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(54) Title: MULTI-MODAL OPTICAL IMAGING SYSTEM FOR TISSUE ANALYSIS

(57) Abrégé/Abstract:

A modular system for organic sample analysis is disclosed which includes a sample stage including a support platform and a motorized positioning mechanism mounted on the support platform, and a sample holder mounted on the motorized positioning mechanism upon which a sample is placed. A probe support rack is mounted on the support platform and two or more bio-imaging probes mounted on the probe support and arranged in a predefined geometry with respect to each other, and at least one bio-imaging probe has a field of view independent of all other bio-imaging probes. The system includes a computer controller connected to the motorized positioning mechanism and the two or more bio-imaging probes. The computer is programmed for controlling motorized positioning mechanism to move the sample holder having the sample located thereon to positions in the field of view of each bio-imaging probe where the sample can be analyzed individually by each of the bio-imaging probes. The computer includes a storage medium for storing an imaging data from each bio-imaging probe. The computer is programmed for spatially correlating imaging data of the selected volume of interest with the imaging data obtained from at least one other bio-imaging probe and storing the spatially correlated imaging data in the computer storage medium.

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ABSTRACT

A modular system for organic sample analysis is disclosed which includes a sample stage including a support platform and a motorized positioning mechanism mounted on the support platform, and a sample holder mounted on the motorized positioning mechanism upon which a sample is placed. A probe support rack is mounted on the support platform and two or more bio-imaging probes mounted on the probe support and arranged in a pre-defined geometry with respect to each other, and at least one bio-imaging probe has a field of view independent of all other bio-imaging probes. The system includes a computer controller connected to the motorized positioning mechanism and the two or more bio-imaging probes. The computer is programmed for controlling motorized positioning mechanism to move the sample holder having the sample located thereon to positions in the field of view of each bio-imaging probe where the sample can be analyzed individually by each of the bio-imaging probes. The computer includes a storage medium for storing an imaging data from each bio-imaging probe. The computer is programmed for spatially correlating imaging data of the selected volume of interest with the imaging data obtained from at least one other bio-imaging probe and storing the spatially correlated imaging data in the computer storage medium.

MULTI-MODAL OPTICAL IMAGING SYSTEM FOR TISSUE ANALYSIS

FIELD

The present disclosure relates to a biopsy analysis system that can be
5 placed in an operating room to provide rapid tissue analysis.

BACKGROUND

During a surgical procedure, there is a need for intra-operative pathology
consultation to guide immediate surgical decisions such as establishing or
10 confirming a diagnosis; or delineating margins of diseases. These pathological
assessments are vital for successful surgical outcomes. Yet, typical intra-
operative pathology procedures are time-consuming since tissue biopsy
samples have to be transferred to a pathology lab where they have to be
correctly prepared and analyzed following which the results need to be
15 adequately communicated to a remote operating room. This long process may
cause discontinuities in surgical workflows and delays in surgical actions.
Under ideal circumstances, it typically takes approximately 20 minutes to
perform a biopsy analysis. However, this interval is usually longer during a
surgery and waiting times of more than 60 minutes are not unusual for a variety
20 of reasons. Reasons for delays may include a large distance between the
operating room and the pathology lab, limited capacity of the pathology lab to
analyze the biopsy sample(s), or inefficient setup of the pathology equipment.

Accordingly, it would be beneficial to provide a biopsy analysis system
that can be placed in an operating room, easily operated, and which can
25 provide fast and reliable relevant pathological assessments.

Further, various types of optical imaging can provide information about
tissue disease states. Examples of such optical imaging modalities include
optical coherence tomography (OCT), incoherent Raman spectroscopy,
coherent Raman spectroscopy, auto-florescence intensity imaging,
30 fluorescence lifetime imaging, diffuse optical imaging, confocal microscopy,
super-resolution microscopy, second harmonic imaging microscopy, third
harmonic imaging microscopy, dark field imaging, phase-contrast microscopy,
and white light imaging (e.g. traditional microscopy).

The imaging information can be further improved by injecting imaging contrast agents into an examined tissue. It has also been realized that insights about a tissue can be enhanced if the tissue is probed with several optical imaging modalities and the data from different imaging modalities are correlated. The reason for the success of such multi-modal imaging approaches is that these optical imaging techniques examine different tissue properties, so they are complimentary in nature. Several embodiments of multi-modal optical imaging systems have been reported in academic literature such as the reference Egodage, Kokila, et al. **"The combination of optical coherence tomography and Raman spectroscopy for tissue characterization."** Journal of Biomedical Photonics & Engineering 1.2 (2015): 169-177., and disclosed in patents DE19854292C2, US6507747B1, US7508524B2.

A shared feature of all the reported multi-modal optical systems for tissue imaging is that their optical sub-systems related to individual imaging modalities (e.g. OCT, Raman spectroscopy, fluorescence spectroscopy, etc.) share a certain number of optical elements such as optical beam splitters, lenses, or mirrors. Such design approach has its advantages since it leads to compact optical systems. However, there is also a potential disadvantage since the performance of individual imaging modalities is usually sub-optimal since the choice of the characteristics of shared optical elements is a compromise between different requirements for individual imaging sub-systems. For example, in Raman spectroscopy, signals are very weak compared to background and the pump laser power, so optical elements with sharp optical filtering characteristics are required. However, such optical filtering characteristics may not be optimal for other imaging modalities for which excitation and signal spectra may partially overlap with the Raman ones.

An optical multi-modal imaging platform in which various optical imaging modalities don't share common optical elements may provide individual optical imaging data with better quality and thus improve overall information content of the multi-modal imaging process.

SUMMARY

The present disclosure discloses a portable optical system comprising of plurality of optical probes and which is used for analyzing tissue samples especially in the context of biopsy analysis and bio-medical research.

