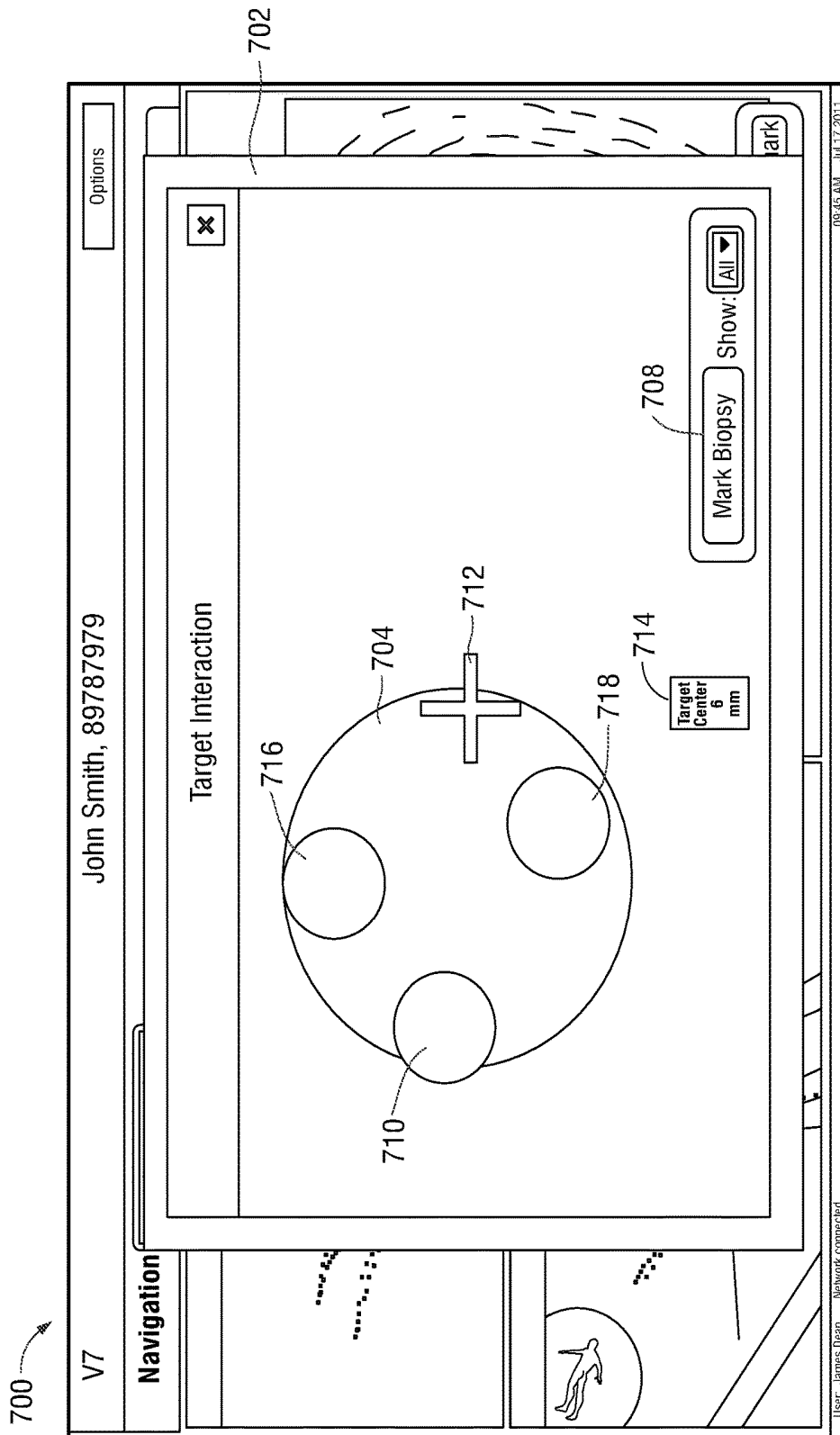


FIG. 7

## ELECTROMAGNETIC NAVIGATION BRONCHOSCOPY USING ULTRASOUND

### CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Application No. 62/648,992, filed on Mar. 28, 2018, the entire contents of which are incorporated by reference herein.

### BACKGROUND

#### Technical Field

[0002] Example aspects described herein relate generally to integrating ultrasound with electromagnetic navigation bronchoscopy, and, more particularly, to systems, methods, and computer-readable media for facilitating electromagnetic navigation bronchoscopy using ultrasound to locate and navigate to a target tissue.

#### Description of Related Art

[0003] A bronchoscope is commonly used to inspect an airway of a patient. Typically, the bronchoscope is inserted into the patient's airway through the patient's nose or mouth or another opening, and can extend into the lungs of the patient. The bronchoscope typically includes an elongated flexible tube having an illumination assembly for illuminating the region distal to the bronchoscope's tip, an imaging assembly for providing a video image from the bronchoscope's tip, and a working channel through which an instrument, such as a diagnostic instrument (for example, a biopsy tool), a therapeutic instrument, and/or another type of tool, can be inserted.

[0004] Electromagnetic navigation (EMN) systems and methods have been developed that utilize a three-dimensional model (or an airway tree) of the airway, which is generated from a series of computed tomography (CT) images generated during a planning stage. One such system has been developed as part of Medtronic Inc.'s ILOGIC® ELECTROMAGNETIC NAVIGATION BRONCHOSCOPY® (ENB™) system. The details of such a system are described in U.S. Pat. No. 7,233,820, entitled ENDOSCOPE STRUCTURES AND TECHNIQUES FOR NAVIGATING TO A TARGET IN BRANCHED STRUCTURE, filed on Apr. 16, 2003, the entire contents of which are hereby incorporated herein by reference. Additional aspects of such a system relating to image registration and navigation are described in U.S. Pat. No. 8,218,846, entitled AUTOMATIC PATHWAY AND WAYPOINT GENERATION AND NAVIGATION METHOD, filed on May 14, 2009; U.S. Patent Application Publication No. 2016/0000356, entitled REAL-TIME AUTOMATIC REGISTRATION FEEDBACK, filed on Jul. 2, 2015; and U.S. Patent Application Publication No. 2016/0000302, entitled SYSTEM AND METHOD FOR NAVIGATING WITHIN THE LUNG, filed on Jun. 29, 2015; the entire contents of each of which are hereby incorporated herein by reference.

[0005] In some cases, a bronchoscope may be too large to reach beyond the first few generations of airway branches or the CT images generated during the planning stages may not provide enough detail for the bronchoscope to reach a target tissue. Additionally, CT images may not represent a real-time depiction of the airways.

