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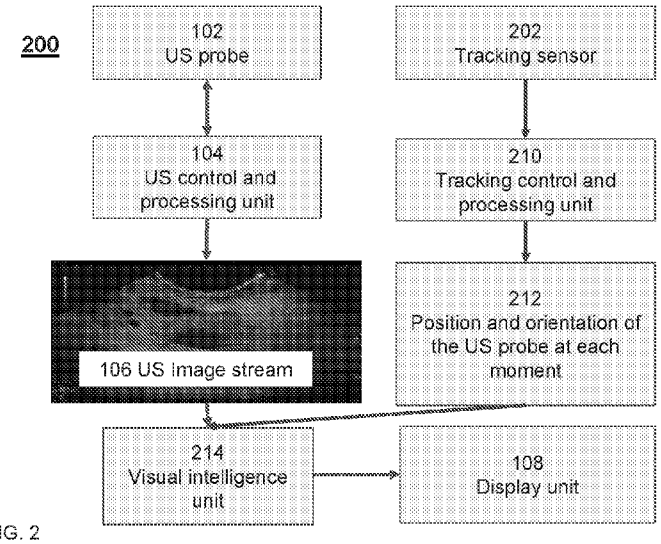


FIG. 2

(57) Abstract: Enhanced endoscopic ultrasound (EUS) systems and methods for enhancing EUS procedures. In a EUS system configured to output an US image stream and a position and orientation of a US probe at any given moment, a method comprises processing the US image stream and position and orientation of the US probe at any given moment into a visual output, and displaying the visual output.

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ENHANCING ENDOSCOPIC ULTRASOUND PROCEDURES WITH TRACKING AND VISUAL INTELLIGENCE

FIELD

This disclosure relates to medical imaging. In particular, the disclosure relates to a novel system and method for improving endoscopic ultrasound procedures by adding a tracking element to the ultrasound probe and using the resulting information to provide the physician with real-time analysis based on computer vision and artificial intelligence. This facilitates more widespread adoption of endoscopic ultrasound procedures, allows for a faster and simpler procedure, and improves the overall success rate.

BACKGROUND

Endoscopic Ultrasound (EUS) is used extensively in the diagnosis of pathologies related to the digestive system, such as lesions in the pancreas, biliary system, liver and gastrointestinal (GI) tract lining. A typical EUS system consists of an endoscope equipped with an Ultrasound (US) probe at the distal end of the scope. When inserted through the mouth of the patient into the GI tract, particularly the stomach or duodenum, the US probe can be used to provide sharp US images of organs adjacent to the GI tract, thus allowing the physician to identify and diagnose pathologies related to these organs. When used in conjunction with a needle inserted through the working channel of the endoscope, the US images can also be used to guide biopsies of suspicious lesions. Such biopsies are known as fine needle aspiration (FNA) and Fine needle biopsies (FNB)

While EUS is a powerful diagnostic tool, it requires that the user has many years of experience in order to correctly obtain and interpret the US images and derive relevant diagnostic information. Even then, the procedure can require a significant amount of time (an hour or more) and can often result in inaccurate diagnosis. This is mainly due to the fact that it is difficult to know the exact location and/or orientation of the US probe within the GI tract, information which is crucial for correctly interpreting the resulting US image (a task which is often challenging even when this information is available).

Furthermore it is often necessary to correlate the information found in the US image to a pre-procedure computer tomography (CT) or magnetic resonance imaging (MRI) scan, for

example, in order to locate a pathology (such as a lesion) identified in the scan. Besides the inherent visual difference between US images and CT/MRI scans, this is further complicated by the fact that the US image is only 2D and covers a relatively small area, thus making it difficult to register the image to the correct location within the larger 3D scan. An additional complication arises from the fact that CT and MRI scans are performed while the subject lies on his/her back, while the EUS procedure is performed while the subject lies on his/her side. This can mean that the size, position and shape of the internal organs may be different during the EUS procedure compared to the pre-procedure scan.

FIG. 1 shows schematically a typical known EUS system numbered **100**. EUS system **100** comprises an US probe **102** which is located at the distal end of an endoscope (not shown). In addition to US probe **102**, the endoscope typically includes a video camera and one or more working channels through which tools, needles, and other diagnostic probes may be inserted into the subject's GI tract. US probe **102** is connected to an US control and processing unit **104** which controls the US signals emitted by the probe and processes the return signals received by the probe in order to produce a stream of US images **106**, which are then displayed on a display unit **108**. Typically, US image stream **106** is updated at a video frame rate in the range of 25-50 frames per second (fps) such that a smooth US video is seen by the user on display unit **108.** The US video may also be stored on a permanent memory system such as a hard disk drive (not shown) for future reference and/or processing.

In operation, the user guides the endoscope through the GI tract of the subject, with the aid of the video camera embedded in the endoscope, to one of a number of positions, also known as "stations", which are typically used for US imaging of the digestive system. Once the endoscope is correctly positioned, the user then switches on US probe **102** and views the US image stream **106** on display unit **108**. Based on the approximate known position of the probe, an experienced user can interpret the US image and identify various organs and vessels shown in the image. The user may also slightly manipulate the endoscope (e.g. by inserting it further or extracting it a little, and by changing the probe direction and/or orientation using the endoscope controls) while viewing and interpreting the real-time US image stream. This way, a more complete view of the area under examination is obtained, allowing the user to identify and analyze items of interest, such as lesions, stones, stenosis or dilation of vessels, and other pathologies related to the digestive system. The user may also use the US image and/or the video camera to guide tools and needles

inserted through the working channel, as for example in the case of FNA or FNB. Once the US examination of the area surrounding a particular station is completed, the user may choose to move the endoscope to another station, and perform another US examination there. During a typical EUS procedure, a number of stations may be imaged in order to obtain a full understanding of the patient's condition.

Performing a EUS procedure as described above requires considerable skill and extensive experience in order to correctly guide and position the endoscope and to interpret the US image. While the video camera allows the user to approximately position the EUS probe at the desired location, the precise position and orientation of the probe can only be inferred by correctly interpreting the resulting US image. Based on this interpretation, the user may then fine-tune the position and orientation of the probe to obtain US images with relevant diagnostic information. This process may require a number of iterations before obtaining the desired US images, and in some cases may fail altogether to provide the desired images. In other cases, misinterpretation of the US image may result in erroneous diagnosis. Furthermore, since the US image is 2D with a relatively restricted field of view, the user may need to mentally reconstruct a 3D image of the region of interest based on the stream of 2D US images. Such mental reconstruction also requires significant experience and skill.

There is therefore a need to make the EUS procedure simpler, faster, and more accessible, by providing the user with additional real-time information and feedback that would allow faster and more accurate interpretation of the US images and enhanced understanding of their relation to a pre-procedure scan.

SUMMARY

Disclosed herein are systems and methods for tracking the position and orientation of the US probe in a EUS procedure and for using the resulting information together with computer vision and visual intelligence techniques to provide real-time and well-targeted feed-back to the user. This reduces the inherent complexity of, and required time for the procedure, and improves the overall diagnostic quality. The feed-back provided to the user may include, but is not limited to, one or more of the following elements:

- Combining all the 2D US images collected during the procedure into a common 3D volume, and allowing the user to view the volume and virtually navigate through it without physically moving the US probe;
- Displaying the current position and orientation of the US probe within the common 3D volume to assist the user in navigation;
- Detecting and identifying various anatomical elements visible in the US image (such as, but not limited to, veins, arteries, bile ducts, liver, pancreas, spleen and gallbladder);
- Accurate and real-time registration of the 2D US image to a pre-procedure CT/MRI scan
- Displaying the current position and orientation of the US probe relative to the pre-procedure scan to assist the user in navigation;
- Marking the location of organs and landmarks on the 2D US image whose identification is enabled through the registration to the pre-procedure scan;
- Guiding the user to locate and image a specific predetermined target (e.g. a lesion) identified in the pre-procedure scan; and
- Automatically identifying and labeling the above specific predetermined target when it appears on the US image.

In various examples, there is provided an enhanced endoscopic ultrasound (EUS) system, comprising: a US probe located at a distal end of the endoscope; a US control and processing unit operatively coupled with the US probe and configured to output an US image stream; a tracking sensor with a known position and orientation relative to the US probe; a tracking control and processing unit operatively coupled with the tracking sensor and configured to calculate and output the position and orientation of the US probe at any given moment; a visual intelligence unit configured to accept as input and process the US image stream and the position and orientation of the US probe at any given moment into a visual output; and a display unit configured to display the visual output.

In some examples, the visual intelligence unit is further configured to accept as input a pre-procedure model. In some examples, the visual output includes a current position and orientation of the US probe shown in relation to the pre-procedure model. In some examples, the visual output includes labels and/or marks of borders and/or one or more key points of selected anatomical elements and/or pathologies overlaid on a US image of the US image stream, and derived from the

pre-procedure model. In some examples, the visual output includes instructions to a user on guidance of the US probe to visualize a target pathology identified in the pre-procedure model.

In various examples, there is provided a method for enhancing EUS procedures in a system configured to output an US image stream and a position and orientation of a US probe at any given moment, comprising: processing the US image stream and position and orientation of the US probe at any given moment into a visual output; and displaying the visual output.

As used herein, "at any given moment" refers to a continuously updated output, i.e. a corresponding position and orientation of the US probe is known for each image in the image stream.

In some examples, the tracking sensor is an electromagnetic (EM) tracking sensor.

In some examples, the visual output includes a current US probe position and orientation shown in relation to a plurality of previous positions and orientations within a common 3D volume.

In some examples, the visual output includes labels and/or marks of borders and/or one or more key points of selected anatomical elements and/or pathologies overlaid on a US image of the US image stream.

In some examples, the visual output includes a 3D model of one or more selected anatomical elements and/or pathologies. In some examples, the visual output includes a current position and orientation of the US probe shown in relation to the 3D model.

In some examples, the processing includes processing the US image stream and position and orientation of the US probe at any given moment together with a pre-procedure model into the visual output. In some examples, the visual output includes a current position and orientation of the US probe shown in relation to the pre-procedure model. In some examples, the visual output includes labels and/or marks of borders and/or one or more key points of selected anatomical elements and/or pathologies overlaid on a US image of the US image stream, and derived from the pre-procedure model. In some examples, the visual output includes instructions to a user on guidance of the US probe to visualize a target pathology identified in the pre-procedure model.

BRIEF DESCRIPTION OF THE DRAWINGS

Non-limiting examples of embodiments of the disclosure are described below with reference to figures attached hereto that are listed following this paragraph. Identical structures,

elements or parts that appear in more than one figure are generally labeled with a same numeral in all the figures in which they appear. The drawings and descriptions are meant to illuminate and clarify embodiments of the disclosure, but should not be considered limiting in any way. In particular, variations and modifications apparent to those skilled in the art may be considered without departing from the claimed scope.

FIG. 1 shows a schematic representation of a typical known EUS system;

FIG. 2 shows a schematic representation of one embodiment of the proposed system for enhancing EUS procedures;

FIG. 3 shows a schematic representation of one embodiment of an US probe with tracking capabilities;

FIG. 4A shows one embodiment of a flow chart of an algorithm implemented in the visual intelligence unit of the system;

FIG. 4B shows an example view of a 3D common volume;

FIG. 5 shows an example of detection and identification of liver and vessels in a 2D US frame;

FIG. 6 shows another example of detection and identification of liver and vessels in a 2D US frame;

FIG. 7 shows an example of a 3D model of the biliary system near the papila, created from segmentation of a sequence of US images;

FIG. 8 shows an example segmentation of a lesion in an US image, and a resulting 3D model created from segmentation of a sequence of US images;

FIG. 9 shows a schematic representation of another embodiment of the proposed system for enhancing EUS procedures;

FIG. 10 shows one embodiment of a flowchart for creating a pre-procedure 3D model;

FIG. 11 shows an example of an abdominal CT slice with segmentation of selected organs;

FIG. 12 shows an example of a pre-procedure model built from a segmented CT scan;

FIG. 13 shows another embodiment of a flow chart of an algorithm implemented in the visual intelligence unit of the system;

FIG. 14A shows an example view of the US probe position and orientation in relation to a pre-procedure model;

FIG. 14B shows an example view of a combined 3D model including a 3D common volume and a part of a pre procedure model;

FIG. 15 shows an example of a segmentation of the pancreas in an US image created with the aid of registration of the US probe to a pre-procedure model;

FIG. 16 shows an example of a segmentation of a target lesion in an US image created with the aid of registration of the US probe to a pre-procedure model;

FIG. 17 shows a flowchart of an embodiment of a method for guiding the user to position and orient the US probe so as to optimally image the target lesion;

FIG. 18 shows a schematic representation of another embodiment of the proposed system for enhancing EUS procedures;

FIG. 19 shows exemplary video images that can be used to help pinpoint the position of the US probe during the EUS procedure.