5 In an embodiment there is provided a modular system for organic sample analysis is disclosed which includes a sample stage including a support platform and a motorized positioning mechanism mounted on the support platform, and a sample holder mounted on the motorized positioning mechanism upon which a sample is placed. A probe support rack is mounted
10 on the support platform and two or more bio-imaging probes mounted on the probe support and arranged in a pre-defined geometry with respect to each other, and at least one bio-imaging probe has a field of view independent of all other bio-imaging probes. The system includes a computer controller connected to the motorized positioning mechanism and the two or more bio-imaging
15 probes. The computer is programmed for controlling motorized positioning mechanism to move the sample holder having the sample located thereon to positions in the field of view of each bio-imaging probe where the sample can be analyzed individually by each of the bio-imaging probes. The computer includes a storage medium for storing an imaging data from each bio-imaging
20 probe. The computer is programmed for spatially correlating imaging data of the selected volume of interest with the imaging data obtained from at least one other bio-imaging probe and storing the spatially correlated imaging data in the computer storage medium.

In an embodiment there is provided a method under computer control of
25 organic sample analysis, which includes,

a) in any order:

- i) affixing two or more bio-imaging probes to a probe support rack which is mounted on a support platform, said two or more bio-imaging probes being mounted in a pre-defined geometry with respect to each
30 other and at least one bio-imaging probe having a field of view independent of all other bio-imaging probes, and
- ii) placing an organic sample on a sample holder, the sample holder being mounted on a motorized positioning mechanism; and

b) initiating a computer controller connected to said motorized positioning mechanism and the two or more bio-imaging probes for instructing the motorized positioning mechanism to move the sample holder having the sample located thereon to positions in the field of view of selected bio-imaging probes where the sample is analyzed individually by each of the bio-imaging probes, storing imaging data from each of the bio-imaging probe, and spatially correlating imaging data of the selected volume of interest with the imaging data obtained from at least one other bio-imaging probe and storing said spatially correlated imaging data in said storage means.

A further understanding of the functional and advantageous aspects of the present disclosure can be realized by reference to the following detailed description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments disclosed herein will be more fully understood from the following detailed description thereof taken in connection with the accompanying drawings, which form a part of this application, and in which:

Figure 1 shows a schematic representation of a portable multi-modal tissue imaging system constructed in accordance with the present disclosure.

Figure 2 shows a schematic of probe imaging volume discretization and its representation in the control computer system.

Figure 3 is a side elevation view of a tissue sample with highlighted sample sections of interest **VS1, VS2,...,VSM** selected after the sample has been observed with an optical probe.

Figure 4 is a perspective view of an embodiment of a sample holder and motorized positioning assembly forming part of the present system.

Figure 5 is a schematic representation of a probe registration module in relation to the portable multi-modal tissue imaging system.

Figure 6A shows a schematic representation of a pinhole registration module as an example of a probe registration module.

Figure 6B is a side view of an embodiment of a pinhole registration module localization with white light imaging probes.

Figure 7 is a side view of an embodiment of localization of sampling volumes of interest.

Figure 8A shows a general system for vertical coordinate determination in relation to sampling volume definition using a 2D optical probe and two guide
5 lasers with crossed beams.

Figure 8B shows a system from **Figure 8A** in the case when alignment is achieved and the vertical coordinate determined.

Figure 9A shows a schematic of an exemplary embodiment of the multi-modal optical imaging system for tissue analysis.

Figure 9B shows the system presented in **Figure 9A** that is mounted on
10 a mobile unit.

Figure 9C shows the system presented in **Figure 9B** that includes an additional enclosure box for the multi-modal probe system.

Figure 10 is a representative process flow chart showing non-limiting
15 process steps involved in using the multi-modal optical imaging system presented in **Figure 9C**.

Figure 11A is the detailed start and initialization steps of the user workflow as presented in **Figure 10**.

Figure 11B is the detailed Raman setup steps of the user workflow as
20 presented in **Figure 10**.

Figure 11C shows OCT scan setup and preview steps of the system showing user workflow as presented in **Figure 10**.

Figure 11D shows 3D OCT scan setup steps of the system user workflow as presented in **Figure 10**.

Figure 11E shows data acquisition steps of the system user workflow as
25 presented in **Figures 11B, 11C, and 11D**.

DETAILED DESCRIPTION

Various embodiments and aspects of the disclosure will be described
30 with reference to details discussed below. The following description and drawings are illustrative of the disclosure and are not to be construed as limiting the disclosure. Numerous specific details are described to provide a thorough understanding of various embodiments of the present disclosure. However, in

certain instances, well-known or conventional details are not described in order to provide a concise discussion of embodiments of the present disclosure.

As used herein, the terms “comprises” and “comprising” are to be construed as being inclusive and open ended, and not exclusive. Specifically,
 5 when used in the specification and claims, the terms “comprises” and “comprising” and variations thereof mean the specified features, steps or components are included. These terms are not to be interpreted to exclude the presence of other features, steps or components.

As used herein, the term “exemplary” means “serving as an example,
 10 instance, or illustration,” and should not be construed as preferred or advantageous over other configurations disclosed herein.

As used herein, the terms “about” and “approximately” are meant to cover variations that may exist in the upper and lower limits of the ranges of values, such as variations in properties, parameters, and dimensions.

As used herein, the term “patient” is not limited to human patients and
 15 may mean any organic sample such as human tissue, animal tissue, plant tissue, cells, and food samples.

As used herein, the term “bio-imaging probe” includes probes that
 20 acquire signals from visible, ultraviolet, infrared, terahertz, X-rays, microwave, and radio frequency part of the electromagnetic spectrum as well as acoustic probes.

The imaging probes can be zero dimension (i.e., single point), 1 dimension (1D), 2 dimensions (2D), 3 dimensions (3D) or 4 dimensions (4D).

Figure 1 shows a schematic view of a portable biopsy system **10** which
 25 includes plurality of optical probes **P1, P2,..., PN** arranged in a fixed geometry relative to each other ; a motorized positioning assembly **14**; a sample holder **16** attached to the motorized positioning assembly **14** on which a sample **18** is mounted; control electronics **15** that drives the motorized positioning assembly **14** and the optical probes **P1, P2,..., PN** ; a computer (microprocessor)
 30 controller **20** that controls the control electronics and which is programmed with instructions to acquire and store data from these optical probes; power supply **19** that provides appropriate power for control electronics **15** and computer **20**.