### SUMMARY

[0006] Existing challenges associated with the foregoing, as well as other challenges, are overcome by methods for facilitating bronchoscopy using ultrasound, and also by systems and computer-readable media that operate in accordance with the methods. In accordance with one aspect of the present disclosure, a method for facilitating electromagnetic navigation bronchoscopy using ultrasound is provided. The method includes receiving, from an electromagnetic sensor coupled to a distal portion of an extended working channel, an electromagnetic sensor signal value corresponding to a location, within a luminal network of a patient, of the distal portion of the extended working channel. Ultrasound image data is received from an ultrasound probe that protrudes from the distal portion of the extended working channel. Based on the ultrasound image data, an ultrasound image is displayed by way of a display device. An instruction to store location data corresponding to a location, within the luminal network of the patient, of target tissue is received by way of an input device. In response to the receiving of the instruction, the location data corresponding to the location of the target tissue is stored in a memory. The location data corresponding to the location of the target tissue is based on the received electromagnetic sensor signal value corresponding to the location of the distal portion of the extended working channel.

[0007] In another aspect of the present disclosure, the method further includes displaying, by way of the display device, a marker representing the location of the target tissue.

[0008] In a further aspect of the present disclosure, the method further includes receiving, from the electromagnetic sensor at a plurality of distinct times, a plurality of electromagnetic sensor signal values corresponding to a plurality of locations, within a luminal network of a patient, of the distal portion of the extended working channel at a respective one of the plurality of distinct times. A plurality of items of location data corresponding to the plurality of locations of the distal portion of the extended working channel at the plurality of distinct times, respectively, are stored in the memory. A plurality of markers representing the plurality of locations of the distal portion of the extended working channel, respectively, are displayed by way of the display device.

[0009] In still another aspect of the present disclosure, one of the plurality of electromagnetic sensor signal values corresponding to one of the plurality of locations of the distal portion of the extended working channel is stored when the one of the plurality of locations is a predetermined distance from a previously stored location of the distal portion of the extended working channel.

[0010] In yet another aspect of the present disclosure, the plurality of markers representing the locations of the extended working channel are displayed on the display device adjacent to the ultrasound image.

[0011] In another aspect of the present disclosure, the method further includes indicating, by way of the display device, that one of the plurality of markers corresponds to the location of the target tissue. In a further aspect of the present disclosure, the indicating includes changing an attribute of the one of the plurality of markers that corresponds to the location of the target tissue.

[0012] In still another aspect of the present disclosure, the attribute is a color, a size, or a pattern.

**[0013]** In yet another aspect of the present disclosure, the displaying of the ultrasound image includes displaying an ultrasound image that includes a representation of at least a portion of the target tissue, and the receiving of the instruction occurs concurrently with the displaying of the ultrasound image that includes the representation of the at least a portion of the target tissue.

**[0014]** In another aspect of the present disclosure, the method further includes determining a location of a distal portion of the ultrasound probe based on the electromagnetic sensor signal value corresponding to the location of the distal portion of the extended working channel.

**[0015]** In a further aspect of the present disclosure, the ultrasound probe protrudes a predetermined distance from the distal portion of the extended working channel, and the location of the ultrasound probe is determined based on the predetermined distance and the location of the distal portion of the extended working channel.

**[0016]** In still another aspect of the present disclosure, the method further includes receiving, from an additional electromagnetic sensor, coupled to the distal portion of the ultrasound probe, an additional electromagnetic sensor signal value corresponding to a location, within the luminal network of the patient, of the distal portion of the ultrasound probe. The determining of the location of the distal portion of the ultrasound probe is based on the additional electromagnetic sensor signal value.

**[0017]** In yet another aspect of the present disclosure, the method further includes determining the location of the target tissue relative to the location of the distal portion of the ultrasound probe, and generating the location data corresponding to the location of the target tissue based on the location of the target tissue relative to the location of the distal portion of the ultrasound probe.

**[0018]** In another aspect of the present disclosure, the method further includes processing the ultrasound image data, and determining, based on the processing of the ultrasound image data and the location of the distal portion of the ultrasound probe, the location of the target tissue within the luminal network of the patient.

**[0019]** In a further aspect of the present disclosure, the method further includes generating the location data corresponding to the location of the target tissue based on the electromagnetic sensor signal value corresponding to the location of the distal portion of the extended working channel at a time the instruction to store the electromagnetic sensor signal value corresponding to a location of target tissue is received.

**[0020]** In still another aspect of the present disclosure, the method further includes displaying, by way of the display device, a virtual target representing the target tissue.

**[0021]** In yet another aspect of the present disclosure, the method further includes generating an overlay representation of a location within the luminal network of the patient where a biopsy has been taken, and displaying the overlay upon a corresponding portion of the virtual target.

**[0022]** In another aspect of the present disclosure, the method further includes receiving, by way of the input device, an input indicating that a current location, within the luminal network of the patient, of the distal portion of the extended working channel corresponds to the location, within the luminal network of the patient, where the biopsy has been taken. In response to the receiving of the input, a

location within the virtual target representing the location within the luminal network of the patient where the biopsy has been taken is identified.

**[0023]** In a further aspect of the present disclosure, the method further includes indicating, by way of the display device, a location within the virtual target where a biopsy needs to be taken.

**[0024]** In still another aspect of the present disclosure, an attribute of the virtual target displayed by way of the display device changes based on changes in the location of the distal portion of the extended working channel within the luminal network of the patient. In yet another aspect of the present disclosure, the attribute includes at least one of a size, a color, or a pattern of the virtual target.

**[0025]** In another aspect of the present disclosure, the method further includes receiving, by way of the input device, an input indicating the location of the target tissue on the ultrasound image displayed on the display device, and generating the location data corresponding to the location of the target tissue based on the received input indicating the location of the target tissue on the ultrasound image.

**[0026]** In a further aspect of the present disclosure, the display device includes a touch screen as the input device, and the input is a touch input received by way of a contact made between a user and the touch screen.

**[0027]** In accordance with another aspect of the present disclosure, a system for facilitating electromagnetic navigation bronchoscopy using ultrasound is provided. The system includes an ultrasound probe, an extended working channel configured to receive the ultrasound probe, a display device, an input device, and a computer. The extended working channel includes a distal portion on which an electromagnetic sensor is disposed. The computer includes a processor and a memory coupled to the processor. The memory has instructions stored thereon which, when executed by the processor, cause the computer to receive, from the electromagnetic sensor, an electromagnetic sensor signal value corresponding to a location, within a luminal network of a patient, of the distal portion of the extended working channel. Ultrasound image data is received from the ultrasound probe, which protrudes from the distal portion of the extended working channel. Based on the ultrasound image data, an ultrasound image is displayed by way of the display device. An instruction to store location data corresponding to a location, within the luminal network of the patient, of target tissue is received by way of the input device. In response to receipt of the instruction, the location data corresponding to the location of the target tissue is stored in the memory. The location data corresponding to the location of the target tissue is based on the received electromagnetic sensor signal value corresponding to the location of the distal portion of the extended working channel.