DETAILED DESCRIPTION

FIG. 2 shows a schematic representation **200** of a system for enhancing EUS procedures and addressing the problems listed above, as disclosed herein. In addition to elements **102**, **104**, **106** and **108** described in relation to FIG. 1, the system includes a tracking sensor **202** connected to a tracking control and processing unit **210**. Tracking sensor **202** is configured to have a known position and orientation relative to US probe **102**, such that measuring the position and orientation of tracking sensor **202** allows the calculation of the position and orientation of US probe **102**. Tracking control and processing unit **210** is configured to receive inputs from tracking sensor **202**, and to compute and output an instant (at each moment) position and orientation **212** of US probe **102**. In some embodiments, tracking processing unit **210** is operationally coupled to additional elements (not shown) in order to compute output **212** US image stream **106** together with US probe position and orientation **212** are provided as input to visual intelligence unit processing unit **214.** Visual intelligence unit **214** uses computer vision (CV) and artificial intelligence (AI) capabilities to process the input and to provide real time visual feed-back to the user performing the EUS procedure, which is then displayed on display unit **108.** In some embodiments, visual intelligence unit **214** may receive additional input (not shown) from the user designed to configure the content of the real time visual feed-back.

In some embodiments, US control and processing unit **104**, tracking control and processing unit **210,** and visual intelligence unit **214** are separate physical units. In other embodiments, two or all of these units may be combined into a single physical unit. It should be apparent to those skilled in the art that different physical configurations of units **104**, **210** and **212** are possible without loss of generality of the disclosure.

In some embodiments, the tracking technology used in the system described in FIG. 2 may be based on electro-magnetic (EM) tracking technology as known in the art. FIG. 3 shows a possible implementation of this technology for the current disclosure. A field generator (FG) **302** generates a spatially varying EM field **304** which is sensed by tracking sensor **202**. FG **302** is positioned such that varying EM field **304** covers a volume that includes the patient's digestive system in which US probe **102** and tracking sensor **202** are inserted for the purpose of carrying out the EUS procedure. FG **302** and tracking sensor **202** are connected to tracking control and processing unit **210**, which is designed to calculate the position and orientation of tracking sensor **202** and thus the US probe position and orientation **212** at any given moment. In some embodiments, tracking sensor **202** is connected to tracking control and processing unit **210** via wires that run through the endoscope. In some embodiments, one or more additional sensors **306** may be connected to the patient's body and used as reference positions and/or to compensate for patient movement during the EUS procedure. In some embodiments, tracking sensor **202** may be a six degree of freedom (6DOF) sensor such that complete translational and rotational information for US probe **102** can be computed by tracking control and processing unit **210** at any given moment. In some embodiments, tracking sensor **202** may be permanently embedded at the distal end of the endoscope in close and fixed proximity to US probe **102**. In other embodiments, tracking sensor **202** is not embedded in the endoscope, but instead inserted through the working channel of the endoscope to a position near US probe **102**, and locked in this position until it is no longer needed.

In some embodiments, a calibration step is implemented following insertion and locking of tracking sensor **202** to determine the position and orientation of the sensor relative to US probe **102**. In some embodiments, the calibration step may involve placing the endoscope with US probe **102** and tracking sensor **202** in one or more predetermined positions and orientations, thus allowing tracking control and processing unit **210** to calculate the position and orientation of tracking sensor **202** relative to US probe **102** In some embodiments, the calibration step may involve inserting the

endoscope into a calibration jig designed to produce a predetermined pattern in an US image, and analyzing the resulting US image to identify the pattern and thus determine the relation between US probe **102** and tracking sensor **202** In some embodiments, tracking sensor **102** is disposable and is disposed of once extracted from the working channel of the endoscope

In other embodiments, different tracking technologies may be used in conjunction with the system shown in FIG. 2. In some embodiments, inertial measurement units known in the art and including magnetometers and/or gyroscopes and/or accelerometers may be included in tracking sensor **202**. In yet other embodiments, a fiber-optics based sensor may be embedded in the endoscope such that the position and orientation of US probe **102** can be determined, as for example described in US Patent application US20110172519A1. It should be apparent to those skilled in the art that different tracking technologies may be used without loss of generality of the disclosure.

FIG. 4A shows a flow chart **400** of a method implemented on visual intelligence unit **214**. In step **402**, patient data is received. In some embodiments, such data is automatically extracted from a centralized database. In other embodiments, the patient data is manually entered by the user via a keyboard or other input device. In yet other embodiments, a combination of automatic extraction and manual input is utilized.

In some embodiments, the patient data may include only informative data such as identity number, name, age and gender. In other embodiments, the data may include additional clinical data such as physical characteristics (height, weight, body mass index) and/or relevant medical history. In yet other embodiments, the patient data may include a pre-procedure scan such as a CT or MRI. In yet other embodiments, the patient data may include a pre-procedure scan enhanced with additional information, such as segmentation of organs and vessels and pathologies.

In step **404**, a new frame is acquired from US image stream **106**, together with the corresponding position and orientation **212** of the US probe. During part of the EUS procedure the US transducer in US probe **202** may be disabled so that a blank or null frame is acquired from US image stream **106** and only the position and orientation **212** of the US probe contains meaningful information. This may occur for example when the US probe is being moved from one EUS station to the other. In some embodiments, while the US transducer is disabled, instead of acquiring a frame from US image stream **106**, a frame from the video camera of the endoscope may be

acquired. In yet other embodiments, a frame from the video camera is acquired in addition to the US frame, regardless of whether or not the US transducer is disabled.

In step **406**, the position and orientation **212** of the US probe is used to register the 2D US frame to a common 3D volume containing all previously acquired 2D US frames. Thus, the position and orientation of any 2D US frame acquired until the current time relative to any other 2D US frame is known. In some embodiments, the settings of US probe **102** (such as gain, frequency, angular opening, depth) are read from US control and processing unit **104** in order to determine the precise shape of the US fan representing the 2D cross section covered by the US frame. In other embodiments, the settings of US probe **102** are determined by identifying markings and/or text produced by US control and processing unit **104** on each of the US images in US image stream **106**. In some embodiments, step **406** includes compensation of patient movement during the procedure by also tracking the position of one or more additional sensors, such as for example **306** in the case of EM tracking, attached to the patient's body, and using this additional information to derive the correct location in the common 3D volume independent of the patient movement. In cases where a null or blank US frame is acquired, only a single point denoting the location of the US probe is registered to the common 3D volume. By tracking the position of the US probe in the common 3D volume, the approximate position of the probe relative to the patient's organs may be calculated. As an example, by tracking the passage of the US probe through the esophagus into the stomach, it is possible to obtain a 3D model of the esophagus which can provide an indication of the size of the patient, which can subsequently be used to estimate the location of the US probe within the stomach or duodenum. In some embodiments, the 3D model of the esophagus may be enhanced by measuring the radius of the esophagus using the endoscopic video camera stream in conjunction with structure from motion technology known to the art.

In some embodiments, a view of the 3D common volume is created and displayed (step **410** of FIG. 4A) to assist the user in the EUS examination. In some embodiments, 3D meshes of different elements of the 3D common volume (such as the path taken by the US probe, and the area covered by the set of 2D US frames collected) are created using, for example, the known marching cubes algorithm. In some embodiments the different meshes are color coded to enhance the visualization. In some embodiments an additional smoothing step, such as the known laplacian smoothing algorithm, is applied to the 3D meshes to improve their visual quality. In other embodiments the 3D common volume is viewed as a point cloud rather than a series of meshes. In

some embodiments, different points in the point cloud can be color coded to enhance the visualization. In yet other embodiments, a combination of meshes and point clouds may be used to view the 3D common volume.

Allowing the user to view the 3D common volume from different angles, positions and zoom levels, using standard 3D visualization techniques known to the art, provides valuable feedback during the examination. For example, when screening a patient for various pathologies, such as cancer of the pancreas, viewing the entire area covered by the US scan during the examination can highlight whether there are gaps representing areas of the anatomy not scanned, and which should be scanned to complete the screening successfully. In another example, showing how different 2D US frames taken at different stations during the examinations relate to each other in the 3D common volume can provide a more thorough 3D understanding of pathologies, such as a lesion, identified during the examination, and visible in the different 2D US frames. In some embodiments, the current US probe position and orientation are shown on the 3D common volume. In some embodiments, means are provided for the user to navigate within the 3D common volume in order to view previously acquired 2D US frames. Thus, the user can easily and intuitively browse and recall the preceding steps of the EUS examination without having to physically reposition the US probe and reacquire a desired US image.

FIG. 4B shows an example mesh view **450** of a 3D common volume including a path **452** of the US probe and an area **454** covered by the US scan, i.e. all the US fans corresponding to the 2D US frames collected during the EUS examination. In the example shown, the EUS examination included three stations, the cardia, the duodenum bulb, and the papilla.

Returning now to FIG. 4A, in step **408,** detection and identification of selected organs and vessels is performed in the US image frame, with the aid of current and previous positions and orientations **212** of the US probe (also referred to below as the tracking data).

In some embodiments detection may be performed using a classical and/or deep learning algorithm known to the art, such as the known UNET segmentation model, followed by use of a second algorithm which identifies and labels the various anatomical structures detected by the detection algorithm. In some embodiments this identification is achieved using pattern based rules and prior knowledge of the digestive system and surrounding vessels and organs. For example, if the tracking data indicates that the US probe has passed from the esophagus into the cardia, and a vessel of diameter in the range of 1.5-3 cm is seen in the US frame, then this vessel can be assumed

to be the abdominal aorta. For example if the tracking data indicates that the US probe has passed from the stomach into the duodenum bulb, and if the detected vessels in the US frame show a confluence of 3 vessels, then this can be assumed to be the venus confluence, and using the known orientation of the US images, the portal vein, splenic vein, and superior mesenteric vein can all be identified. In other embodiments, a dedicated deep learning model is trained to perform the identification. In one embodiment this model is a long short term memory (LSTM) neural network model which accepts as input the output of the detection algorithm (e.g. segmentation) for a sequence of US images in US image stream **106**, together with the corresponding tracking data, and is trained to identify and label each element detected by the detection algorithm. In yet other embodiments, a 3D model of selected vessels and/or organs is constructed using the common volume described in step **406,** together with the output of the detection algorithm for a sequence of US frames in US image stream **106**. This 3D model is then registered, using standard 3D registration methods known to the art, to a pre-procedure model of the digestive system and surrounding vessels and organs (see FIG. 9 below and related text), and the output of the registration is used to perform the identification, by reference to the pre-procedure model.

In yet other embodiments, detection and identification of the anatomical structures is performed by a single classical and/or deep learning model. In one embodiment, the tracking data is first used to identify the EUS station at which the US probe is currently located and oriented. Then, a specifically trained object detection model (such as the known YOLO model) or semantic segmentation model (such as UNET) is used to identify specific anatomical regions and/or landmarks in this US view (i.e. the typical US image frame expected given the EUS station and probe orientation). For example, if the tracking data indicates that the US probe has passed from the stomach to the duodenum bulb, then a model specifically trained to identify the superior mesenteric artery, the common bile duct, and the pancreatic duct in this US view is selected and provided with the current US frame as input. The output of this model is the location of each of these anatomical elements, optionally together with a confidence level associated with each element. In one embodiment, the model used for simultaneous detection and identification is a variation of the LSTM model described above, where the model is provided with the raw US image stream **106** rather than the output of a separate detection model.

In yet other embodiments, detection and/or identification may be performed manually or semi-manually by the physician performing the EUS procedure. For example, based on the

tracking data the EUS station is automatically identified, and the physician is then presented with a number of typical US views visible from this station. After the physician selects the view which most closely matches the current US frame, a specific model pre-trained for this US view is then applied to the US frame in order to detect and identify the various anatomical elements visible in this view

In some embodiments, detection takes the form of full segmentation of the organs and/or vessel. In other embodiments, detection takes the form of locating the center or other specific key points of organs and/or vessels. In yet other embodiments, detection takes the form of a bounding box surrounding the organs and/or vessels. In some embodiments, detection is performed on a single 2D US frame. In other embodiments, detection is performed on a sequence of US frames from US image stream **106** after registration to a 3D common volume as described in step **406**.