The contents of biopsy system **10**, or, at least, the optical probes **P1, P2,..., PN** and motorized positioning assembly **14** may be enclosed within a

light-tight enclosure **12** to prevent any ambient light from contaminating the optical signals detected by any one or combination of the sensitive optical probes **P1** to **PN**.

The contents of biopsy system **10**, or, at least, the optical probes **P1**, **P2**,..., **PN** and motorized positioning assembly **14** may be mounted on a vibrationally damped base to prevent mechanical vibrations which may cause noise in the optical signals.

The housing enclosing all the components forming part of biopsy system **10** may include a ventilation system to prevent deterioration of sensitive biological samples due to the presence of any air contamination inside the light tight enclosure. Air contamination can be detrimental if long-term sample preservation is required due to the need for an extended period to do the tissue analysis. Similarly, system **10** may include a sample cooling system provided to slow the deterioration of some biological samples by being able to cool them below room temperature. A non-limiting exemplary cooling system may include a thermoelectric cooling (TEC) system within sample holder **16**.

For each probe **Pi** among probes **P1**, **P2**,..., **PN**, there is a probe imaging volume **Vi** that is stationary relative to probe **Pi** and which defines the region of space that can be probed with probe **Pi**. Also, for each probe imaging volume **Vi** there is a coordinate system **CSi** which is fixed relative to probe **Pi** and which defines the coordinates of the points within the given probe imaging volume **Vi**. In the remaining text, it will be assumed without loss of generality that the coordinate systems **CSi** are Cartesian coordinate systems with axes **xi**, **yi**, **zi**. If alternative coordinate systems, such as cylindrical or spherical coordinate systems, are used, they can be transformed to Cartesian coordinate systems through coordinate transformations known to a person as having ordinary skill in the art.

As shown in **Figure 2**, each probe imaging volume **Vi** **22** is divided into a virtual spatial array of sampling discrete cells **24**. The minimum useful size of the discrete cells **24** is determined by the imaging resolution of corresponding probe **Pi** **26**. The dimension **Ns** of the spatial array **24** can be 0, 1, 2, 3, depending on the type of probe **Pi**. For example, spatial arrays related to simple point base probes (such as Raman probes with static laser excitation beams) are zero-dimensional (scalars), while those related to OCT probes are

three-dimensional (**3D**). Also, for a probe with any spatial array dimension, it is possible to record an additional time coordinate indicating the moment when the imaging measurement takes place at a specific discrete cell. Recording time coordinates can be useful in case when dynamic phenomena are observed in a sample. The spatial array **24** is mapped into a data array **28** in the memory storage device of the computer controller **20** such that data array **28** has at least a dimension **Ns + 1** where its **Ns** dimensions correspond to **Ns** dimensions of spatial array **24** while additional **>Ns** dimensions are related to imaging data acquired in a particular discrete cell of spatial array **24**. The number and size of additional **>Ns** dimensions correspond to the number of data types acquired in individual discrete cells.

For computational convenience, the informational content of data arrays **28** can be represented by a set of several data arrays with smaller dimensions and size. Such data array representations will be known to persons having ordinary skill in the art; so, hereinafter it will be assumed that the spatial array is mapped into a single data array with dimension **(Ns + 1)**.

For each set of coordinates **xi, yi, zi** in physical coordinate system **CSi**, there are unique coordinates of data array **28** along **Ns** dimensions and a vector of imaging data along the **(Ns + 1)-th** dimension where imaging data are acquired from the discrete spatial cell overlapping with **xi, yi, zi** coordinates. Using data from data array **28**, it is possible to assign values of imaging data to any point with coordinates **xi, yi, zi** using interpolation methods that will be known to those of ordinary skill in the art. Imaging data from a particular discrete cell of spatial array **24** is mapped to a corresponding element of data array **28** by controlling the position of the volume element being excited by the excitation optical signal of probe **Pi**.

For example, in case when detector of probe **Pi** is an array element whose dimension is equal to the dimension of spatial array **24** (as in case of white light imaging with a CCD camera), such excitation position control can be accomplished by simple switching on/of the excitation source such that all cells of spatial array **24** will be imaged and mapped to data array **28** simultaneously.

Another example is with scanning optical probes (such as OCT) where the optical probe **Pi** contains an optical scanner controlled by computer **20** and where the position of optical scanner mirrors dictate the position of the

excitation laser beam and thus the position of the excitation volume. To simplify further discussion, we will relate imaging data to physical coordinate system **CSI** and continuous coordinates **xi**, **yi**, **zi** assuming tacitly that all data and positions are recorded and processed in computer controller/processor **20** in the form of discrete data arrays.

During a probe registration process, coordinate transformation equations are established that relate coordinates **xi**, **yi**, **zi** of each probe imaging volume **Vi** to the corresponding Cartesian coordinates of all other probe imaging volumes **V1**, **V2**, ...**VN**. These coordinate transformation equations are recorded and stored by the computer **20**.

A few practical and non-limiting embodiments for such optical probe registration processes are described here below. The optical probe registration process can be performed only occasionally assuming the optical probes **P1**, **P2**, ..., **PN** remain fixed at their positions relative to each other.

Also, at least one designated probe **PV** (shown in **Figure 3**) of the probes **P1**, **P2**, ..., **PN** is configured to provide a user with the ability to mark sample volumes of interest **Vs1**, **Vs2**, ..., **VsM** observed on an image of the sample **18** created by the probe **PV**. As shown in **Figure 3**, a sample **18** which is positioned on sample holder **16** is imaged with the probe **PV 34** which is controlled by computer **20**. The image **38** of sample **18** is shown on a computer display **37** where a user can mark a set **39** of images of sample sections of interest **Vs1'**, **Vs2'**, ..., **VsM'** which correspond to a set **32** of sample sections of interest **Vs1**, **Vs2**, ..., **VsM** in physical space. The process of marking set **39** on display **37** can be done by using computer user interface techniques and user interface devices which will be known to those having ordinary skill in the art. An example of a user interface technique may include a graphical user interface (GUI) and examples of user interfaces devices may include a computer monitor, a touchscreen display, and a mobile device such as a phone or tablet.