**[0028]** In accordance with another aspect of the present disclosure, a non-transitory computer-readable medium is described. The non-transitory computer-readable medium stores instructions that, when executed by a processor, cause the processor to perform a method for facilitating electromagnetic navigation bronchoscopy using ultrasound. The method includes receiving, from an electromagnetic sensor coupled to a distal portion of an extended working channel, an electromagnetic sensor signal value corresponding to a location, within a luminal network of a patient, of the distal portion of the extended working channel. Ultrasound image data is received from an ultrasound probe that protrudes

from the distal portion of the extended working channel. Based on the ultrasound image data, an ultrasound image is displayed by way of a display device. An instruction to store location data corresponding to a location, within the luminal network of the patient, of target tissue is received by way of an input device. In response to the receiving of the instruction, the location data corresponding to the location of the target tissue is stored in a memory. The location data corresponding to the location of the target tissue is based on the received electromagnetic sensor signal value corresponding to the location of the distal portion of the extended working channel.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0029] Various aspects and features of the present disclosure are described herein below with reference to the drawings, wherein:

[0030] FIG. 1 depicts a perspective view of an electromagnetic navigation system in accordance with the present disclosure;

[0031] FIG. 2 is a schematic diagram of an example computing device employed in the system of FIG. 1;

[0032] FIG. 3 is a flow diagram of an example method for identifying, navigating to, and performing a biopsy of a target tissue;

[0033] FIGS. 4A and 4B show a more detailed flow diagram of a portion of the example method of FIG. 3;

[0034] FIG. 5 illustrates an example user interface provided by way of the computing device of FIG. 2, presenting a view for navigation throughout a luminal network of a patient;

[0035] FIG. 6 is a more detailed flow diagram of a portion of the example method of FIGS. 3; and

[0036] FIG. 7 illustrates an example user interface provided by way of the computing device of FIG. 2, presenting a view for performing a biopsy of target tissue.

#### DETAILED DESCRIPTION

[0037] It would be beneficial to have improved EMN systems that are capable of assisting a clinician in identifying and navigating to target tissue, even in a case where the target tissue is located beyond the first few generations of the airway branches. For instance, it would be beneficial to employ ultrasound to assist in identifying and confirming the location of the bronchoscope and navigate to target tissue. One technical challenge in doing so, however, is that, because an ultrasound probe is capable of imaging tissue only within a finite distance from the probe itself (for example, air in the lungs may prevent the ultrasound probe from detecting a lesion or may otherwise limit the distance at which the ultrasound probe can detect a lesion) and the direction the ultrasound probe is imaging may be unknown, searching airways for target tissue can become laborious and, in some cases, may involve unintentionally searching particular airways multiple times, thus reducing the speed and efficiency with which the target tissue can be located.

[0038] This disclosure is related to systems, methods, and computer-readable media for facilitating electromagnetic navigation bronchoscopy using ultrasound. As will be appreciated in view of this disclosure, the systems, methods, and computer-readable media described herein facilitate location of and/or navigation to target tissue and the performing of a biopsy of the target tissue with improved efficiency and

effectiveness, even in cases where target tissue is located beyond the first few generations of the airway branches. In general, the various embodiments described herein employ an ultrasound probe to identify and navigate to a target tissue. Despite ultrasound probes generally being capable of imaging tissue only within a finite distance from the probes themselves, the embodiments described herein avoid the need to conduct laborious and repetitive searching of airways for target tissue, and thereby improve the speed and efficiency with which the target tissue can be located. Additionally, the various embodiments described herein facilitate improved accuracy of biopsy procedures by supplementing electromagnetic navigation bronchoscopy with an ultrasound. In particular, ultrasound is used in cooperation with electromagnetic navigation bronchoscopy to confirm the location of an extended working channel of the bronchoscope. Particular embodiments of this disclosure are described below with reference to the accompanying drawings.

[0039] FIG. 1 illustrates an example electromagnetic navigation (EMN) system 100 provided in accordance with this disclosure. In general, the EMN system 100 is configured to identify a location and/or an orientation of a medical device being navigated toward a target location within a patient's body. In some cases, the EMN system 100 is further configured to augment computed tomography (CT) images, magnetic resonance imaging (MRI) images, fluoroscopic images, and/or ultrasonic images employed during navigation of the medical device through the patient's body toward a target of interest, such as a diseased portion of tissue in a luminal network of the patient's lung.

[0040] The EMN system 100 includes a catheter guide assembly 102, a bronchoscope 104, a computing device 106, a display device 108, a tracking device 110, a patient platform 112, antenna assembly 114, reference sensors 116, a monitoring device 118, and an ultrasound probe 120. The bronchoscope 104 is operatively coupled to the computing device 106 (by way of the tracking device 110) and the monitoring device 118 via respective wired connections (as shown in FIG. 1) or wireless connections (not shown in FIG. 1). During a navigation phase of an EMN bronchoscopy procedure, the bronchoscope 104 is inserted into the oral cavity of a patient "P" and captures images of the luminal network of the patient "P's" lung. The catheter guide assembly 102 is inserted into the bronchoscope 104 to access the periphery of the luminal network of the lung of the patient "P." The catheter guide assembly 102 includes a catheter or extended working channel (EWC) 122 with an EM sensor 124 affixed to a portion, for example, a distal portion 126, of the EWC 122. The EM sensor 124 is communicatively coupled to the tracking device 110 by way of one or more wired or wireless communication paths. For instance, in some embodiments, the EM sensor 124 is communicatively coupled to the tracking device 110 by way of one or more wires 132 that protrude from a port of the catheter guide assembly 102. In some examples, at least a portion (which is not explicitly shown in FIG. 1) of the one or more wires 132 (including a portion where the one or more wires 132 are coupled to the EM sensor 124) is internal to, included as a part of, and/or otherwise affixed to, the catheter guide assembly 102. The EM sensor 124 is configured to receive a signal based on an electromagnetic field radiated by the antenna assembly 114, provide the received signal to the tracking device 110, which uses the received signal to

determine a location and/or an orientation of the EM sensor 124 and, thus, the location of the distal portion 126 of EWC 122 during navigation through the luminal network of the lung. Although the context of the present embodiment is one in which EM sensor 124 is affixed to a portion of the EWC 122, other embodiments without the EWC 122 are also envisioned, such as where the EM sensor 124 is affixed to a distal portion of the bronchoscope 104 itself.