FIG. 5 shows an example of semantic segmentation followed by identification. Here, the UNET neural network model is trained to identify vessels and liver tissue in any 2D US Image (i.e. regardless of the US view). Image **502** shows an example 2D US frame, while image **504** shows the corresponding frame with vessels (dark gray) and liver (light gray) segmented. This segmentation is performed for a sequence of 2D frames, and then using the registration of the frames to a common 3D volume (step **406** in FIG. 4), a 3D model of selected vessels and/or liver tissue is constructed, as shown in image **506**. Given this particular arrangement of liver tissue and vessels, and given that the tracking data shows that the US probe is located in the duodenum bulb, the two selected vessels are identified and labeled, as shown in image **508**.

FIG. 6 shows an example of simultaneous detection and identification in a single algorithm. Here, analysis of the tracking data indicates that the US probe is located in the duodenum bulb, while analysis of the orientation of the US probe indicates that the relevant US view should show the liver, portal vein, and common bile duct. Then, a customized deep learning model specifically designed and trained to analyze this view is selected, and given image **502** as input. In this case the model is a 2D UNET Model trained to locate the center (white circles) of three anatomical features (liver, portal vein and common bile duct) seen in the US view in image **502**. The resulting output of this model is shown in image **604**. The identification and labeling of these anatomical features follows automatically since the deep learning model is specifically designed to analyze the shown view.

Returning to FIG. 4A, in some embodiments the combined output of steps **406** and **408** is used to create 3D models designed to provide specific and targeted feedback to the physician. These models are constructed by using the registration of segmented US images (step **408**) to a common 3D volume (step **406**), common interpolation routines to interpolate regions between two successive images, followed by applications of the known marching cubes algorithm to create a 3D surface. Optionally, a surface smoothing algorithm such as the Laplacian smoothing algorithm may be applied to create a smoother and more realistic model. In some embodiments, a 3D model may combine contributions from US images collected at multiple EUS stations, with each set of images contributing to a different part of the model. In some embodiments, the 3D model may be combined with a view of the common volume (e.g. FIG. 4B) so that the physician can see which areas to scan in order to complete and/or enhance the model. In some embodiments the 3D model can be combined with a view of the current US probe position and/or current US fan in order to better understand the relation between the 3D model and the current 2D US frame. In some embodiments, the user is provided with the means to view the 3D model from different angles, positions and zoom levels, using standard 3D visualization techniques known to the art.

FIG. 7 shows an example view **700** of a 3D model of the biliary system near the papila, including a papila **702**, a common bile duct **704**, and a pancreatic duct **706**. The model was created by automatic segmentation and identification of the common bile duct and pancreatic duct in the region of the papilla in a sequence of 2D US images taken from EUS stations just below the papilla and from the duodenal bulb. Such a 3D model is especially useful during an endoscopic retrograde cholangiopancreatography procedure (ERCP), where navigation errors within the biliary system can lead to complications such as pancreatitis.

FIG. 8 shows an example **800** of a segmentation of a lesion in the head of the pancreas. Image **802** shows a manual segmentation of the lesion, performed by the user, in one example 2D US image. This manual segmentation is performed on a number of US images representing different cross sections of the lesion. Then, using the 3D common volume, in a manner similar to that described above in relation to FIG. 7, a 3D model of the lesion is then created. Once the 3D model is created, it is displayed together with the position and orientation of the US fan at any given moment, as shown in image **804**. This allows the physician performing the EUS procedure to better characterize the lesion under study, and also to better prepare for a biopsy in the case of FNA or FNB.

Returning again to FIG. 4A, step **410** updates display unit **108** with information derived from the previous steps that provides real time visual feed-back to the user performing the EUS procedure. In some embodiments, this visual feedback includes an annotated version of the 2D US frame, as for example shown in images **504**, **508**, and **604**. In some embodiments this visual feedback includes a 3D anatomical model derived from multiple US frames, as shown in images **506**, and **700**. In some embodiments this visual feedback includes a 3D model derived from multiple US frames together with the location of the US fan in the current frame, as for example shown in image **804.** In some embodiments, the visual feedback may include a representation of the 3D common volume with the path of the US probe shown with the volume, the areas covered by all previous US images, and the location of the current US image, as for example shown in FIG. 4B. It should be apparent to one skilled in the art that any visual representation of the information derived in prior steps of the flow chart (including steps not shown in FIG. 4A) may be included in the update of display unit **108**.

FIG. 9 shows a schematic representation **900** of another embodiment of the proposed system for enhancing EUS procedures disclosed herein. Here, a pre-procedure model **916** of the digestive system and surrounding organs and vessels is provided as input to visual intelligence unit **214** in addition to the US image stream **106** and the position and orientation of the US probe **212**. In some embodiments, the pre-procedure model is a generic model adapted to the patient's characteristics, such as gender, height, and BMI. In other embodiments, the pre-procedure model is a generic model adapted to the patient's anatomy using data gathered from the tracking data**.** In yet other embodiments, the pre-procedure model is derived from segmentation of relevant anatomical structures in a pre-procedure 3D CT or MRI scan. In some embodiments, the segmentation is performed automatically. In other embodiments, the segmentation is performed manually by a radiologist or physician. In yet other embodiments, the segmentation is performed semi-automatically together with manual input from a radiologist or physician. In some embodiments, the segmentation of a pre-procedure scan may include segmentation of a region of interest (ROI), such as a lesion or tumor or other potential pathology identified as suspicious, and which is a target for investigation during the EUS procedure.

FIG. 10 shows a flow chart **1000** of an exemplary method embodiment used to generate a pre-procedure model **916**. In step **1002**, a 3D scan such as a CT or MRI is received as input. In step **1004**, segmentation is performed for selected organs and vessels relevant to the EUS

procedure. The segmented organs and vessels may include, but are not limited to, the esophagus, stomach, duodenum, pancreas, spleen, liver, gallbladder, bile ducts and surrounding veins and arteries such as the abdominal aorta, the inferior vena cava (IVC), the portal venous system and mesenteric veins and arteries. In some embodiments, a physician or radiologist may select which organs and vessels to segment based on the specific EUS examination to be performed. In some embodiments, the segmentation may be performed automatically, for example by a deep learning model such as the UNET model. In other embodiments, the segmentation may be performed manually by the radiologist or physician. In yet other embodiments, semi-automatic segmentation may be performed with guidance from a radiologist or physician. In some embodiments, automatic segmentation may be performed on individual 2D slices. In other embodiments, automatic segmentation may be performed in 3D on all slices simultaneously.

In step **1006**, a 3D mesh is created for each segmented organ or vessel using, for example, the marching cubes algorithm. In some embodiments, a single mesh may be created for multiple organs or vessels that are connected one to the other. For example, a single mesh could be created for all the bile ducts and the gallbladder. In step **1008**, the 3D meshes created in step **1006** are smoothed using, for example, a known Laplacian smoothing algorithm. In step **1010**, individual 3D models are optionally compared to generic versions of these models with the purpose of identifying and correcting anomalies in the underlying segmentation (step **1004**). To perform this comparison, the generic model is first registered to the 3D model taking into account reasonable deformations (such as resizing) and using standard known 3D registration techniques. Once the two models are registered, the difference between them is analyzed and anomalies are identified. For example, if the model represents a blood vessel, then differences that depart significantly from cylindrical symmetry are marked as anomalies and corrected. In step **1012**, all 3D models are combined into a single 3D model using the base coordinate system of the 3D scan received as input in step **1002**.

In step **1014**, the resulting 3D model is deformed to take into account a possible difference between the orientation of the patient for the 3D scan used as input in step **1002** and the orientation of the patient during the EUS procedure. For example, during a CT scan the patient is typically lying on his/her back, while during a EUS procedure the patient is typically lying on his/her side. In some embodiments, this deformation may be performed using a generic deformation map derived from anatomical knowledge. In other embodiments, the generic deformation map may be

augmented using anatomical landmarks derived from tracking the US probe, as for example described in relation to step **406** of FIG. 4A. In yet other embodiments, this deformation may be performed using a deep learning model trained to accept as input a 3D model and output a customized deformation map for the input model. In yet other embodiments, combinations of the above methods are employed to derive the deformation map.

FIG. 11 demonstrates segmentation of a 2D slice of a CT scan. Image **1100** shows a 2D slice of an abdominal CT scan. Curve **1102** (white) denotes the borders of the pancreas in this slice. Curve **1104** (black) denotes the borders of the spleen in this slice

FIG. 12 shows an example view **1200** of a 3D model of selected organs, vessels and ducts relevant to a typical EUS procedure, created from a segmented CT scan as described in FIG. 10. The model includes a gallbladder **1202**, a pancreas **1204**, a spleen **1206**, a common bile duct **1208**, a splenic vein **1210**, and a portal vein **1212**.

FIG. 13 shows a flow chart **1300** of another method implemented on visual intelligence unit **214**. Step **1302** is similar to step **402** in FIG. 4A, with the specific requirement that a pre-procedure model **916** is received as part of the patient data. In step **1304**, registration of the US probe position and orientation **212** to the pre-procedure model **916** is initialized or updated. In some embodiments, the registration is initialized by calculating the position and orientation of the US probe with respect to one or more additional sensors, as for example **306** in FIG. 3, connected to the patient's body, which themselves have been registered to the pre-procedure model. For example, the additional sensors may be connected to surface anatomy landmarks such as the umbilicus, the tip of the xiphoid, and/or the anterior superior iliac spine, which have also been identified manually or automatically in a pre-procedure CT used to construct pre-procedure model **916**.

In other embodiments, information derived from the tracking data may be used to initialize the registration. For example, the point at which the probe moves from the esophagus to the stomach may be identified, and together with the direction of movement from the esophagus to the stomach, the registration is initialized. Identification of the point between the esophagus and stomach can, for example, be achieved manually via input from the user, automatically by following the trajectory of the US probe in the esophagus, or automatically by using computer vision to analyze the video feed from the endoscope camera. In some embodiments, the user may be requested to perform an US scan of a particular anatomical element, and the resulting

segmentation and 3D model of this anatomical element may be used to perform the registration to the 3D model using known standard 3D registration techniques. For example, as the user enters the cardia from the esophagus, he/she may be requested to perform a US scan of the branching point of the celiac trunk from the abdominal aorta. Once the scan is complete, the abdominal aorta and celiac trunk are segmented (either manually by the user or automatically using known segmentation methods), and the 3D model of the branching point is constructed and used to initialize the registration to the pre-procedure model. In yet other embodiments, initialization of the registration may be achieved by using a combination of the above methods.

Once the registration has been initialized, it can be updated and fine-tuned in subsequent iterations of the algorithm, using information derived from previous iterations of the algorithms. In some embodiments, a 3D segmentation of selected organs and/or vessels derived from previous US images, such as that shown in image **506**, is used to fine tune the registration using standard 3D registration techniques known to the art. In other embodiments, selected anatomical landmarks, such as the confluence between the splenic vein, portal vein and superior mesenteric vein, are identified in the US images and used to update the registration. In yet other embodiments, additional anatomical landmarks are identified by tracking the path of the US probe, for example, the pyloric orifice connecting the stomach to the duodenum. In yet other embodiments, additional anatomical landmarks are identified by using computer vision to analyze the video feed from the endoscope camera. In yet other embodiments, a combination of one or more of the above methods is used to update the registration.

In some embodiments, the registration between pre-procedure model **916** and US probe position and orientation **212** is utilized to create and display (in step **410** of FIG. 13) a view of a combined 3D model which includes pre-procedure model **916**, the position of the US probe, and the US fan representing the 2D cross section covered by the current US frame in US image stream **106**. FIG. 14A shows an example of such a view **1400**, with the position of the US probe **1402** and the US fan **1404** shown in relation to an example of pre-procedure model **916**. The shape and size of the US fan are determined according to the methods described in relation to step **406** in FIG. 4A. In some embodiments, the user is able to zoom, rotate and pan the combined 3D model using standard known 3D visualization techniques to create different views of the model. The ability to clearly visualize in 3D the location and orientation of the US probe and the US fan relative to the

patient's anatomy (represented by pre-procedure model **916**) facilitates the interpretation and analysis of the US image, and thus enhances the overall EUS procedure.