The positions of **Vs1**, **Vs2**, ..., **VsM** are recorded by the computer **20** and they can be specified in physical coordinates **xi**, **yi**, **zi** related to designated probe **PV** or equivalently in the coordinates of the corresponding data array. For the purpose of this disclosure, the process of marking and recording sample sections of interest **Vs1**, **Vs2**, ..., **VsM** is called sampling volume

definition. A few practical and non-limiting embodiments for such sampling volume definition are described here below.

During the process of sampling volume definition it is also beneficial to mark and record a tissue landmark **35** as a fiducial marker for establishing spatial correlations between imaging data acquired by the multi-modal optical imaging system and other previous or subsequent imaging and analysis modalities such as MRI or histological analysis. Alternatively, a fiducial marker **36** can be located on sample holder **16** if the sample remains rigidly attached to sample holder **16** for the above mentioned previous or subsequent alternative imaging procedures.

In a sample analysis process, sample **18** is attached to sample holder **16** which in turn is attached to the motorized positioning assembly **14**. This allows the operator to position of sample **18** under various optical probes **P1**, **P2**, ..., **PN** to perform optical imaging. In case the spatial orientation of sample **18** relative to the optical probes **P1**, **P2**, ..., **PN** is fixed and only translations of sample **18** using motorized positioning assembly **14** are performed, the shape of sample **18** remains approximately the same during the sample movements. Since sample sections of interest **Vs1**, **Vs2**, ..., **VsM** are defined within the coordinate system **CSv**; and since the coordinates of the coordinate system **CSv** are correlated to coordinates of all other coordinate systems **CSi** through the probe registration process, it is possible to completely or partially overlap the sample sections of interest **Vs1**, **Vs2**, ..., **VsM** with volume **Vi** of each probe **Pi** and specify locations of these sections by using coordinates of the local coordinate system **CSi**. Thus, it is possible to spatially correlate imaging data obtained across the sections **Vs1**, **Vs2**, ..., **VsM** by using probe **Pi** to imaging data acquired across these sections by using any other probe **Pj**. These data can be recorded, stored and possibly analyzed by computer **20**.

The spatial data correlation process described above is performed under the assumption that sample **18** does not change its orientation relative to the optical probes. However, in case of a large soft tissue sample and sample tilting during the positioning under probes **P1**, **P2**, ..., **PN**, the sample shape and position may slightly change due to the force of gravity so consequently relative positions of two sample features within a sample section of interest **Vsj** may change when the sample section of interest **Vsj** is analyzed under a probe **Pi**.

If this relative change of feature position is larger than the required imaging resolution for the probe **P_i**, it is necessary to create correction coordinate transformation equations that relate initial relative positions of these two features to the final ones in order to spatially correlate optical data for these two features acquired with the probe **P_i** to the data acquired by other probes **P₁**, **P₂**,..., **P_N**. Creating such correlations of relative positions of tissue features when the tissue undergoes some kind of deformation will be well known to those of ordinary skill in the art. An example can be found in the reference Suwelack, Stefan, et al. "**Physics-based shape matching for intraoperative image guidance.**" *Medical physics* 41.11 (2014): 111901.

Motorized Positioning Assembly

The motorized positioning assembly **14** (the same as mechanism **102** in **Figure 9A** so the present discussion applies to mechanism **102**) may be comprised of any motorized positioning components known to persons having ordinary skill in the art. Such motorized positioning components may have actuators based, for example, on DC motors, stepper motors, or piezoelectric effect. Typically, the motorized positioning assembly **14** has three translation stages for moving a sample **18** along three perpendicular axes of travel (X,Y,Z). The traveling ranges of these translation stages should be long enough to allow positioning sample sections of interest **Vs1**, **Vs2**,...,**VsM** within probe volumes **V1**, **V2**,..., **VN**. Besides the translation stages, additional positioning degrees of freedom may be useful such as rotations and tilts. Tilt stages can be beneficial in case the optical probe response depends on the tilt sample orientation such as is the case with polarization sensitive optical coherence tomography.

For all motorized positioning components, keeping track of their positions is useful in order to perform optical probe registration processes and sampling volume definition as well as to track coordinates of sections of interest **Vs1**, **Vs2**,...,**VsM** of the sample being interrogated

This may be done using position encoders or sensors configured and positioned to detect typical stage positions (home and end positions) and to provide reference points for measuring position deviations. **Figure 4** shows an example of a motorized positioning assembly consisting of an X translation

stage **40**, a Y translation stage **44**, a Z translation stage **46**, a tilt stage **48** and, perpendicular to it, a second tilt stage **49**. A sample holder **16** is mounted on the top of the second tilt stage **49**. The whole system is fixed to a baseplate **42** for system robustness and rigidity.

5 **Optical Probe Registration**

In practical applications, the optical probe registration can be accomplished by using a registration object fixed to motorized positioning assembly **14**. As shown in **Figure 5**, the registration object **50** contains a geometric feature **52** which can be recognized on images of all probes **P1**,
10 **P2**,..., **PN**. The feature **52** resembles a cross; however any geometric feature with the characteristic size smaller than required optical probe registration precision and accuracy can be used for this purpose.

By using motorized positioning assembly **14**, feature **52** is brought within various probe imaging volumes **V1**, **V2**, ...**VN** and imaged. The relative physical
15 positions of feature **52** for recorded images can be easily measured by recording positioning coordinates of motorized positioning assembly **14** which are tracked by the computer **20**.

Also, the position of feature **52** within a certain probe imaging volume **Vi** relative to the origin of corresponding coordinate system **CSi** can be
20 determined by the image of feature **52** acquired with probe **Pi**. In this way, relative positions of origins of all coordinate systems **CSi** can be calculated. The type of coordinate systems **CSi** (Cartesian, cylindrical, spherical, etc.) and directions of their axes can be made the same for all probes **P1**, **P2**,..., **PN** and coincident with degrees of freedom of motorized positioning assembly **14**. As
25 noted above, the motorized positioning assembly **14** typically contains translational motorized stages moving along the three perpendicular directions, however in principle the device can have motorized stages with rotational stage replacing one of the translational stages. These directions can be used to define axes of Cartesian coordinate systems **CSi** related to probes **Pi** so that
30 the coordinate axis of the coordinate systems **CSi** are parallel to the perpendicular directions of the motorized translational stages.