[0041] Due to its size, the bronchoscope 104 is limited in how far it can travel through the periphery of the luminal network of the lung of the patient "P." Thus, the EWC 122 of the catheter guide assembly 102 is inserted into the bronchoscope 104 to access the periphery of the lungs. To assist in visualizing and navigating the periphery of the lungs, an ultrasound probe 120 is inserted into the catheter guide assembly 102 and EWC 122. Ultrasound probe 120 may be any number of types of endobronchial ultrasound probes suitable for use in a bronchoscope 104 and/or a catheter guide assembly 102. For example, in embodiments, ultrasound probe 120 may be a radial ultrasound, a linear ultrasound, or a convex ultrasound. The ultrasound probe 120 includes a proximal portion 130 and a distal portion 128. The distal portion 128 of the ultrasound probe 120 protrudes past the distal portion 126 of the EWC 122 to aid in visualizing the surrounding area of the distal portion 126 of the EWC 122.

[0042] Before continuing to describe the EMN system 100 illustrated in FIG. 1, reference will be made to FIG. 2, which shows example aspects of the computing device 106 of the system 100. The computing device 106 is generally configured to execute the various functions of the procedures described herein. Additionally, in some embodiments, instead of including a tracking device 110 that is separate from, and communicatively coupled to, the computing device 106, the functions and/or procedures of the tracking device 110 are implemented by the computing device 106. The computing device 106, which, in various embodiments, may be a laptop, desktop, tablet, or any other suitable computing device, includes a display device 108, one or more processors 202, one or more memories 204, a network interface 206, one or more input devices 208 and one or more output modules 216. Memory 204 includes any non-transitory computer-readable storage media for storing data, instructions, and/or other types of software that is executable by processor 202 and which controls the operation of computing device 106. In an embodiment, memory 204 may include one or more solid-state storage devices such as flash memory chips. Alternatively, or in addition to the one or more solid-state storage devices, memory 204 may include one or more mass storage devices connected to the processor 202 through a mass storage controller (not shown in FIG. 2) and a communications bus (not shown in FIG. 2).

[0043] Although the description of computer-readable media contained herein refers to a solid-state storage, it should be appreciated by those skilled in the art that computer-readable storage media can be any available media that can be accessed by the processor 202. That is, computer readable storage media includes non-transitory, volatile and non-volatile, removable and non-removable media implemented in any method or technology for storage of information such as computer-readable instructions, data structures, program modules or other data. For example, computer-readable storage media includes RAM, ROM, EPROM, EEPROM, flash memory or other solid-state

memory technology, CD-ROM, DVD, Blu-Ray or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to store the desired information and which can be accessed by computing device 106.

[0044] Memory 204 may store application 212 and/or data 210, for example, image data, location data, and/or other types of data. Application 212 may include user interface instructions 214 that, when executed by the processor 202, cause the display device 108 to present one or more user interfaces, such as, for example, the example user interface 500 illustrated in FIG. 5 and/or the example user interface 700 illustrated in FIG. 7. Network interface 206 may be configured to connect to a network such as a local area network (LAN) consisting of a wired network and/or a wireless network, a wide area network (WAN), a wireless mobile network, a Bluetooth network, and/or the internet. Input device 208 may be any device by means of which a clinician may interact with computing device 106, such as, for example, a mouse, a keyboard, a foot pedal, a touch screen, and/or a voice interface. Output module 216 may include any connectivity port or bus, such as, for example, parallel ports, serial ports, universal serial busses (USB), or any other similar connectivity port known to those skilled in the art.

[0045] The particular configuration of the computing device 106 illustrated in FIG. 2 is provided as an example, but other configurations of the components shown in FIG. 2 as being included in the computing device 106 are also contemplated. In particular, in some embodiments, one or more of the components shown in FIG. 2 as being included in the computing device 106 may instead be separate from the computing device 106 and may be coupled to the computing device 106 and/or to any other component(s) of the EMN system 100 by way of one or more respective wired or wireless path(s) to facilitate the transmission of power and/or data signals throughout the EMN system 100.

[0046] In some aspects, the EMN system 100 may also include multiple computing devices 106, wherein the multiple computing devices 106 are employed for planning, treatment, visualization, or helping clinicians in a manner suitable for medical operations. The display device 108 may be touch-sensitive and/or voice-activated, enabling the display device 108 to serve as both an input device and an output device. The display device 108 may display two-dimensional (2D) images or three-dimensional (3D) images, such as a 3D model of a lung, to enable a practitioner to locate and identify a portion of the lung that displays symptoms of lung diseases. The display device 108 may also display ultrasound images received from the ultrasound probe 120.

[0047] The one or more memories 204 store one or more programs and/or computer-executable instructions that, when executed by the one or more processors 202, cause the one or more processors 202 to perform various functions and/or procedures, such as, for instance, the procedures described herein in connection with FIG. 3, FIG. 4A, FIG. 4B, and/or FIG. 6. For example, the processors 202 may calculate a location and/or an orientation of the EM sensor 124 based on the electromagnetic signal that is radiated by the antenna assembly 114 and received by the EM sensor 124. The processors 202 may also perform image-processing functions to cause the 3D model of the lung to be displayed on the display device 108 or cause the ultrasound

image received from the ultrasound probe 120 to be displayed on the display device 108. The processors 202 may also generate one or more electromagnetic signals to be radiated by way of the antenna assembly 114. In some embodiments, the computing device 106 may further include a separate graphic accelerator (not shown) that performs only the image-processing functions so that the one or more processors 202 may be available for other programs. The one or more memories 204 also store data 210, such as mapping data for EMN, image data, patients' medical record data, prescription data, and/or data regarding a history of the patient's diseases, and/or other types of data.

[0048] Referring now back to FIG. 1, the patient platform 112 is configured to provide a flat surface upon which the patient "P" lies during the EMN navigation procedure. The antenna assembly 114, which may also be referred to as an EM field-generating device, is arranged upon the platform 112 or is included as a component of the platform 112. The antenna assembly 114 includes one or more antennas (not shown in FIG. 1). With the patient "P" lying upon the platform 112, the one or more processors 202 (or another signal generator not shown in FIG. 1) generate and provide to the antenna(s) of the antenna assembly 114 one or more AC current signals that the antenna(s) convert into one or more respective EM signal(s) and radiate in a manner sufficient to overlap with a volume occupied by the patient "P." In this manner, EMN system 100 generates an electromagnetic field that allows for the tracking of the position of the EM sensor 124 within the generated electromagnetic field.