Returning to FIG. 13, in some embodiments, the registration between pre-procedure model **916** and US probe position and orientation **212** derived in step **1304** is utilized to create and display (in step **410** of FIG. 13) a view of a combined 3D model which includes pre-procedure model **916**, and the 3D common volume created in step **406**. In some embodiments, only a selected part of interest of pre-procedure model **916** is included in the combined 3D model. In some embodiments, the selected part of interest is a particular organ, or part thereof, which the physician would like to screen for pathologies during the EUS procedure. In some embodiments, the user is able to zoom, rotate and pan the combined 3D model using standard known 3D visualization techniques, to create different views of the model and hence to gain further insight.

FIG. 14B shows an example view **1450** of such a combined 3D model including the 3D common volume with path **452** of the US probe and the area covered by the US scan **454**, i.e. all the 2D US frames collected during the EUS examination (as in FIG. 4B). In addition the pancreas **1452** taken from pre-procedure model **916** is also visible, allowing the user to see which parts of the pancreas **1454** have been covered by the US scan. This is particularly useful during a screening examination of Pancreas, where it is important to cover all the pancreas in order to ensure there are no suspicious pathologies.

Returning to FIG. 13, in some embodiments, the registration derived between the US probe and the pre-procedure model in step **1304** is used in step **408** for the detection and identification of organs and vessels, as for example described above in the context of FIG. 5 and FIG. 6.

In step **1306**, information found in the pre-procedure model is mapped to the 2D US image. In some embodiments, this information may include the location and/or boundaries of anatomical elements or landmarks that are part of the pre-procedure model, and which were not detected and identified in step **408**. In some embodiments, this information may include the location and/or borders of a target lesion identified in the pre-procedure scan

FIG. 15 shows an example of a segmentation of the pancreas in a US image **1500** created with the aid of registration of the US image to a pre-procedure CT scan as described in step **1304** of FIG. 13. Since the pancreas was already segmented in the CT scan, the registration of the US image to the CT scan allows the segmentation to be automatically transferred to the US image, as

shown by the overlaid white line **1502**. An additional label **1504** may also be overlaid on the US image, with the resulting modified image displayed in step **410** of FIG. 13.

FIG. 16 shows an example of a segmentation of a target lesion in a US image **1600** created with the aid of registration of the US image to a pre-procedure CT scan as described in step **1304** of FIG. 13. Since the target lesion was already segmented in the CT scan, the registration of the US image to the CT scan allows the segmentation to be automatically transferred to the US image, as shown by the overlaid white line **1602**. The resulting modified image can be displayed in step **410** of FIG. 13.

FIG. 17 shows an embodiment of a flowchart **1700** for guiding the user to position and orient the US probe so as to optimally image a target pathology (e.g. lesion) identified in pre-procedure model **916**. In step **1702**, the optimal position and orientation of the EUS probe for imaging the target lesion is determined. In some embodiments, the best EUS station to image the lesion from is first determined using a database of lesion positions and corresponding EUS stations. In other embodiments, the user may be prompted to manually enter the best EUS station from a predetermined selection. In yet other embodiments, a pre-procedure model **916** may be used to locate the position on the wall of the stomach or duodenum closest to the lesion, and then the best orientation of the EUS probe at that position is determined in order to obtain an optimal cross-section of the lesion. In yet other embodiments, a deep learning model may be trained to accept as input a pre-procedure model **916** including the target lesion and to output the optimal position and orientation of the US probe.

In step **1704**, the current position and orientation **212** of the US probe is read. In step **1706**, the current and desired position and orientation of the US probe are compared to determine whether the US probe position and orientation are correct. If not, step **1708** is executed where the user is instructed on how to move the US probe to reach the desired position and orientation. In some embodiments, this step may require keeping track of all previous positions of the US probe to map the 3D endoscope topology in the body, and to provide the user with exact instruction on how to manipulate the endoscope controls (for example, insertion, extraction, left/right angulation, up/down angulation, rotation). In other embodiments, the current and desired US probe position and orientation may be shown on a 3D model such as **1400** to guide the user. In yet other embodiments, a combination of the above methods may be used.

Returning to step **1706**, if it is determined that the US probe is in the correct position and has the correct orientation, step **1710** is executed where the user is provided with a set of optimal US settings such as gain, frequency and depth, with which to best view the target lesion. In some embodiments, these settings may be automatically adjusted using US control and processing unit **104**. Finally, in step **1712** the lesion position is overlaid on the US image, as for example shown in image **1600**, and the user is notified that the correct US probe position and orientation has been achieved.

FIG. 18 shows a schematic representation **1800** of another embodiment of a proposed system for enhancing EUS procedures. Here, a video camera **1802,** located at the distal end of the endoscope in close proximity to US probe **102** and tracking sensor **202**, is connected to a video control and processing unit **1804** which controls the video camera settings (such as focus and zoom) and processes the video camera output signal. Video control and processing unit **1804** outputs a video stream **1806**, which is used as input to visual intelligence unit **214**, in addition to the US image stream **106** and the position and orientation of the US probe **212**. In operation, visual intelligence unit **214** uses video stream **1806** to provide enhanced visual feedback to the user. In some embodiments, visual intelligence unit **214** may also receive as input pre-procedure model **916** (not shown) in addition to video stream **1806**, US image stream **106** and position and orientation of the US probe **212.**

In some embodiments, visual intelligence unit **214** may use individual images from video stream **1806** to help in pinpointing the location of US probe **102** relative to the patient's anatomy. This information can then be used to facilitate detection and identification step **408** in FIG. 4A, and/or to facilitate registration step **1306** in FIG. 13. For example, FIG. 19 shows examples **1900** of such individual images. Image **1902** shows the diaphragm separating the esophagus from the stomach. By using standard image classification techniques, such as the known VGG deep learning model, it is possible to automatically identify the diaphragm when it appears in video stream **1806**, and thus automatically determine that US probe 102 is currently located near the diaphragm. Image **1904** is a typical image of the major papilla in the duodenum, which is a well-known station for EUS examinations. By automatically identifying the papilla in video steam **1806**, it is possible to determine that US probe **102** is located at this station.

Returning to FIG. 18, in another embodiment, visual intelligence unit **214** uses video stream **1806**, together with position and orientation of US probe **212** to construct 3D models of the

esophagus and/or the stomach and/or the duodenum, or parts thereof, using structure from motion methods known to the art. These 3D models are then used in step **1306** of FIG. 13 to initialize and/or update the registration to pre-procedure model **916**.

In yet another embodiment, the information derived by visual intelligence unit **214** from video stream **1806** is provided as direct feedback to the user during the examination in order to assist the user in navigation. For example, if a particular point of interest, such as the papilla, is identified in the video stream, this can be displayed to the user so that he/she knows that they are located at this particular EUS station within the duodenum.

In some embodiments, video control and processing unit **1804** is a separate physical unit. In other embodiments, video control and processing unit **1804** is combined in a single physical unit with one or more of US control and processing unit **104**, tracking control and processing unit **210**, and visual intelligence unit **214**.

It is appreciated that certain features of the presently disclosed subject matter, which are, for clarity, described in the context of separate examples, may also be provided in combination in a single example. Conversely, various features of the presently disclosed subject matter, which are, for brevity, described in the context of a single example, may also be provided separately or in any suitable sub-combination.

Some stages (steps) of the aforementioned method(s) may also be implemented in a computer program for running on a computer system, at least including code portions for performing steps of the relevant method when run on a programmable apparatus, such as a computer system or enabling a programmable apparatus to perform functions of a device or system according to the disclosure. Such methods may also be implemented in a computer program for running on the computer system, at least including code portions that make a computer execute the steps of a method according to the disclosure.

A computer program is a list of instructions such as a particular application program and/or an operating system. The computer program may for instance include one or more of: a subroutine, a function, a procedure, a method, an implementation, an executable application, an applet, a servlet, a source code, code, a shared library/dynamic load library and/or other sequence of instructions designed for execution on a computer system.

The computer program may be stored internally on a non-transitory computer readable medium. All or some of the computer program may be provided on computer readable media

permanently, removably or remotely coupled to an information processing system. The computer readable media may include, for example and without limitation, any number of the following: magnetic storage media including disk and tape storage media; optical storage media such as compact disk media (e.g., CD-ROM, CD-R, etc.) and digital video disk storage media; nonvolatile memory storage media including semiconductor-based memory units such as FLASH memory, EEPROM, EPROM, ROM; ferromagnetic digital memories; MRAM; volatile storage media including registers, buffers or caches, main memory, RAM, etc.

A computer process typically includes an executing (running) program or portion of a program, current program values and state information, and the resources used by the operating system to manage the execution of the process. An operating system (OS) is the software that manages the sharing of the resources of a computer and provides programmers with an interface used to access those resources. An operating system processes system data and user input, and responds by allocating and managing tasks and internal system resources as a service to users and programs of the system.

The computer system may for instance include at least one processing unit, associated memory and a number of input/output (I/O) devices. When executing the computer program, the computer system processes information according to the computer program and produces resultant output information via I/O devices.

Unless otherwise stated, the use of the expression “and/or” between the last two members of a list of options for selection indicates that a selection of one or more of the listed options is appropriate and may be made.

It should be understood that where the claims or specification refer to "a" or "an" element, such reference is not to be construed as there being only one of that element.

All references mentioned in this specification are herein incorporated in their entirety by reference into the specification, to the same extent as if each individual reference was specifically and individually indicated to be incorporated herein by reference. In addition, citation, or identification of any reference in this application shall not be construed as an admission that such reference is available as prior art to the present disclosure.

While this disclosure has been described in terms of certain embodiments and generally associated methods, alterations and permutations of the embodiments and methods will be apparent to those skilled in the art. The disclosure is to be understood as not limited by the specific

embodiments described herein, but only by the scope of the appended claims.

WHAT IS CLAIMED IS:

1. An enhanced endoscopic ultrasound (EUS) system, comprising:

an ultrasound (US) probe located at a distal end of the endoscope;

a US control and processing unit operatively coupled with the US probe and configured to output an US image stream;

a tracking sensor with a known position and orientation relative to the US probe;

a tracking control and processing unit operatively coupled with the tracking sensor and configured to calculate and output the position and orientation of the US probe at any given moment;

a visual intelligence unit configured to accept as input and process the US image stream and the position and orientation of the US probe at any given moment into a visual output; and

a display unit configured to display the visual output.

2. The system of claim 1, wherein the tracking sensor is an electromagnetic (EM) tracking sensor.

3. The system of claim 1, wherein the visual output includes a current US probe position and orientation shown in relation to a plurality of previous positions and orientations within a common 3D volume.

4. The system of claim 1, wherein the visual output includes labels and/or marks of borders and/or one or more key points of selected anatomical elements and/or pathologies overlaid on a US image of the US image stream.

5. The system of claim 1, wherein the visual output includes a 3D model of one or more selected anatomical elements and/or pathologies.

6. The system of claim 1, wherein the processing includes using the position and orientation of the US probe at any given moment to place all or a subset of the 2D US frames of the US image

stream into a 3D common volume, and using the 3D common volume to derive information about the contents of one of more of the 2D US frames of the US image stream.

7. The system of claim 1, wherein the visual intelligence unit is further configured to accept as input a pre-procedure model and process the pre-procedure model.

8. The system of claim 7, wherein the visual output includes a current position and orientation of the US probe shown in relation to the pre-procedure model.

9. The system of claim 7, wherein the visual output includes labels and/or marks of borders and/or one or more key points of selected anatomical elements and/or pathologies overlaid on a US image of the US image stream, and derived from the pre-procedure model.

10. The system of claim 7, wherein the visual output includes instructions to a user on guidance of the US probe to visualize a target pathology identified in the pre-procedure model.

11. The system of claim 1, wherein the visual intelligence unit is further configured to accept as input a video stream and process the video stream.

12. A method for enhancing EUS procedures in a system configured to output an US image stream and a position and orientation of a US probe at any given moment, comprising:

processing the US image stream and position and orientation of the US probe at any given moment into a visual output; and

displaying the visual output.

13. The method of claim 12, wherein the visual output includes a current US probe position and orientation shown in relation to a plurality of previous positions and orientations within a common 3D volume.

14. The method of claim 12, wherein the visual output includes labels and/or marks of borders and/or one or more key points of selected anatomical elements and/or pathologies overlaid on an US image of the US image stream.