In the disclosure herebelow, several non-limiting examples of probe registration modules are described in cases when all probes **P1**, **P2**,...,**PN** are either imaging probes that provide 2D (two dimensional) or 3D (three

dimensional) images or they are laser based probes where a sample is probed with a focused laser beam. A pinhole registration module is shown in **Figure 6A**. The pinhole registration module comprises a housing **62**, module cover **64** having a pinhole **65** and a photo-detector **66** placed below the pinhole **65**. The photo-detector **66** is sensitive at all laser wavelengths of the laser based optical probes.

The pinhole **65** and the photo-detector **66** are mounted in housing **62** such that the only light incident at the photo-detector **66** is the light that passes through the pinhole **65**. The position of the focused laser beam of the laser based optical probes can be located by scanning the pinhole in the vicinity of such optical probes using the motorized positioning assembly **14**. When the pinhole is at the laser focus, the signal from the photo-detector **66** will be maximal which can be easily detected. For 3D imaging probes (e.g. 3D scanners, OCT probes, confocal scanning microscopes), the position of the pinhole can be easily detected by making a 3D image of the pinhole **65** where pinhole geometry can be easily recognized due to its known shape and size. Similarly, for the optical probes generating 2D images it is possible to detect two coordinates of the pinhole **65** position in the plane defined by the 2D imaging. However, for determining the third coordinate for such a 2D probe, an additional position sensing detector is required.

In that case, two auxiliary laser beams **68** can be used as shown in **Figure 6B**. Referring again to the example registration module shown on **Figure 5**, two auxiliary laser beams **68** are aligned such they intersect within the probe volume **Vi** corresponding to the 2D probe. Then the motorized positioning assembly **14** can be used to place the pinhole **65** at the laser intersection point. That position can be detected either by observing the overlap of the laser spot reflections off the pinhole body on an image created by probe **Vi** or by detecting the maximum laser beam transmission through the pinhole **65** by using the photo-detector **66**. In all cases, the detected position of pinhole **65** can be recorded using the X, Y, Z coordinates of the motorized positioning assembly **14** and can be used as the origin of the local probe coordinate system.

In a second embodiment of a probe registration module design, the registration module contains a pattern that is photo-sensitive at the laser

wavelengths of laser based optical probes. When excited with such lasers, the pattern should emit a signal that can be detected with the corresponding optical probes (e.g. Raman or fluorescent signals) thus helping to localize a characteristic pattern point that can provide the origin location of the local coordinate system. Also, the pattern at the registration module should be recognizable when imaged with 2D and 3D imaging probes in order to provide well defined origins of their local coordinate systems. Similar to the pinhole module, in case of 2D imaging probes two auxiliary intersecting laser beams can be used to provide the third coordinate of the characteristic pattern point.

In a third embodiment of a probe registration module design, the registration module contains a photo-sensitive material whose appearance (e.g. color or shade) can be changed when exposed to the laser beams of the laser based optical probes. In this way, for laser based probes, a pattern can be written on the probe registration module at well-defined local coordinates providing simple registration. Such patterns can be subsequently detected by 2D and 3D imaging probes in the same way as described for the second registration module allowing their registration as well.

Sampling Volume Definition

For the sampling volume definition process, a **PV** probe is used as shown in **Figure 3**. For exemplary embodiments, we will consider two types of **PV** probes. The first type may be a 3D **PV** probe which can provide a 3D image of a sample or a portion of the sample volume. Referring to **Figure 3**, a portion **32** of sample **18** is imaged by probe **PV** and presented on form **39** on computer display **37**. Examples of 3D type **PV** probes include 3D scanners, optical coherence tomography probes, confocal microscopy probes, and non-linear optical probes. The 3D scanners can be of any type known to a person skilled in the art. Examples include 3D scanners based on time-of-flight, triangulation, structured light, modulated light, stereoscopic systems, and photometric systems. The stereoscopic 3D scanners are usually implemented by using two video cameras, slightly apart, looking at a sample. In our case, the stereoscopic effect is also possible to create by using a single camera that observes a sample at two different positions where sample is positioned by using the motorized positioning assembly. The 3D image of a sample provides

coordinates of the sample surface profile relative to the coordinate system with respect to the 3D scanner probe. Once a 3D image of tissue volume **39** is presented to a user, she/he can indicate sample sections of interest **Vs1'**, **Vs2'**, ..., **VsM'** on image **39**. The techniques of presenting 3D volumes on 2D and 3D computer displays as well as techniques of indicating sections of such 3D displayed images are known to a person having ordinary skill in the art.

Examples of such techniques include direct user input through a graphics user interface (GUI), voice input, or text input. Also, user selection can be facilitated by using predetermined algorithms and other computer inputs such as machine learning and artificial intelligence (AI) instructions. In case predetermined algorithms, machine learning, and AI algorithms perform the majority of the sampling volume definition process, the user interface can establish a simple form that includes only the steps such as inserting and removing a sample into the multi-modal imaging system and activating the imaging process.

The second type of **PV** probe is a 2D **PV** probe. An example of a 2D **PV** probe is a bright field microscope with a camera. In this case, the **PV** probe provides a 2D projection image of a 3D surface of a sample **122**. Since optical probes generally have limited penetration into tissue, the optical probe penetration depth can be used to define the 3rd dimension and complete volume definition. Referring again to **Figure 3**, image **39** is a 2D image in this case and a user makes choices of **Vs1'**, **Vs2'**, ..., **VsM'** which are 2D projections of physical sampling volumes **V1**, **V2**, ...**VN**. The 3rd dimension added to **Vs1'**, **Vs2'**, ..., **VsM'** that defines **V1**, **V2**, ...**VN** sample volumes of interest can be the longest penetration depth among probes **P1**, **P2**, ..., **PN**.