[0049] Having described aspects of the EMN system 100 with reference to FIG. 1 and FIG. 2, reference will now be made to FIG. 3, FIG. 4A, FIG. 4B, and FIG. 6 to describe aspects of an example procedure 300 for utilizing the system 100 to identify, navigate to, and/or perform a biopsy of, a target tissue. Before describing particular details of the procedure 300 in the context of FIG. 4A, FIG. 4B, and FIG. 6, a general overview of the procedure 300 will be provided in the context of FIG. 3. In general, the procedure 300 includes three phases—a target tissue search phase (block 302), a target tissue location data storage phase (block 304), and a biopsy phase (block 306). The procedure 300 begins at block 302 with a search for a target tissue. Once the bronchoscope 104 and the catheter guide assembly 102 are inserted into the oral cavity of the patient "P," the ultrasound probe 120 is inserted into the EWC 122 of the catheter guide assembly 102. Using the EM sensor 124 disposed on the distal portion 126 of EWC 122, the location of the distal portion 126 of the EWC 122, and, by extension, the locations of the EWC 122 and the ultrasound probe 120 can be tracked. Ultrasound probe 120 is used to perform a more exact search in the periphery of the bronchial tree. Specifically, ultrasound probe 120 can be used to generate an ultrasound image (for example, the ultrasound image 508 described below) of the periphery of the bronchial tree that is presented to the clinician by way of the display device 108. The clinician observes the generated ultrasound images while repositioning the ultrasound probe 120 within the luminal network of the patient "P" to locate the target tissue within the luminal network. By utilizing the tracked location of the EM sensor 124, the clinician can perform a more efficient search of the periphery of the bronchial tree. In particular, the tracking of the EM sensor 124 informs the clinician of what areas of the periphery of the bronchial tree

is currently being searched and what areas have already been searched. This ensures that the clinician does not search the same area multiple times and ensures that the search is done in the vicinity of the target tissue.

[0050] At block 304, once the target tissue has been reached and identified by using the ultrasound probe 120, location data corresponding to the location of the target tissue is stored in the memory 204 of the computing device 106 for subsequent use by the clinician. As will be described in further detail below, the location data stored at block 304 is based on a received electromagnetic sensor signal value corresponding to a location of the distal portion 126 of the EWC 122. In particular, at block 304, using the location of the EM sensor 124 disposed on the distal portion 126 of the EWC 122, as determined by the tracking device 110 and/or the computing device 106, the location of the distal portion 128 of the ultrasound probe 120, and thus the location of the target tissue, is determined by the tracking device 110 and/or the computing device 106. Once the location data has been stored at block 304, the stored location data is used during a subsequent phase of the procedure, for instance, to facilitate accurate navigation to the target tissue during a tool exchange, whereby the ultrasound probe 120 is removed from the patient "P" and is replaced with a biopsy tool (not shown in FIG. 1), and/or during a biopsy phase of the procedure conducted at block 306.

[0051] The final stage of the procedure 300, depicted in block 306, is the management of the biopsy procedure of the target tissue. Once the location of the target tissue has been determined and/or the location data has been stored at block 304, a biopsy tool (not shown in FIG. 1) is inserted into the luminal network of the patient "P" by way of the EWC 122 to extract a portion of the target tissue, which is to be subsequently tested for various characteristics. As described in further detail below, the computing device 106 utilizes the previously acquired ultrasound image of the target tissue to render a virtual target to assist in the biopsy procedure of the target tissue.

[0052] Having provided a general overview of the procedure 300 in the context of FIG. 3, more detailed aspects of the procedure 300 will now be described with reference to FIGS. 4A-7. In particular, flow diagrams of FIG. 4A, FIG. 4B, and FIG. 6 illustrates more detailed aspects of the target tissue search phase (block 302 of FIG. 3), the target tissue location data storage phase (block 304 of FIG. 3), and the biopsy phase (block 306 of FIG. 3), respectively, of the procedure 300. FIG. 5 illustrates an example user interface 500 provided by way of the computing device 106 during the target tissue search phase (block 302 of FIG. 3) and target tissue location data storage phase (block 304 of FIG. 3) of the procedure 300, and FIG. 7 illustrates an example user interface 700 provided by way of the computing device 106 during the biopsy phase (block 306 of FIG. 3) of the procedure 300.

[0053] Although not shown in FIG. 4A, prior to block 402, computing device 106 receives CT scan data of a luminal network of the patient "P." Utilizing the CT scan data, computing device 106 generates a 3D model 502 (depicted in the user interface 500 of FIG. 5) corresponding to the luminal network of the patient "P." The 3D model 502 is displayed to the clinician via the user interface 500 of display device 108. Computing device 106 also utilizes the 3D model 502 to create a planned pathway through the luminal network of the patient "P" to the target tissue that,

together with the generated 3D model, is employed by the clinician to assist in navigation throughout the luminal network of the patient "P."

[0054] Patient "P" is then placed on antenna assembly 114, which generates one or more electromagnetic fields that are sensed by reference sensors 116 and the EM sensor 124 affixed to the EWC 122. The computing device 106 then indicates to the clinician, by way of the 3D model 502, a suggested path within the luminal network of the patient "P" along which to navigate the EWC 122 to arrive at the target tissue. To begin, a bronchoscope 104 is inserted into the oral cavity of the patient "P." The EWC 122 is then inserted into the bronchoscope 104. At block 402, computing device 106 receives, from EM sensor 124 coupled to the distal portion 126 of the EWC 122, an EM sensor 124 signal value corresponding to a location, within the luminal network of the patient "P," of the distal portion 126 of the EWC 122.

[0055] At block 404, computing device 106 stores, in memory 204, the EM sensor 124 signal value, which was received at block 402, and which corresponds to the location of the distal portion 126 of the EWC 122. Thus, as the EWC 122 is navigated through the luminal network of the patient "P", computing device 106 continually or periodically tracks and stores data indicating the historical locations of the distal portion 126 of the EWC 122 at various times during navigation, and thus indicating the pathway that the EWC 122 has traveled within the luminal network.

[0056] At block 406, the display device 108 displays, by way of the user interface 500, one or more markers 504, each of the markers 504 corresponding to one of the locations of the distal portion 126 of the EWC 122 for which corresponding data was stored at block 404. In particular, as depicted in FIG. 5, markers 504 are displayed on user interface 500 in a survey window 506 to depict the pathways in the luminal network of the patient "P" that the EWC 122 has already traveled during the target tissue search phase (block 302 of FIG. 3). In some embodiments, the markers 504 are superimposed over the 3D model 502 corresponding to the luminal network of the patient "P." In this manner, the clinician is provided, by way of the user interface 500, with a continually updated indication of the particular paths within the luminal network of the patient "P" that the EWC 122 has already traversed, thereby enabling the clinician to avoid searching particular paths multiple times, thus improving the speed and efficiency with which the target tissue can be located. In some examples, the computing device 106 stores in the memory 204 a timestamp associated with each of the EM sensor 124 signal values corresponding to a time the EM sensor 124 signal values were received.