15. The method of claim 12, wherein the visual output includes a 3D model of one or more selected anatomical elements and/or pathologies.

16. The method of claim 15, wherein the visual output includes a current position and orientation of the US probe shown in relation to the 3D model.

17. The method of claim 12, wherein the processing includes processing the US image stream and position and orientation of the US probe at any given moment together with a pre-procedure model into the visual output.

18. The method of claim 17, wherein the visual output includes a current position and orientation of the US probe shown in relation to the pre-procedure model.

19. The method of claim 17, wherein the visual output includes labels and/or marks of borders and/or one or more key points of selected anatomical elements and/or pathologies overlaid on a US image of the US image stream, and derived from the pre-procedure model.

20. The method of claim 19, wherein the visual output includes instructions to a user on guidance of the US probe to visualize a target pathology identified in the pre-procedure model.

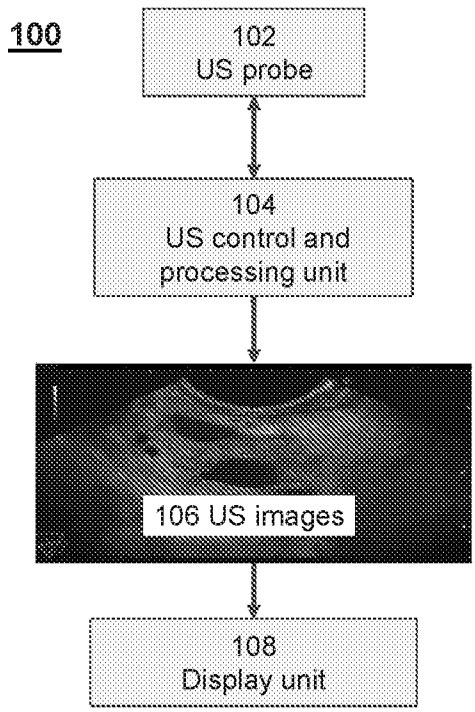


FIG. 1 KNOWN ART

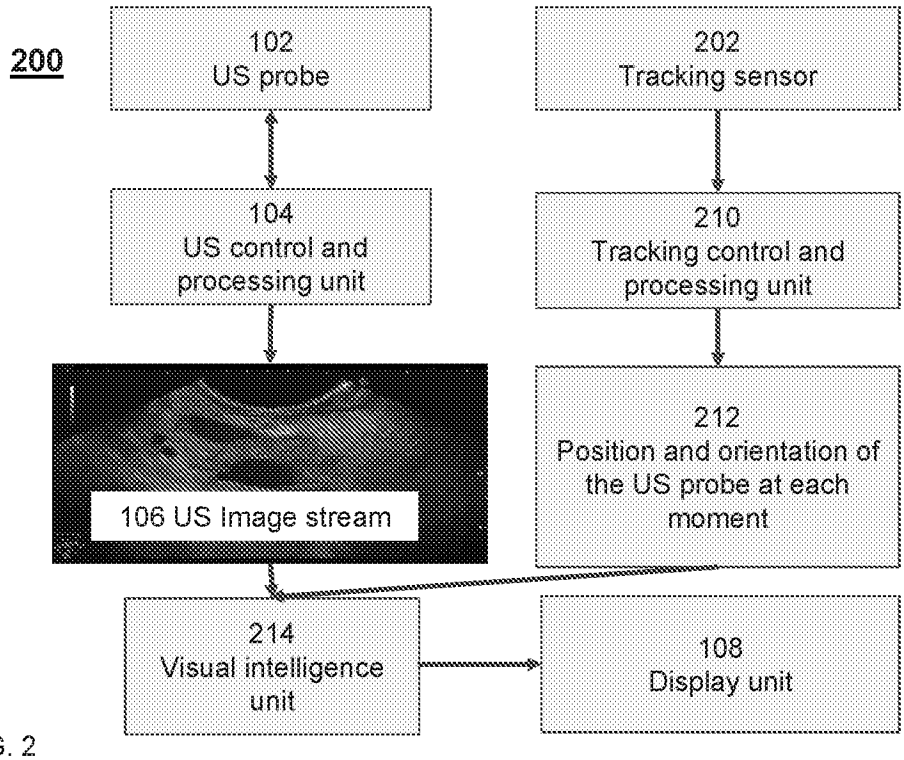

200
102
US probe
202
Tracking sensor
104
US control and processing unit
210
Tracking control and processing unit
106 US Image stream
212
Position and orientation of the US probe at each moment
214
Visual intelligence unit
108
Display unit

FIG. 2

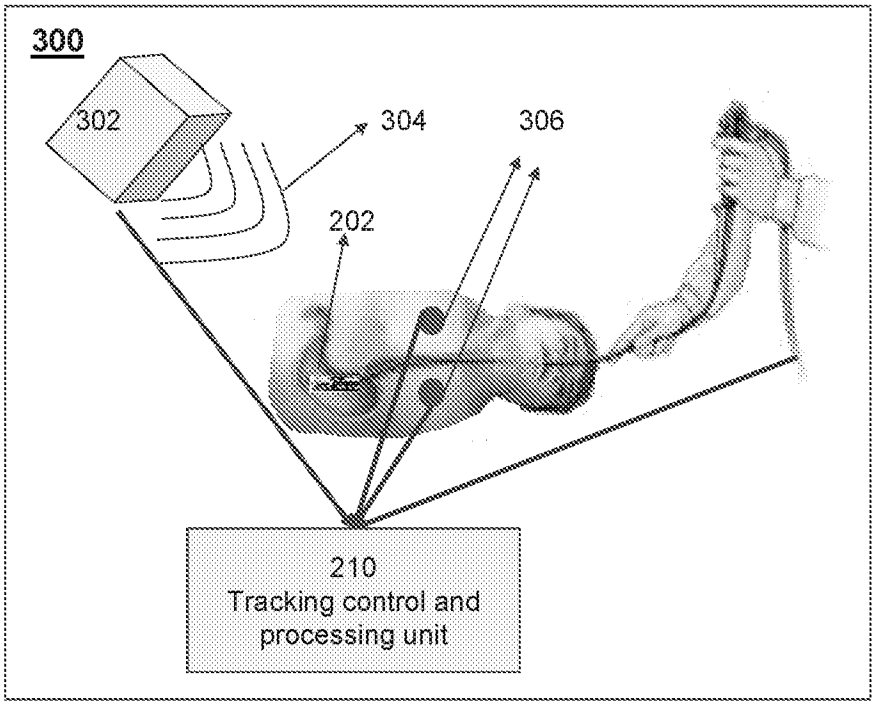

300
302
304
306
202
210
Tracking control and processing unit

FIG. 3

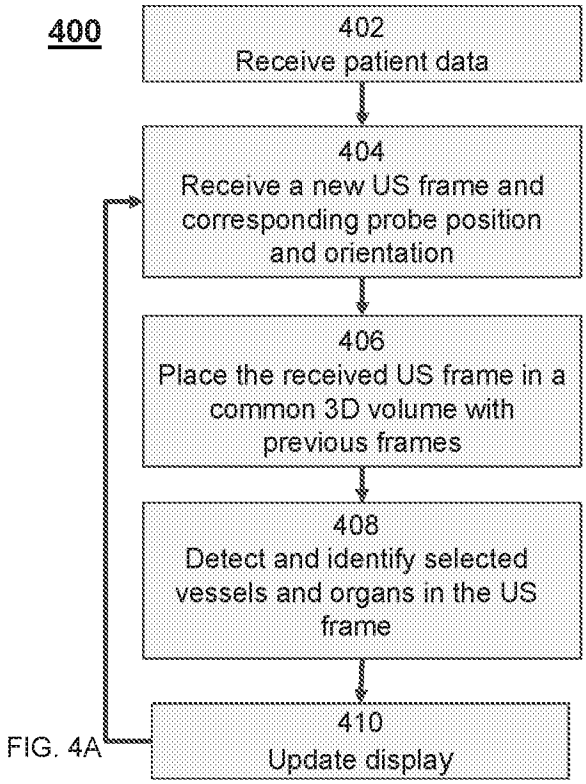

400
402
Receive patient data
404
Receive a new US frame and corresponding probe position and orientation
406
Place the received US frame in a common 3D volume with previous frames
408
Detect and identify selected vessels and organs in the US frame
410
Update display

FIG. 4A

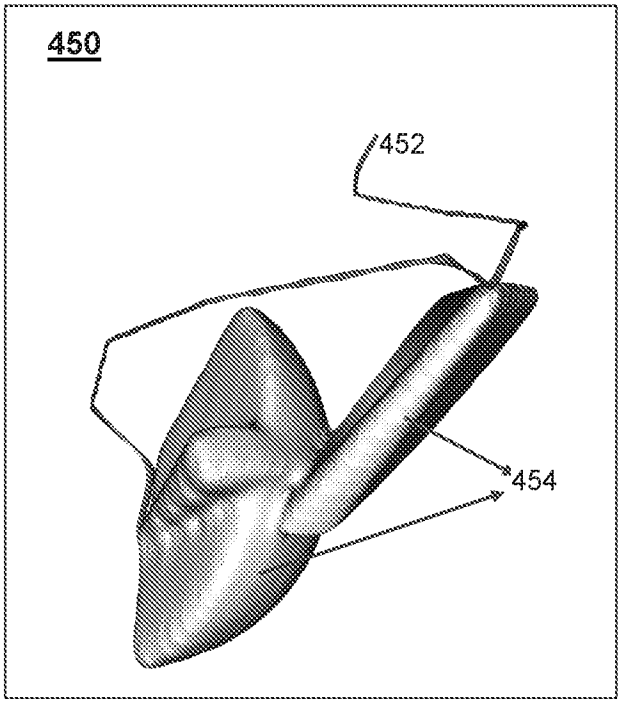


FIG. 4B

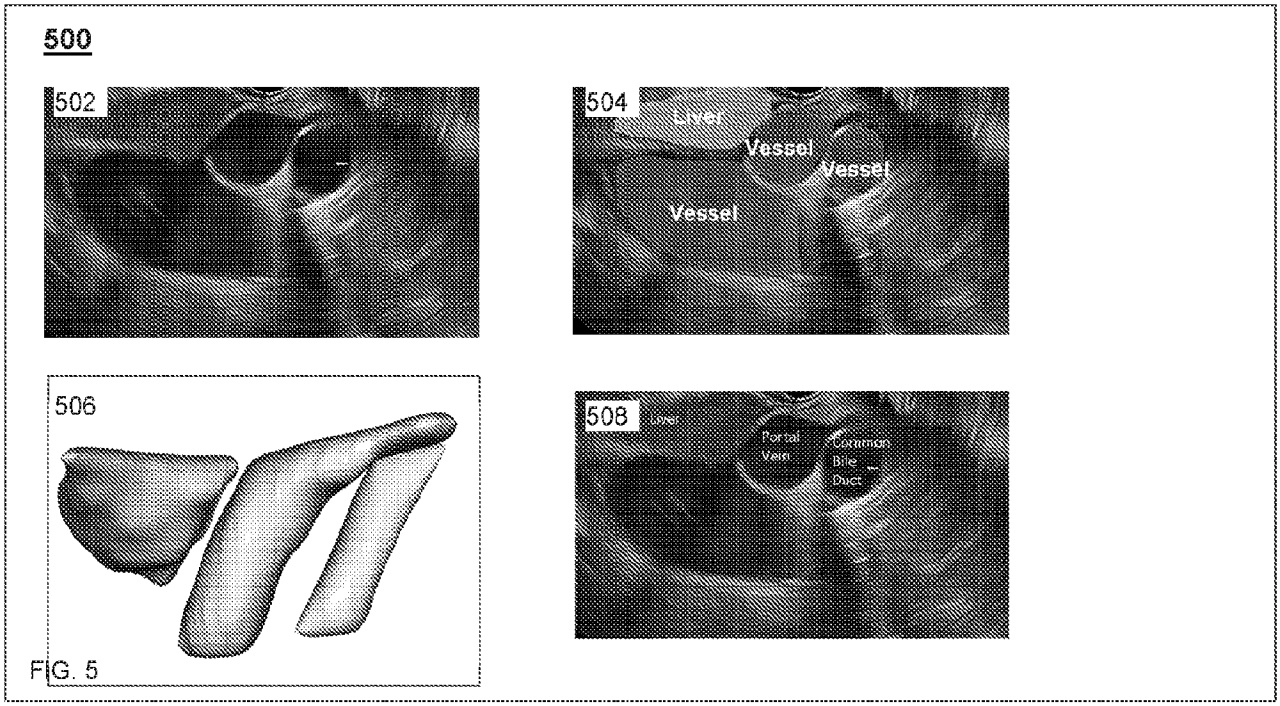

500
502
504
Liver
Vessel
Vessel
Vessel
506
508
Liver
Portal Vein
Common Bile Duct