Figure 7 shows a schematic of a sample volume of interest in case of a 2D **PV** probe. Elements **16**, **20**, **34**, **37**, **38**, and **39** have the same meaning as specified for **Figure 3**. Element **70** in **Figure 7** is a cross section of a portion of a sample whose image **38** is presented on computer display **37**. The cross section plane is perpendicular to the imaging plane of 2D probe **PV 34**. The portion of the sample that is imaged is represented by line **74** on image **38**. If the sample is subsequently examined by a probe **PM** whose imaging penetration depth in the tissue is **d**, the sample volume of interest **72** is

represented in **Figure 7** as a layer whose thickness is **d** and whose 2D image **39** is presented on computer display **37**.

The remaining parameter required to completely define the contour of volume **72** in coordinate system **CSv** of probe **PV** is the distance of volume **72** from probe **PV**, that is coordinate **Z** as shown in **Figure 7**. A schematic of an exemplary embodiment to determine the **Z** coordinate of volume **72** is shown in **Figures 8A** and **8B**. A pair of auxiliary lasers **80** and **82** have fixed positions above the sample holder in a way that their respective laser beams **81** and **83** intersect within the probe imaging volume **Vv** of probe **PV** in case of unoccupied volume **Vv**.

If a sample is present within volume **Vv**, the laser intersection point will not generally coincide with the surface of the sample as shown in **Figure 8A** where the sample is represented by its cross section **70**. The reflections of two laser beams can be visible as two dots **84** and **85** at the image of sample **38** on computer display **37**. If the sample is moved perpendicular to the imaging 2D plane of probe **PV** by using the motorized positioning assembly described previously, at certain point the surface of the sample will coincide with the intersection point of two lasers as shown in **Figure 8B**. This position can be recognized on sample image **38** when images of reflected laser beams merge into a single dot **86**. Since the position of the intersection point between two laser beams is fixed in coordinate system **CSv**, the sample position shown in **Figure 8B** uniquely determines the position of the sample within volume **Vv**.

Another way of determining the vertical position of a sample in coordinate system **CSv** is by using a 2D optical probe **Pv** with a small depth of field and a known focal plane position. By moving a sample section of interest along the vertical coordinate by using the motorized positioning assembly **14** (or mechanism **102** as shown in **Figure 9A**), it is possible to bring the image of the sample section of interest into sharp focus on the computer display indicating the position of the sample section of interest at the focal plane of probe **PV** thus determining the **Z** coordinate of the sample section of interest within the coordinate system **CSv**.

Optical Probe Description

After the position of sample **18** is registered and sample sections of interest **Vs1, Vs2,...,VsN** are chosen, data acquisition can begin. The data acquisition procedure will depend on the type of a corresponding optical probe being used. For the present optical biopsy system, any type of bio-imaging
5 probe and any possible mode of operation of such a probe known to a person skilled in the art may be used. These include optical probe systems previously disclosed in academic and patent literature, sold by a commercial vendor, or developed in-house.

Non-limiting examples include probes based on the following techniques.

10 (a) **Spontaneous Raman scattering**

In this case, optical signals originate from inelastic Raman scattering of an excitation laser beam off a sample. The spectrum of the Raman signal depends on the type of chemical bonds within the sample. More details about the nature of the signal and Raman probes can be found in references: Latka *et al.*, '**Fiber optic probes for linear and nonlinear Raman applications –**
15 **Current trends and future development,**' *Laser Photonics Rev.* 7, No. 5, 698–731 (2013).

(b) **Stimulated Raman scattering (SRS)**

20 SRS carries similar information as the spontaneous Raman scattering however the optical interaction is amplified through coherent amplification. More details about the nature of the signal and SRS probes can be found in reference Ji *et al.*, '**Rapid, Label-Free Detection of Brain Tumors with Stimulated Raman Scattering Microscopy,**' *Sci Transl Med* 5, 201ra119
25 (2013).

(c) **Coherent anti-Stokes Raman scattering (CARS)**

CARS is another variant of coherent Raman scattering. More details about the nature of the signal and CARS probes can be found in the reference: Latka *et al.*, '**Fiber optic probes for linear and nonlinear Raman applications –**
30 **Current trends and future development,**' *Laser Photonics Rev.* 7, No. 5, 698–731 (2013).

(e) **Optical Coherent Tomography (OCT)**

OCT is technique analogue to ultrasound in which 3D image of the object can be generated from time-of-flight information. OCT uses light wave instead of sound wave as in ultrasound which provides images with a much
5 higher resolution. More information on OCT can be found in the reference: Jafri *et al.*, '**Optical coherence tomography guided neurosurgical procedures in small rodents**,' *Journal of Neuroscience Methods* 176 (2009) 85–95.

(f) **Polarization Sensitive Optical Coherent Tomography (PS-OCT)**

10 PS-OCT is a functional variant of OCT in which the polarization of the sample can also be imaged. This enables contrast like tissue organization to be imaged. More information on PS-OCT can be found in the reference: Ding *et al.*, '**Technology developments and biomedical applications of polarization-sensitive optical coherence tomography**' *Front. Optoelectron.*
15 2015, 8 (2): 119-121.

(g) **Hyperspectral imaging (HSI)**

HSI is a hybrid modality that combines imaging and spectroscopy. By collecting spectral information at each pixel of a two-dimensional (2-D) detector
20 array, hyperspectral imaging (HSI) generates a three-dimensional (3-D) dataset of spatial and spectral information. More information on HIS can be found in the reference: Lu *et al.*, '**Medical hyperspectral imaging: a review**,' *Journal of Biomedical Optics* 19(1), 010901 (2004).

25 (h) **Fluorescence imaging**

In vivo fluorescence imaging uses a sensitive camera to detect fluorescence emission from fluorophores in whole-body living small animals. More info on fluorescence imaging can be found in the reference: Yao *et al.*, '**Fluorescence imaging in vivo: recent advances**,' *Current Opinion in*
30 *Biotechnology* 2007, 18:17–25.