[0057] At block 408, with the ultrasound probe 120 inserted into the EWC 122 such that the distal portion 128 of the ultrasound probe 120 protrudes from the distal portion 126 of the EWC 122, the location of the distal portion 128 of the ultrasound probe 120 is determined based on the location of the distal portion 126 of the EWC 122. The location of the distal portion 128 of the ultrasound probe 120 is determined in a number of different ways, in accordance with various embodiments. In one embodiment, the distal portion 128 of the ultrasound probe 120 protrudes from the distal portion 126 of the EWC 122 by a known distance. In this embodiment, for example, the ultrasound probe 120 locks to the EWC 122 at a distal portion and/or a proximal portion of the ultrasound probe 120 and the EWC 122 (not shown in FIG. 1). Thus, once the location of the distal

portion 126 of the EWC 122 is determined in the manner described above, the location of the distal portion 128 of the ultrasound probe 120 is determined based on the known distance by which the distal portion 128 of the ultrasound probe 120 protrudes from the distal portion 126 of the EWC 122. In another embodiment, the EWC 122 has a known length and the ultrasound probe 120 has hash marks (not shown in FIG. 1) disposed, along the proximal portion 130 of the ultrasound probe 120, at known and/or marked distances from the distal end of the ultrasound probe 120. Thus, as the ultrasound probe 120 is pushed past a distal portion 126 of the EWC 122, the location of the distal portion 128 of the ultrasound probe 120 relative to the EM sensor 124 disposed at a distal portion 126 of the EWC 122 can be determined by measuring the visible hash marks. In yet another embodiment, an additional EM sensor (not shown in FIG. 1) is coupled to the distal portion 128 of the ultrasound probe 120, and the computing device 106 receives from the additional EM sensor an additional EM sensor signal value corresponding to a location, within the luminal network of a patient "P," of the distal portion 128 of the ultrasound probe 120.

[0058] At block 410, computing device 106 receives ultrasound image data from the ultrasound probe 120. The computing device 106 processes the ultrasound image data and, based on the received ultrasound image data, displays at block 412, via display device 108, an ultrasound image 508 (FIG. 5) of the region of the luminal network of the patient "P" where the distal portion 128 of the ultrasound probe 120 is located. Display of the ultrasound image 508 allows the clinician to inspect various portions of tissue of the luminal network, including, for example, tissue located at a target site and/or tissue located elsewhere in the luminal network.

[0059] When the ultrasound probe 120 reaches the target tissue, an ultrasound image including an ultrasound image of a portion of the target tissue 510 is displayed in the ultrasound image 508. When the clinician observes the ultrasound image including the portion of the target tissue 510 in the ultrasound image 508, the clinician provides to the computing device 106, by way of the input device 208, an instruction (also referred to herein as a storage instruction) to store location data corresponding to the location, within the luminal network of the patient "P", of the EM sensor 124, while the target tissue 510 remains displayed in the ultrasound image 508. The location data that corresponds to the location, within the luminal network of the patient "P", of the EM sensor 124 while the target tissue 510 remains displayed in the ultrasound image 508 corresponds to the location of the target tissue 501. In various embodiments, the clinician may instruct the computing device 106 to store the location data in a number of different ways. For example, in a case where the display device 108 includes a touch screen that functions as the input device 208, the clinician can instruct the computing device 106 to store the location data by selecting a bookmark button 512 (FIG. 5) displayed on the user interface 500. Alternatively, in a case where the input device 208 is a foot pedal or a computer mouse, the clinician may instruct the computing device 106 to store the location data by actuating the foot pedal and/or the computer mouse. These examples of types of input devices 208 by which the clinician may provide instructions to the computing device 106 are merely provided by way of illustration, not limitation. In other embodiments, any suitable type of

input device 208 may be used by the clinician to provide instructions to the computing device 106.

[0060] At block 414, a determination is made as to whether the storage instruction is received by way of the input device 208. If it is determined at block 414 that the storage instruction has not been received, for instance, indicating that the target tissue has not yet been reached, then the procedures of blocks 402-412 are repeated. In this manner, blocks 402-412 are continually repeated as the EWC 122 and the ultrasound probe 120 are navigated throughout the luminal network of the patient "P." As the EWC 122 is moved a predetermined distance from a previously stored location, a new EM sensor 124 signal value corresponding to a new location of the EWC 122 is stored in the memory 204 by the computing device 106. If, on the other hand, it is determined at block 414 that the storage instruction has been received by way of the input device 208, the procedure progresses to block 416.

[0061] In various embodiments, the location data for which the storage instruction was received at block 414, can be any type of location data that enables the clinician to navigate a tool back to the target tissue 510, for example, after a tool exchange. In each embodiment, the location data generally corresponds to the location of the target tissue within the luminal network of the patient "P". In some embodiments, the location data indicates a location, within the luminal network of the patient "P", of the EM sensor 124, the distal portion 126 of the EWC 122, and/or the distal portion 128 of the ultrasound probe 120, as determined at a time when the EM sensor 124, the distal portion 126 of the EWC 122, and/or the distal portion 128 of the ultrasound probe 120 are positioned, within the luminal network of the patient "P", proximal to the target tissue.

[0062] In another embodiment, the location data indicates a location, within the luminal network of the patient "P", of the target tissue itself. In this embodiment, at block 416, the location, within the luminal network of the patient "P", of the target tissue 510 is determined. In particular, the location of the target tissue 510 relative to the EM sensor 124 and the distal portion 128 of the ultrasound probe 120 is determined. In embodiments, the location data indicating the location of the target tissue 510 is utilized by the computing device 106 to update the registration and location of the target tissue obtained in a planning stage. In embodiments, the location data corresponding to the location of the target tissue 510 relative to the ultrasound probe 120 is compared with the EM sensor 124 signal value corresponding to the location of the distal portion 126 of the EWC 122. The distance between the location of the distal portion 126 of the EWC 122 and the location of the target tissue 510 is determined based on a result of this comparison. The computing device 106 generates location data corresponding to the location of the target tissue 510 to be stored in the memory 204. At block 418, the location data for which the storage instruction was received at block 414 is stored in the memory 204.