FIG. 5

600

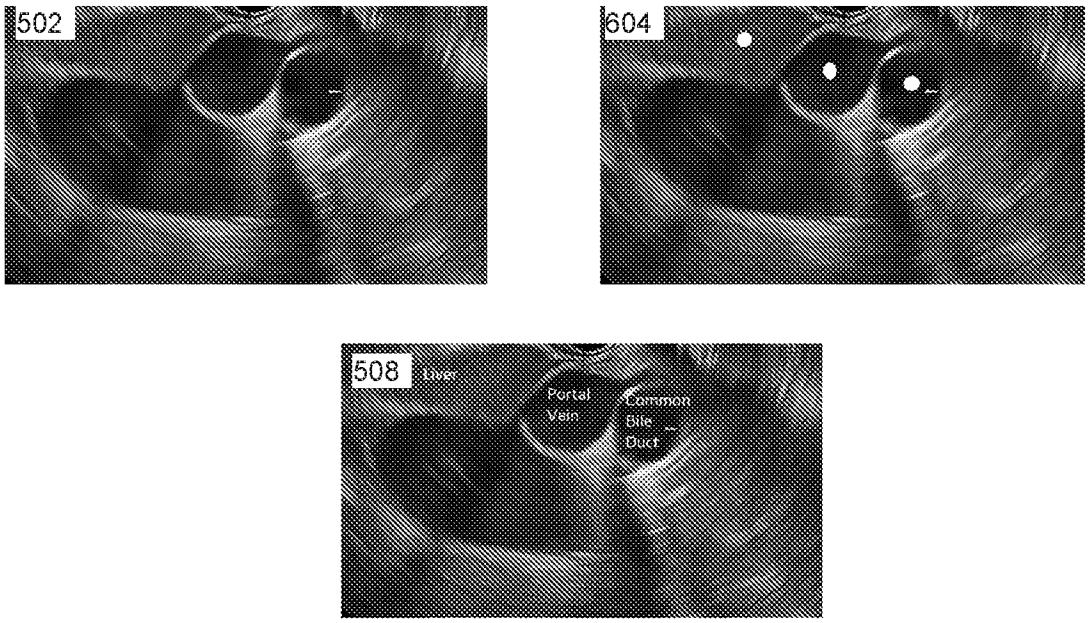


FIG. 6

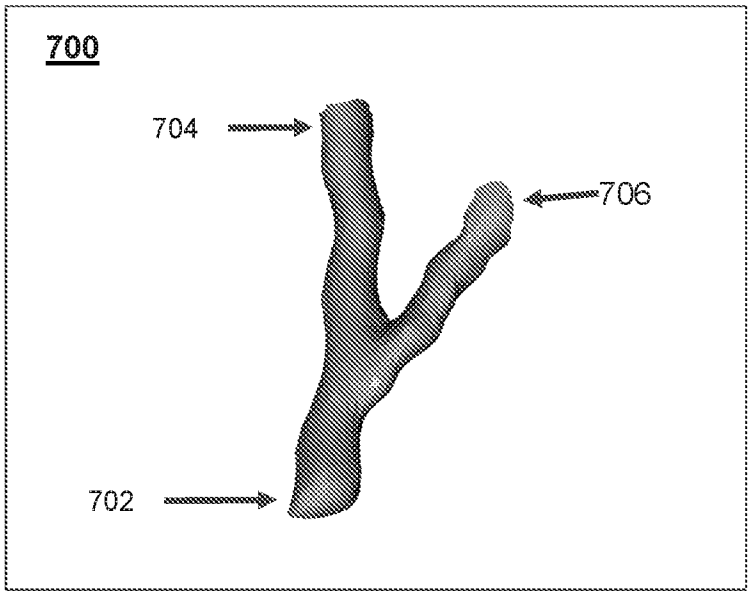


FIG. 7

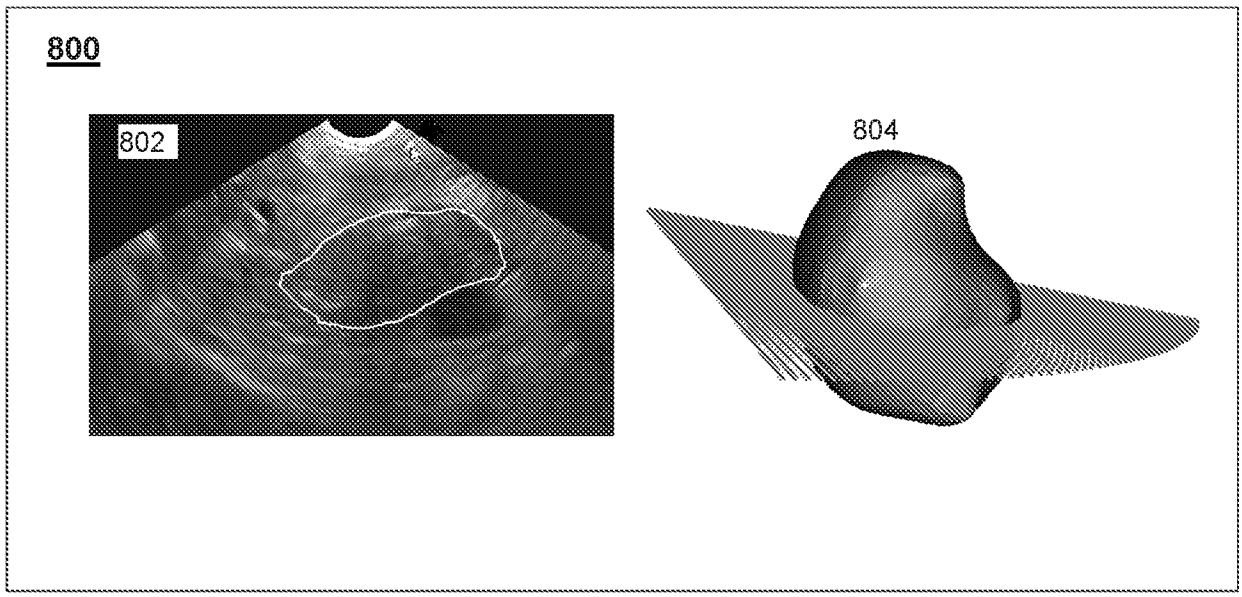


FIG. 8

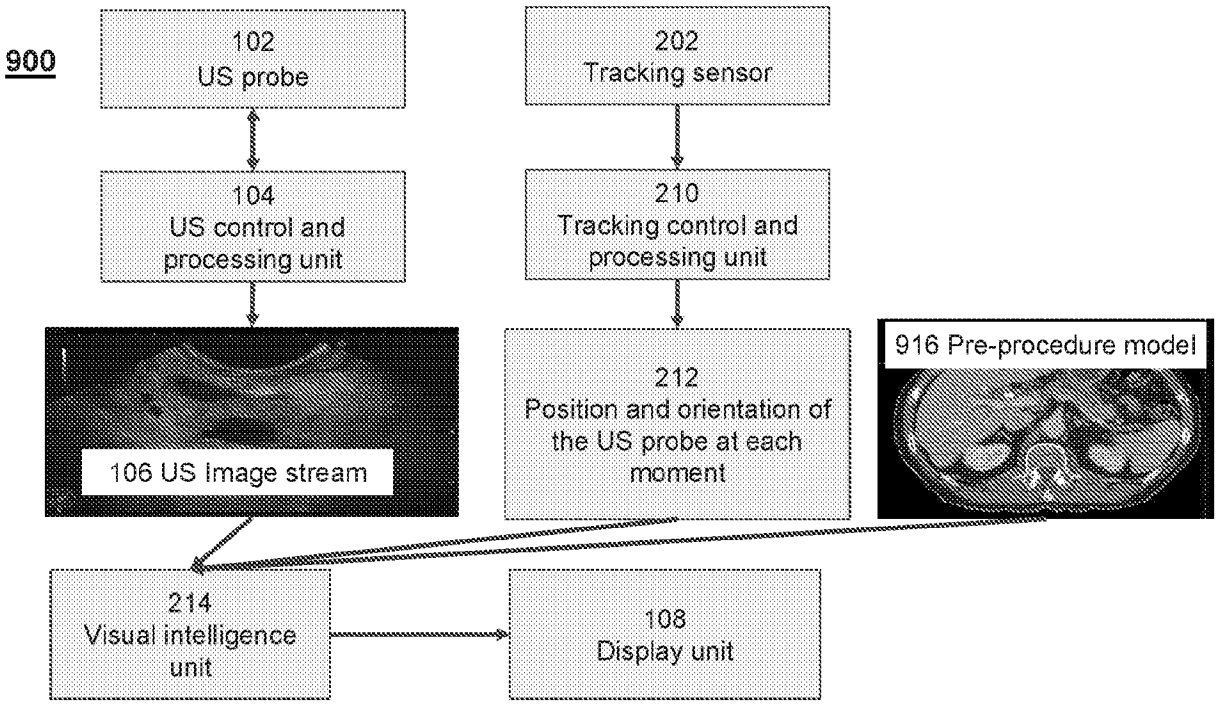

900
102
US probe
202
Tracking sensor
104
US control and processing unit
210
Tracking control and processing unit
106 US Image stream
212
Position and orientation of the US probe at each moment
916 Pre-procedure model
214
Visual intelligence unit
108
Display unit

FIG. 9

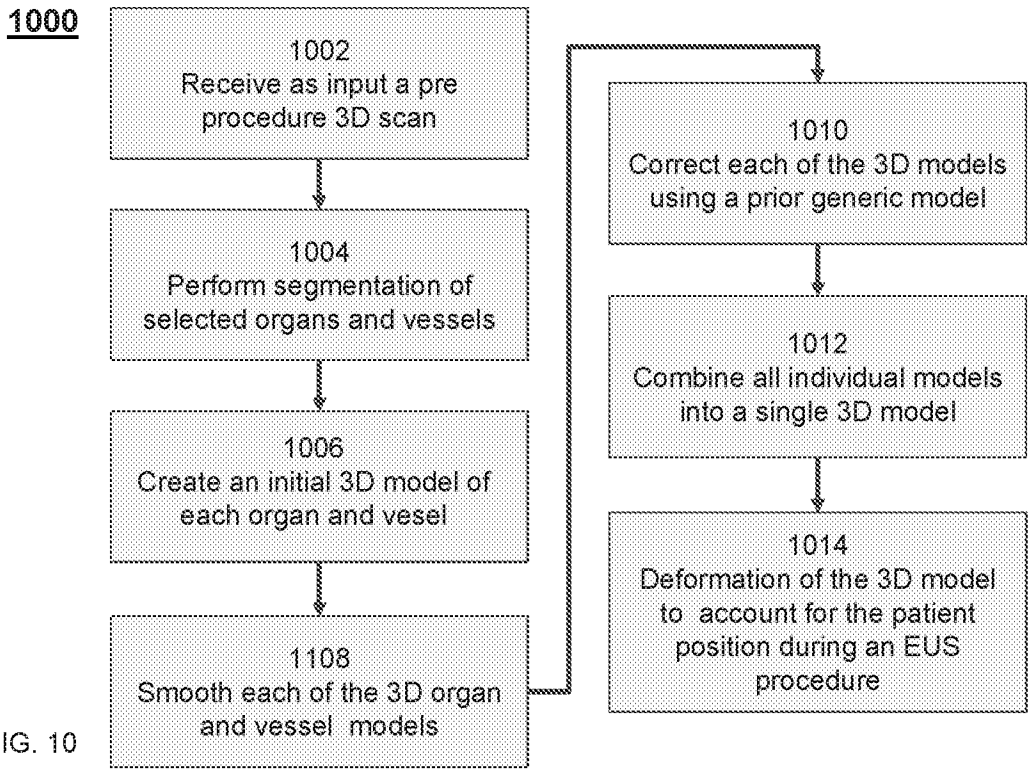

1000
1002
Receive as input a pre procedure 3D scan
1004
Perform segmentation of selected organs and vessels
1006
Create an initial 3D model of each organ and vesel
1108
Smooth each of the 3D organ and vessel models
1010
Correct each of the 3D models using a prior generic model
1012
Combine all individual models into a single 3D model
1014
Deformation of the 3D model to account for the patient position during an EUS procedure