(i) **Fluorescence Lifetime Imaging Microscopy (FLIM)**

FLIM is an imaging technique for producing an image based on the differences in the exponential decay rate of the fluorescence from a fluorescent sample. The lifetime of the fluorophore signal, rather than its intensity, is used to create the image in FLIM. This has the advantage of minimizing the effect of photon scattering in thick layers of sample. More information on FLIM can be found in the reference: Becker., '**Fluorescence lifetime imaging techniques and applications**,' Journal of Microscopy 2012, May 24.

(j) **Second Harmonic Imaging Microscopy (SHIM)**

Second harmonic imaging microscopy is based on a nonlinear optical effect known as second-harmonic generation (SHG). More details about the nature of the signal and probes for second harmonic imaging microscopy can be found in Campagnola, Paul J., and Leslie M. Loew. "**Second-harmonic imaging microscopy for visualizing biomolecular arrays in cells, tissues and organisms**." Nature biotechnology 21.11 (2003): 1356-1360, and relevant references referred to therein.

(k) **Third Harmonic Imaging Microscopy**

Third harmonic imaging microscopy is based on a nonlinear optical effect known as third-harmonic generation (THG). More details about the nature of the signal and probes for third harmonic imaging microscopy can be found in Kuzmin, N. V., et al. "**Third harmonic generation imaging for fast, label-free pathology of human brain tumors**." Biomedical Optics Express 7.5 (2016): 1889-1904, and references referred to therein.

An example of full embodiment

A layered structure of an example of an embodiment of a multi-modal optical imaging system for tissue analysis constructed in accordance with the present disclosure is presented in **Figures 9A, 9B, 9C**. In **Figure 9A**, the main opto-mechanical components are indicated. For fiber coupled optical probes described in the present disclosure, the term "distal" refers to the end of the

optical fiber closest to a sample **122** while the term “proximal” refers to the opposite end of the optical fiber.

A sample **122** is placed on a sample holder **120** which is attached to a motorized positioning assembly **102** which is the same as assembly **14**
5 described previously in relation to **Figure 4**. For structural integrity and robustness, motorized positioning assembly **102** is fixed on the top of a sample system base-plate **100** which can be made of a stainless steel or aluminum and is typically 10-15 mm thick. Motorized positioning assembly **102** is controlled through a motorized stage driver **104** that provides necessary electrical driving
10 signals for the motorized stage actuators as well as collects electrical signals from the assembly sensors (such as encoders) that inform about the state of the assembly. Electrical power and control signals for motorized stage driver **104** are provided through a main control system **106** that includes electrical power supplies **108** and control computer **110** that has the same role as
15 computer **20** described previously in relation to **Figures 1, 2, 3, 5, 7, 8A, and 8B**.

A user interacts with the computer **110** through a computer display **118**, keyboard **112**, mouse **116**, and potentially by using any other computer interacting peripheral device available on the market. Optical probes used for
20 sample analysis are attached to a mechanical frame **152** that is fixed to sample system base-plate **100**. Simple brackets used to attach the optical probes to mechanical frame **152** are not shown in **Figure 9A** for drawing simplicity.

An optical coherence tomography (OCT) optical probe system can be any OCT system mentioned previously and in this exemplary embodiment
25 includes an OCT control system **126**, optical scanner **124**, and an optical scanner driver **128**. OCT control system **126** contains typical OCT system components described in the previously disclosed references, such as a laser excitation source, an interferometer, a reference arm, optical detectors, electrical circuitry needed for the operation, as well as electrical and optical
30 cables connecting individual components. An optical fiber acting as an OCT sample arm connects OCT control system **126** to optical scanner **124** that can scan the OCT sample laser beam across sample **122**. The electrical power and control computer signals are provided through control system **106**.

A coupled Raman probe **140** is used to excite sample **122** using a fiber coupled narrow line-width laser source **142** and further collects and transfers the corresponding Raman signal to a spectrometer **144**. The electrical power and control computer signals for laser source **142** and spectrometer **144** are provided through control system **106**.

In addition, a wide-field microscope **132** and narrow-field microscope **130** are installed as convenient probes for quick sample examination as well as for sampling volume definition. Microscope signals are recorded by integrated cameras that are powered and controlled by the control system **106**.

Illumination sources **134** and **136** provide illumination for the wide-field and narrow-field microscopes **130** and **132** and they are controlled through an illumination controller **138** which is powered and controlled with the control system **106**. Guide lasers **146** and **148** are fixed in a geometry such that their laser beams cross approximately at the center of fields of view of the narrow-field and wide field microscopes. Lasers **146** and **148** are controlled through a guide laser driver **150** which is powered and controlled with the control system **106** as well. The function of guide lasers **146** and **148** was described in relation to **Figures 6A, 8A, 8B**.

To facilitate deployment of the system presented in **Figure 9A** at the place of interest (e.g. a surgical operating room), this system can be installed within a mobile unit described in **Figures 9B** and **9C**.

As shown in **Figure 9B**, the electrical components and the optical elements at the distal sides of the fiber coupled optical probes can be enclosed in a cabinet **200** that is attached at the top of a base plate **208**. Base plate **208** is mounted on casters **210, 212, 216**, and a 4th caster that is not visible on in the figure. A break **218** provides a means to lock the casters in place and fix the system within a place of interest for safety and for reducing mechanical disturbances during optical signal acquisitions. Additional elements for improving mechanical stability are vibrational isolators **202, 204, 206** that fix the base plate **100** to cabinet **200**. More vibrational isolators could be present and not visible in the figure. For mounting simplicity, some smaller electrical components and optical elements on the distal fiber ends can be placed on base plate **100** as well. For drawing simplicity, electrical and optical cables connecting various elements are not shown in **Figure 9B**.

As shown in **Figure 9C**, an additional enclosure **300** can be installed on the top of cabinet **200** which encloses the optical probe system mounted on base plate **100**. Enclosure **300** protects the internal optics from external disturbances, protects a user from exposure to optical probe laser beams, creates a controlled environment for sample data acquisition, including a stable thermal environment and creates light-tight space within the enclosure **300** suitable for optical probe acquisitions of small signals that can be otherwise overwhelmed by external ambient light.