[0063] At block 420, the location data that was stored at block 418 and that corresponds to the location of the target tissue 510 is associated with a corresponding marker, such as, for example marker 504 (FIG. 5). In some embodiments, the location of the target tissue 510 is digitally stored and in other embodiments, the location of the target tissue 510 is digitally stored and also displayed by way of the display device 108 via a corresponding marker. Although not shown in FIG. 5, in some embodiments, the marker 504 associated

with the location of the target tissue is a different shape, color, or pattern than other ones of the markers 504 to allow a clinician to easily identify which marker 504 corresponds to the location of the target tissue. As depicted in FIG. 5, the ultrasound image 508 is displayed adjacent the survey window 506. However, other configurations are also envisioned. For example, the markers 504 may be superimposed over the ultrasound image 508 and/or the 3D model 502.

[0064] Once the target tissue search phase (block 302 of FIG. 3) and target tissue location data storage phase (block 304 of FIG. 3) have been completed, the procedure 300 proceeds to the biopsy phase (block 306 of FIG. 3), which is described in further detail in connection with FIG. 6 and FIG. 7, and in which the clinician performs a biopsy of the target tissue 510 with the assistance of the system 100. In particular, to facilitate the biopsy, a tool exchange is performed in which the clinician removes the ultrasound probe 120 from the EWC 122 in order to navigate the biopsy tool (not shown in FIG. 1) to the target tissue. Since the biopsy is performed without the aid of a live ultrasound image from the ultrasound probe 120, when a clinician begins the biopsy of the target tissue, the computing device 106 displays a user interface 700 including a biopsy screen 702 via the display device 108 at block 602 to assist the clinician in performing the biopsy. In particular, the computing device 106 generates a virtual target 704, which is displayed via the biopsy screen 702, and which represents the target tissue. In some embodiments, the virtual target 704 is generated by mapping a predetermined set of locations within the luminal network of the patient "P" to a geometrical shape. In other embodiments, the computing device 106 performs image processing of the ultrasound image 508 including the ultrasound image of the portion of the target tissue 510 to generate a virtual target 704. In some examples, the computing device 106 automatically displays biopsy screen 702 and virtual target 704 on the display device 108 when the distal portion 136 of the EWC 122 is navigated to within a predetermined distance, for example, from about 1 cm to about 5 cm, from the location indicated by the location data that was stored at block 418 and that corresponds to the location of the target tissue.

[0065] At block 604, once a biopsy has been taken by the clinician, by extracting a portion of the target tissue, the clinician provides to the computing device 106, by way of the input device 208, an input indicating a portion of the virtual target 704 that corresponds to the portion of the target tissue where the biopsy was taken. In some embodiments, the exact direction of the target tissue cannot be determined, therefore, the virtual target 704 may correspond to portions of the pathway that are targets for biopsy locations. Therefore, a user is aided to ensure that a biopsy has been taken in all directions, thereby increasing the likelihood that a biopsy of the target tissue is acquired. In various embodiments, the input provided by the clinician can be provided by any type of the input device 208, such as a computer mouse, a touch screen device, and/or the like, together with a selection of the "Mark Biopsy" button 708, for instance.

[0066] The biopsy screen 702 allows the clinician to indicate on the biopsy screen 702 the portion of the virtual target 704 that corresponds to the portions of the target tissue at which the clinician has taken the biopsy. At block 606, the computing device 106 generates an overlay 710 indicating the portion of the virtual target 704 that corresponds to the portion of the target tissue at which the biopsy has been

taken by the clinician. As the clinician extracts subsequent biopsy samples at other portions of the target tissue, the clinician provides additional inputs to the computing device 106 indicating the portions of the virtual target 704 that correspond to the portions of the target tissue where the biopsy portions have been extracted. The computing device generates additional overlays, such as overlays 716 and 718, indicating the additional portions of the virtual target 704 that correspond to the portions of the target tissue at which the biopsy samples have been extracted by the clinician. In this manner, the clinician may keep track of which portions of the target tissue have been biopsied, to ensure a thorough and accurate biopsy yield is obtained. Thus, the accuracy of the biopsy procedure may be improved, despite the orientation of the target tissue with respect to the ultrasound probe 120 possibly remaining unknown.

[0067] In some embodiments, an attribute of the virtual target 704 and/or the overlays 710, 716, 718 changes based on the location of the distal portion 126 of the EWC 122 within the luminal network of the patient "P." In other embodiments, the size of the displayed virtual target 704 and/or the overlays 710, 716, 718 changes when the EWC 122 is closer to the target tissue 510. For example, the virtual target 704 and/or the overlays 710, 716, 718 is smaller when the location of the distal portion 126 of the EWC 122 is farther from the target tissue 510, and vice versa, is larger when the location of the distal portion 126 of the EWC 122 is closer to the target tissue 510.

[0068] At block 608, if the biopsy is incomplete (for instance, if any locations within the virtual target 704 remain where a biopsy still needs to be taken), the functions of blocks 602-606 are repeated. If, on the other hand, no locations within the virtual target 704 where a biopsy needs to be taken remain, the biopsy is marked complete. In some embodiments, when no locations where a biopsy needs to be taken remain, an indicator (not shown in FIG. 7) is displayed, by way of the display device 108. The indicator, in various embodiments, can be a textual message, an audible sound, and/or any other suitable indicator. Biopsy screen 702, in some embodiments, further includes an indicator 712 that represents the location of the distal portion 126 of the EWC 122 relative to the target tissue 510. In embodiments, the indicator is a crosshair and moves relative to the location of the distal portion 126 of the EWC 122. Biopsy screen 702 also includes, in some examples, a distance indicator 714 which displays the distance between the distal portion 126 of the EWC 122 and the approximate center of the target tissue 510.

[0069] While several embodiments of the disclosure have been shown in the drawings, it is not intended that the disclosure be limited thereto, as it is intended that the disclosure be as broad in scope as the art will allow and that the specification be read likewise. Therefore, the above description should not be construed as limiting but merely as exemplifications of particular embodiments. Those skilled in the art will envision other modifications within the scope and spirit of the claims appended hereto.

What is claimed is:

1. A method for facilitating electromagnetic navigation bronchoscopy using ultrasound, the method comprising:

receiving, from an electromagnetic sensor coupled to a distal portion of an extended working channel, an electromagnetic sensor signal value corresponding to a

location of the distal portion of the extended working channel within a luminal network of a patient;

receiving ultrasound image data from an ultrasound probe that protrudes from the distal portion of the extended working channel;

displaying, by way of a display device, an ultrasound image based on the ultrasound image data;

receiving, by way of an input device, an instruction to store location data corresponding to a location of target tissue within the luminal network of the patient while at least a portion of the target tissue is shown in the ultrasound image; and

in response to the receiving of the instruction, storing the location data corresponding to the location of the target tissue in a memory, wherein the location data corresponding to the location of the target tissue is based on the received electromagnetic sensor signal value corresponding to the location of the distal portion of the extended working channel.