FIG. 10

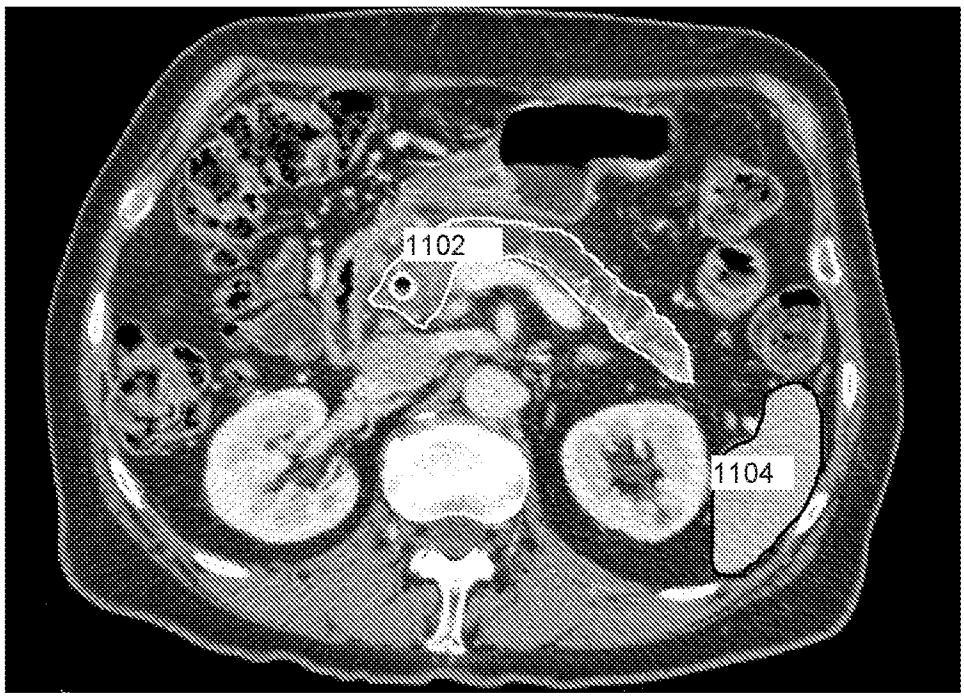


FIG. 11

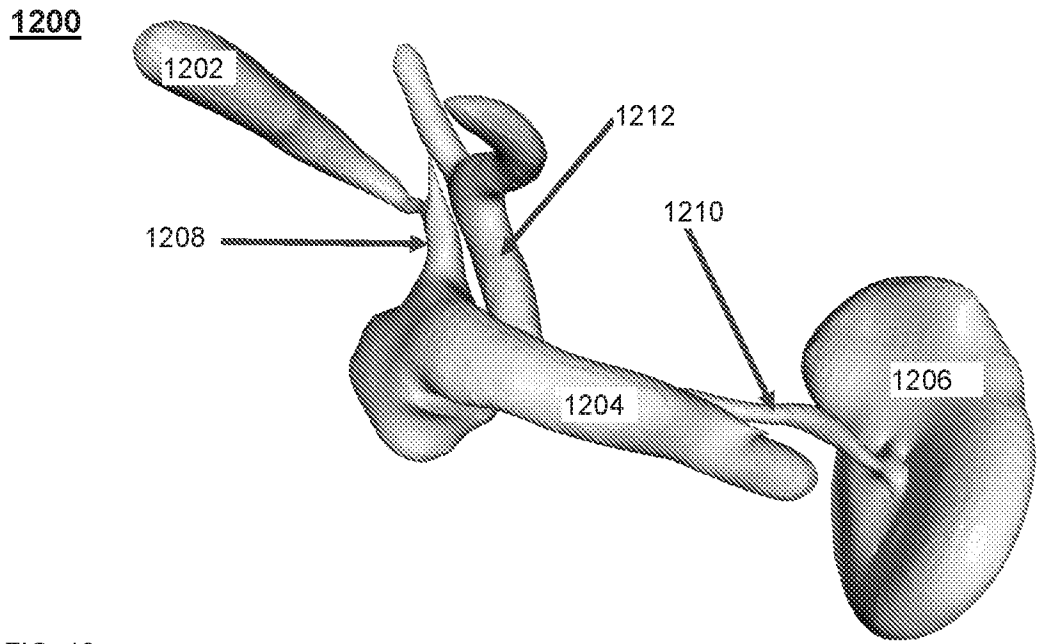


FIG. 12

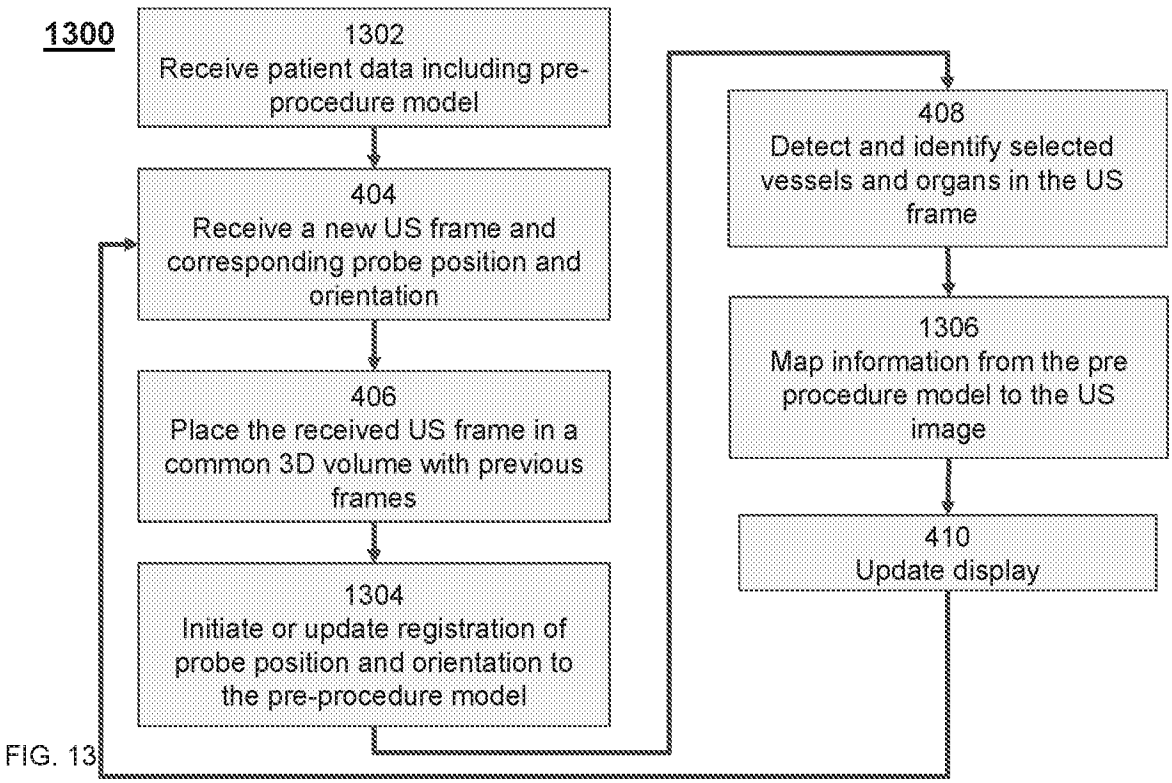

1300
1302
Receive patient data including pre-procedure model
404
Receive a new US frame and corresponding probe position and orientation
406
Place the received US frame in a common 3D volume with previous frames
1304
Initiate or update registration of probe position and orientation to the pre-procedure model
408
Detect and identify selected vessels and organs in the US frame
1306
Map information from the pre procedure model to the US image
410
Update display