2. The method according to claim 1, further comprising: displaying, by way of the display device, a survey window adjacent to the ultrasound image; and

displaying, in the survey window, a marker indicating the location of the target tissue .

3. The method according to claim 2, further comprising: receiving, from the electromagnetic sensor at a plurality of distinct times, a plurality of electromagnetic sensor signal values corresponding to a respective plurality of locations of the distal portion of the extended working channel within a luminal network of a patient;

storing in the memory the plurality of electromagnetic sensor signal values; and

displaying, in the survey window, a plurality of markers indicating the plurality of locations of the distal portion of the extended working channel, respectively.

4. The method according to claim 3, wherein one of the plurality of electromagnetic sensor signal values corresponding to one of the plurality of locations of the distal portion of the extended working channel is stored when one of the plurality of locations is a predetermined distance from a previously stored location of the distal portion of the extended working channel.

5. The method according to claim 3, further comprising changing an attribute of the marker indicating the location of the target tissue.

6. The method according to claim 1, further comprising: determining a location of a distal portion of the ultrasound probe based on the electromagnetic sensor signal value corresponding to the location of the distal portion of the extended working channel.

7. The method according to claim 6, wherein the ultrasound probe protrudes a predetermined distance from the distal portion of the extended working channel, and

wherein the location of the ultrasound probe is determined based on the predetermined distance and the location of the distal portion of the extended working channel.

8. The method according to claim 6, further comprising receiving, from an additional electromagnetic sensor, coupled to the distal portion of the ultrasound probe, an additional electromagnetic sensor signal value corresponding to a location, within the luminal network of the patient, of the distal portion of the ultrasound probe, wherein the

determining of the location of the distal portion of the ultrasound probe is based on the additional electromagnetic sensor signal value.

9. The method according to claim 6, further comprising determining the location of the target tissue relative to the location of the distal portion of the ultrasound probe; and

generating the location data corresponding to the location of the target tissue based on the location of the target tissue relative to the location of the distal portion of the ultrasound probe.

10. The method according to claim 6, further comprising: processing the ultrasound image data; and

determining, based on the processing of the ultrasound image data and the location of the distal portion of the ultrasound probe, the location of the target tissue within the luminal network of the patient.

11. The method according to claim 1, further comprising: generating the location data corresponding to the location of the target tissue based on the electromagnetic sensor signal value corresponding to the location of the distal portion of the extended working channel at a time the instruction to store the electromagnetic sensor signal value corresponding to a location of target tissue is received.

12. The method according to claim 1, further comprising displaying, by way of the display device, a virtual target representing the target tissue.

13. The method according to claim 12, further comprising:

generating an overlay representation of a location within the luminal network of the patient where a biopsy has been taken; and

displaying the overlay representation on a corresponding portion of the virtual target.

14. The method according to claim 13, further comprising:

receiving, by way of the input device, an input indicating that a current location of the distal portion of the extended working channel within the luminal network of the patient corresponds to the location where the biopsy has been taken within the luminal network of the patient; and

in response to the receiving of the input, identifying a location within the virtual target representing the location where the biopsy has been taken within the luminal network of the patient.

15. The method according to claim 14, further comprising indicating a location within the virtual target where a biopsy needs to be taken.

16. The method according to claim 12, wherein an attribute of the displayed virtual target changes based on changes in the location of the distal portion of the extended working channel within the luminal network of the patient.

17. The method according to claim 1, further comprising: receiving, by way of the input device, an input indicating the location of the target tissue on the ultrasound image displayed on the display device; and

generating the location data corresponding to the location of the target tissue based on the received input indicating the location of the target tissue on the ultrasound image.

18. A system for facilitating electromagnetic navigation bronchoscopy using ultrasound, comprising:

an ultrasound probe;  
an extended working channel configured to receive the ultrasound probe, the extended working channel including a distal portion on which an electromagnetic sensor is disposed;

a display device;

an input device; and

a computer including:

a processor; and

a memory coupled to the processor, the memory having instructions stored thereon which, when executed by the processor, cause the computer to:

receive, from the electromagnetic sensor, an electromagnetic sensor signal value corresponding to a location of the distal portion of the extended working channel within a luminal network of a patient;

receive ultrasound image data from the ultrasound probe, wherein the ultrasound probe protrudes from the distal portion of the extended working channel;

display, by way of the display device, an ultrasound image based on the ultrasound image data;

receive, by way of the input device, an instruction to store location data corresponding to a location of target tissue within the luminal network of the patient while at least a portion of the target tissue is shown in the ultrasound image; and

in response to receipt of the instruction, store the location data corresponding to the location of the target tissue in the memory, wherein the location data corresponding to the location of the target tissue is based on the received electromagnetic sensor signal value corresponding to the location of the distal portion of the extended working channel.

19. A non-transitory computer-readable medium storing instructions that, when executed by a processor, cause the processor to perform a method for facilitating electromagnetic navigation bronchoscopy using ultrasound, the method comprising:

receiving, from an electromagnetic sensor coupled to a distal portion of an extended working channel, an electromagnetic sensor signal value corresponding to a location of the distal portion of the extended working channel within a luminal network of a patient;

receiving ultrasound image data from an ultrasound probe;

displaying an ultrasound image based on the ultrasound image data;

receiving an instruction to store location data of target tissue within the luminal network of the patient while at least a portion of the target tissue is shown in the ultrasound image; and

in response to the receiving of the instruction, storing location data corresponding to the location of the target tissue in a memory.

\* \* \* \* \*

专利名称(译)	超声波导航支气管镜		
公开(公告)号	<a href="#">US20190298305A1</a>	公开(公告)日	2019-10-03
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[标]申请(专利权)人(译)	柯惠有限合伙公司		
申请(专利权)人(译)	COVIDIEN LP		
当前申请(专利权)人(译)	COVIDIEN LP		
[标]发明人	KOPEL EVGENI KLEIN EYAL WEINGARTEN OREN P GREENBURG BENJAMIN		
发明人	KOPEL, EVGENI KLEIN, EYAL WEINGARTEN, OREN P. GREENBURG, BENJAMIN		
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摘要(译)

描述了用于使用超声促进电磁导航支气管镜检查的方法和系统。一种这样的方法包括从与延伸的工作通道的远端部分耦合的电磁传感器接收与延伸的工作通道的远端部分的位置相对应的电磁传感器信号值。从延伸的工作通道的远端部分突出的超声探头接收超声图像数据。基于超声图像数据，经由显示装置显示超声图像。接收指令以存储与目标组织的位置相对应的位置数据，并且作为响应，与目标组织的位置相对应的位置数据被存储在存储器中。与目标组织的位置相对应的位置数据是基于所接收的与延伸的工作通道的远端部分的位置相对应的电磁传感器信号值。