FIG. 13

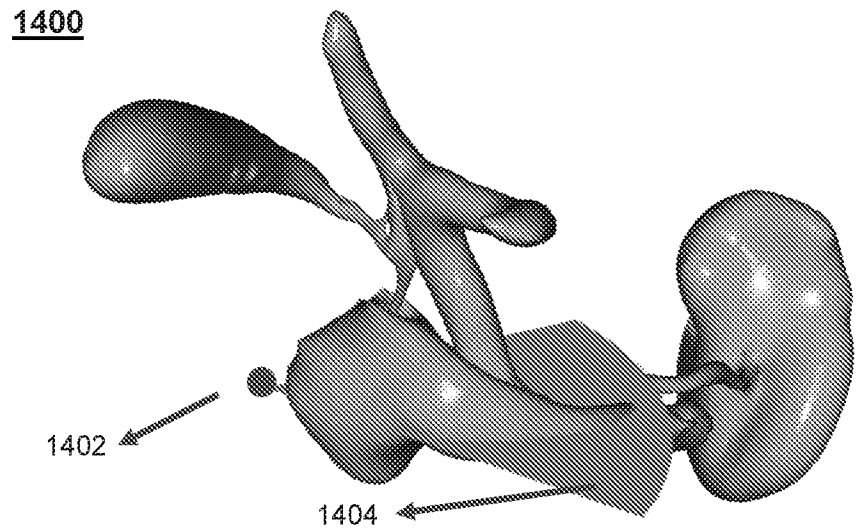


FIG. 14A

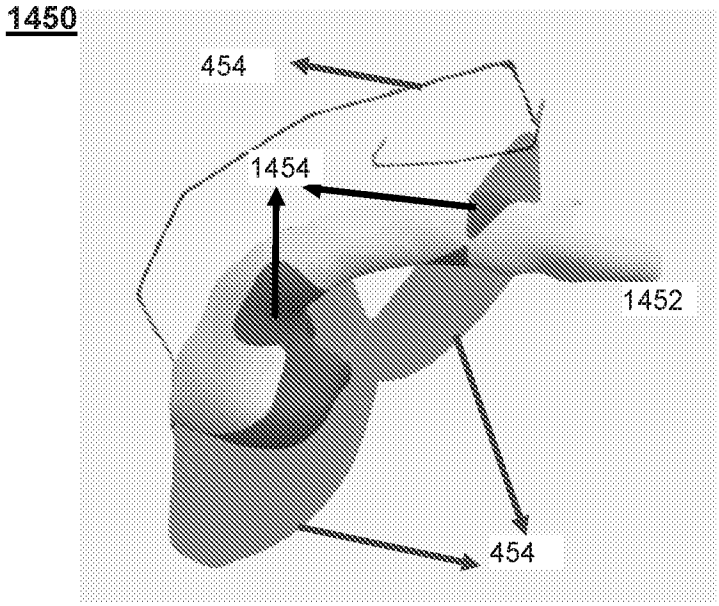


FIG.14B

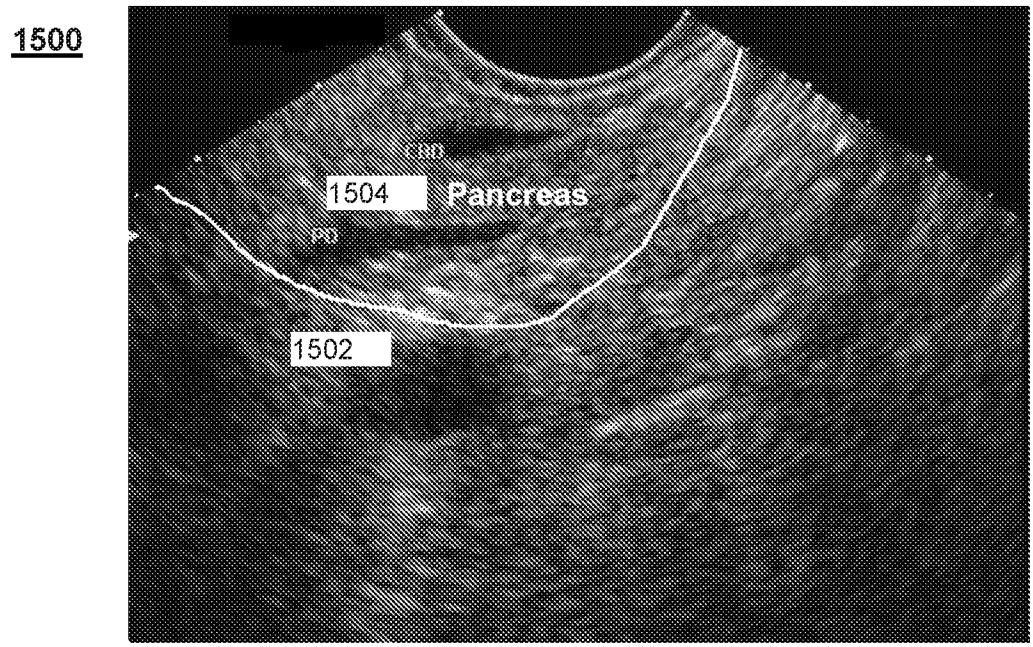


FIG. 15

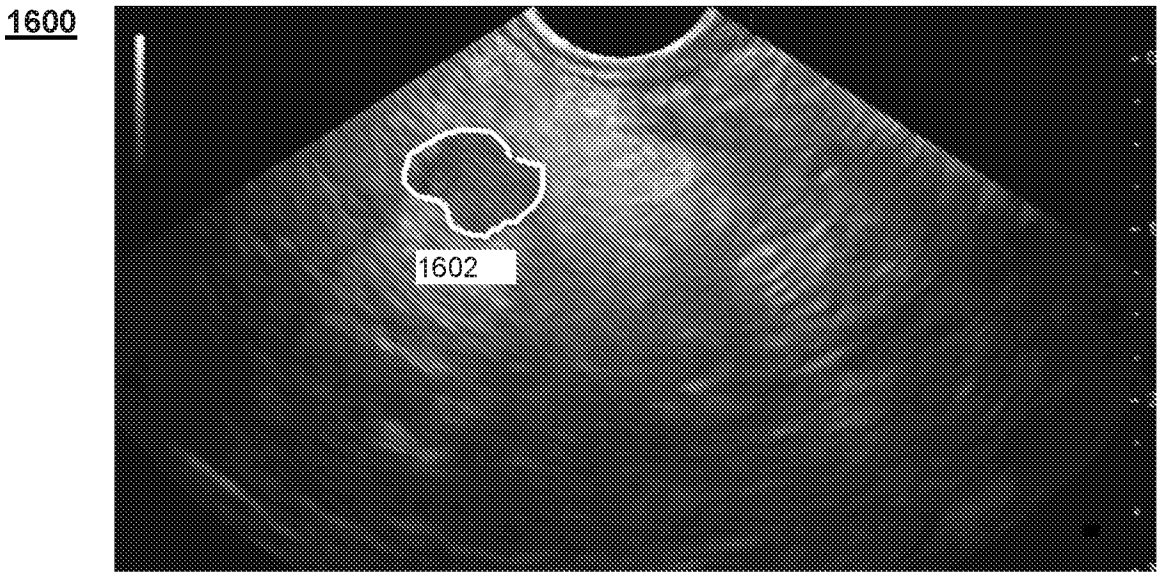


FIG. 16

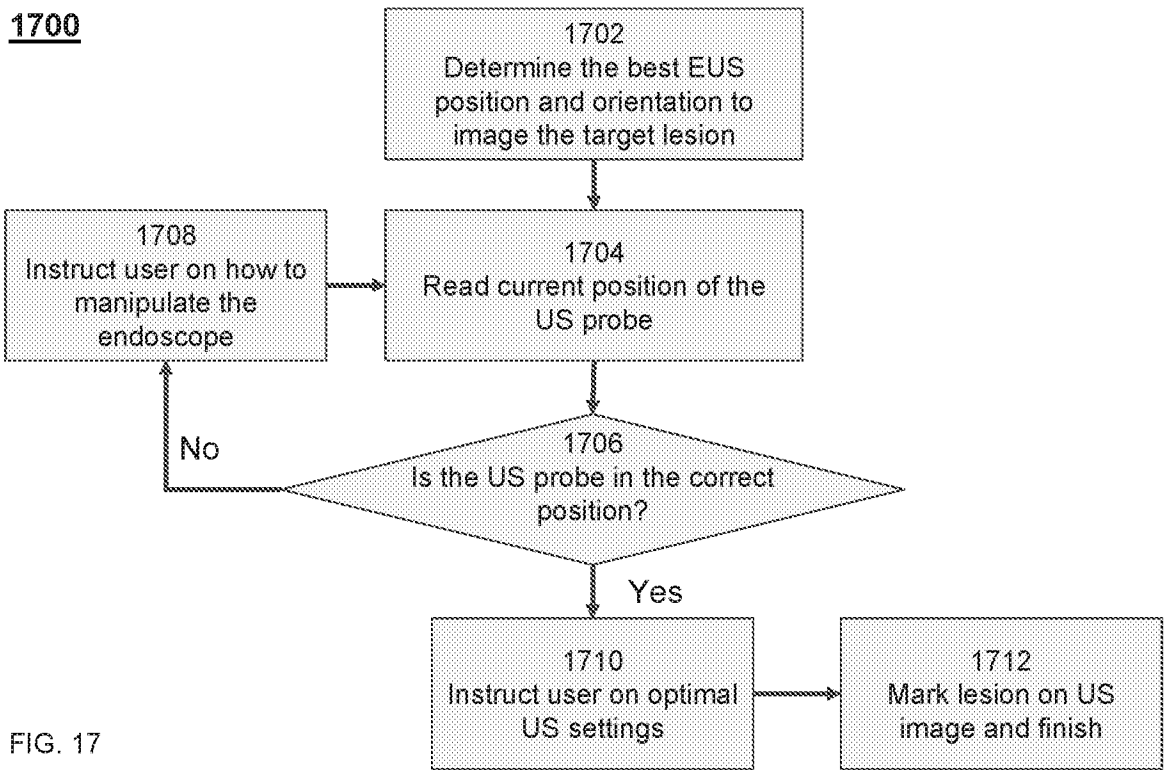

1700
1702
Determine the best EUS position and orientation to image the target lesion
1704
Read current position of the US probe
1706
Is the US probe in the correct position?
No
1708
Instruct user on how to manipulate the endoscope
Yes
1710
Instruct user on optimal US settings
1712
Mark lesion on US image and finish

FIG. 17

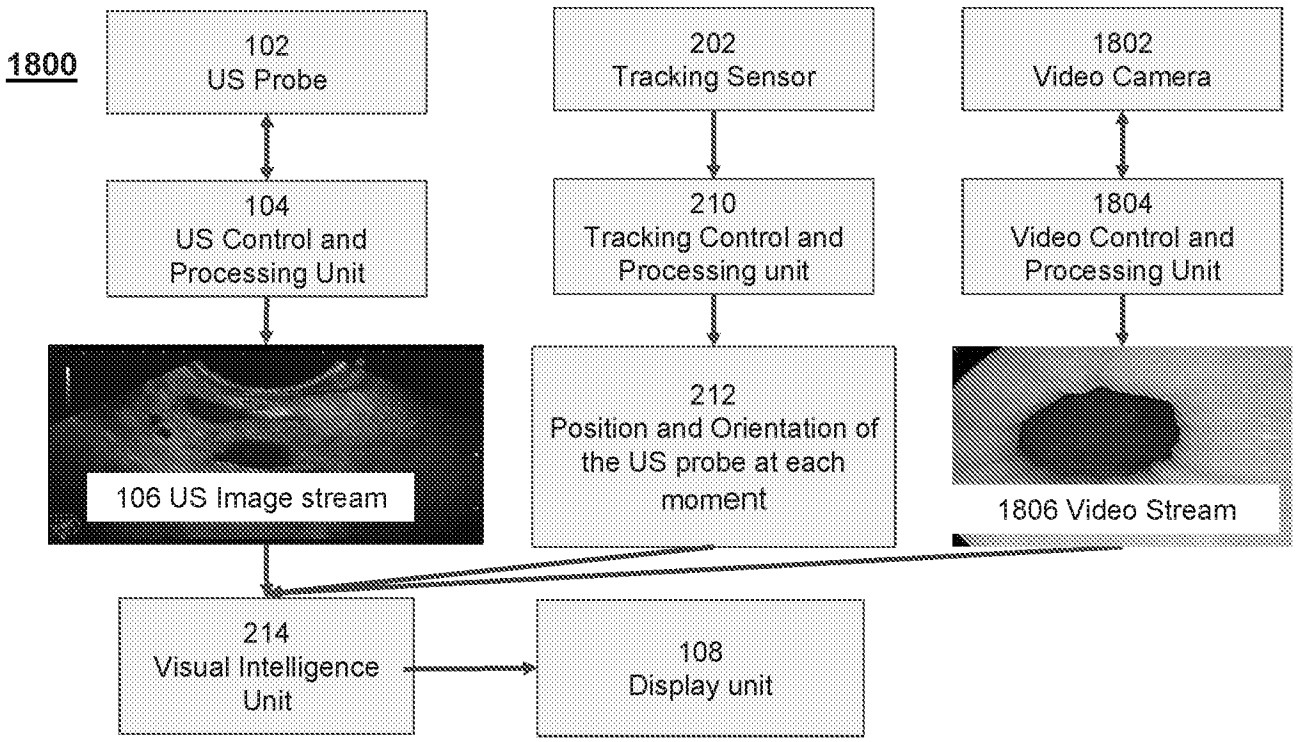

1800
102
US Probe
202
Tracking Sensor
1802
Video Camera
104
US Control and
Processing Unit
210
Tracking Control and
Processing unit
1804
Video Control and
Processing Unit
106 US Image stream
212
Position and Orientation of
the US probe at each
moment
1806 Video Stream
214
Visual Intelligence
Unit
108
Display unit

FIG. 18

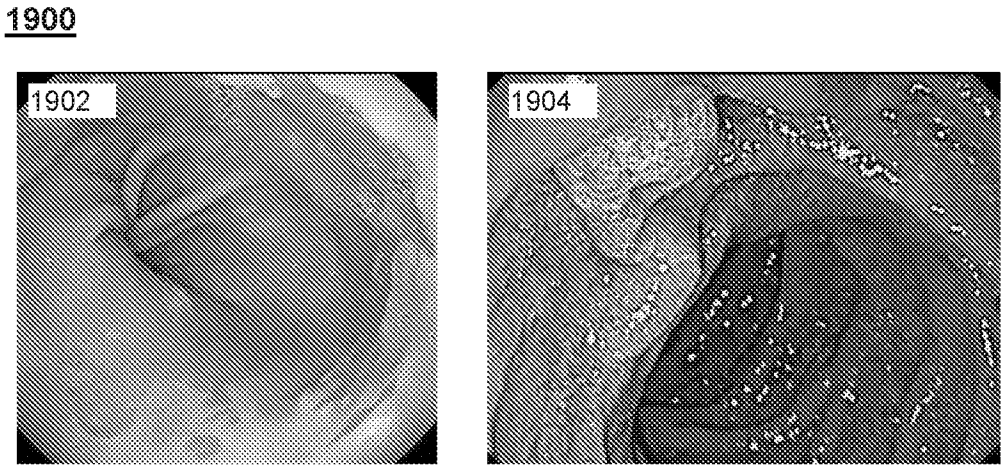


FIG. 19

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB 22/56270

A. CLASSIFICATION OF SUBJECT MATTER

IPC - INV. A61B 8/12, A61B 34/20 (2022.01)
ADD. A61B 10/04 (2022.01)

CPC - INV. A61B 8/12, A61B 34/20
ADD. A61B 8/44, A61B 8/4444, A61B 10/04, A61B 2090/3782, A61B 2090/3784

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
See Search History document

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X — Y	US 2016/0183767 A1 (SIEMENS MEDICAL SOLUTIONS USA, INC.) 30 June 2016 (30.06.2016) entire document, especially FIGS. 1-4, FIGS. 7-8, para [0018]-[0021], [0037], [0050]-[0053]	1, 2, 12 ——— 3-11, 13-20
Y	US 2018/0042680 A1 (INTUITIVE SURGICAL OPERATIONS, INC.) 15 February 2018 (15.02.2018) entire document, especially FIG. 4, FIG. 7, para [0041]-[0042], [0044]-[0045], [0061], [0069], [0075], [0083], [0085], [0087], [0113]-[0114], [0157], [0183]	3-11, 13-20

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
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"D" document cited by the applicant in the international application
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 September 2022	OCT 20 2022
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer Kari Rodriquez Telephone No. PCT Helpdesk: 571-272-4300