The enclosure **300** has a door **314** which can be used as an entrance point for inserting in and removing sample **18** out of sample holder **120**. A monitor stand **310** provides a fixture for computer display **118**. A front console **320** provides a mounting space for an emergency stop button **322**, power button **324**, as well as computer peripheral connections such as USB ports or video connections (DVI, HDMI, or VGA).

In case of very sensitive optical probes or more dangerous optical probe excitation laser beams, an additional enclosure within enclosure **200** can be installed.

Figure 10 presents the basic work-flow for the system described in relation to **Figure 9C**. Since optical probes are rigidly mounted on a common frame, optical probe registration can be done only occasionally. During a daily procedure, the system is initialized and started typically by pressing power button **324**. The control computer **110** functions described earlier can be incorporated in a single control software program with a suitable user interface. After a user fixes a sample **122** onto sample holder **120**, he/she can enter the sample information within the control software where that information will be linked to acquired data. Subsequently, motorized positioning assembly **102** brings the sample underneath the designated probes where sampling volume definition is performed. In this case, these probes are narrow-field and wide-field microscopes.

After the user chooses the sampling regions of interest, motorized positioning assembly **102** moves sample **122** underneath OCT and/or (depending on the user choice) Raman probes where data acquisition is performed. The user then reviews the data, and based on the feedback may decide to terminate the session by unloading the sample; or to define and

analyze new sampling regions of interest; or to load another sample. In case of an emergency, the user has an option to terminate the session at any time by pressing emergency stop button **322** in which case the current acquired data is saved and the sample **122** gets ejected.

5 Referring to **Figure 10**, the workflow initiates at the start with an initialize system **1000** step. Next a sample **122** is loaded at step **1002**. Patient and sample information can also be entered into the system at step **1014**. Next, the area of interest in the system is aligned with respect to the white light camera at step **1004**.

10 Once the sample **122** is aligned, the user can setup for a Raman scan (step **1006**) and OCT scan (step **1016**). Thereafter, the sample **122** is scanned at step **1008**. After completion of the scan, the data can be reviewed by the user, and / or saved for export (step **1010**).

15 Once the scan is completed (step **1010**), the user may select to continue scanning where the workflow will revert back to one of the previous steps (i.e., steps **1002**, **1004**, **1006** or **1016**). Alternatively, if all scanning is completed, the user may unload the sample (step **1018**) and shut down the system (step **1026**).

20 During any operation steps of the system (i.e., steps **1000** to **1018**, also illustrated by box **1026**), an emergency stop action can take place to interrupt this process. If an emergency stop is required, the emergency stop button **322** is pressed (step **1020**). Thereafter, the system is interrupted and all action is stopped (step **1022**). The user is also presented with an option to save and / or export the data (step **1024**). If the emergency stop is initiated, the system will
25 also terminate with the system being shut down (step **1026**).

Figure 11A is the detailed start and initialization steps of the user workflow as presented in **Figure 10**, in particular, step **1000**. As seen in **Figure 11A**, the process starts at step **1100**. The computer **20** (**Figure 1**) or **110** (**Figure 9B**) is turned on (step **1102**) and the service is initiated (step **1104**).
30 Thereafter, the service turns on the power distribution unit (**1106**) to power on the various system modules. The power distribution unit will power on the OCT module (step **1108**), the Raman module (step **1110**), the cooling sequence (step **1114**) and turn on LED illumination (step **1114**). Subsequently, the sample stage is moved to the home configuration orientation (step **1116**).

Figure 11B is the detailed Raman setup steps of the user workflow as presented in **Figure 10**, in particular step **1006**. As seen in **Figure 11B**, the process starts at step **1120**. The sample is placed underneath the white light camera (step **1112**). Next, the user selects the points for the Raman scan
 5 based on the image presented on the white light camera at step **1124**. After the sample is placed under the white light camera, the user can select the point to do the Raman measurement and select the scan parameters for the points selected in step **1116**.

Once steps **1124** or **1126** is completed, the user is presented with a
 10 choice (step **1128**) of either proceeding with an OCT scan setup (step **1130**) for the same sample or continue with sample acquisition (step **1132**). Both of these steps will be further elaborated in Figures **11C**, **11D** and **11E**.

Figure 11C is an OCT scan setup and preview steps of the system user workflow as presented in **Figure 10** as step **1016** and step **1130** in **Figure 11B**.
 15 As shown in **Figure 11C**, the process initiates at step **1140**. Thereafter, a snapshot of the sample is captured by the white light camera and saved within the system in step **1142**. Next, the sample is moved underneath the OCT scanner (step **1144**) where the scan parameters and the area / line of interest can be selected (step **1146**). Next, the system starts a 2D continuous
 20 acquisition (step **1148**).

During the acquisition stage (step **1148**), the user can view the acquired data in real-time and can select one or more options as outlined in block **1162**. These options include, saving or exporting the acquisition (step **1150**), adjusting the scan parameters as well as moving the sample height and tilt (step **1152**),
 25 and / or selecting another scan position (step **1154**). Once the options are completed (step **1156**), the workflow proceed to a 3D OCT setup (step **1158**) which is further elaborated in **Figure 11D** or a Raman setup (step **1160**) which is further explained in **Figure 11B**.

Figure 11D discloses the 3D OCT scan setup steps of the system user workflow as presented in as step **1016** in **Figure 10** and step **1158** in **Figure**
 30 **11C**. As seen in **Figure 11D**, the process initiates at step **1200**. Thereafter, a snapshot of the sample is captured by the white light camera and saved within the system in step **1202**. Next, the sample is moved underneath the OCT

scanner (step **1204**). Thereafter, the system selects the 3D scan parameters (step **1208**) and / or the 3D scan area on the white light image (step **1206**).

Once the parameters are selected (step **1210**), the system further proceeds to start a sample acquisition (step **1212**) which is further explained in **Figure 11E**, conduct a 2D OCT setup (step **1214**) which is further explained in **Figure 11C** or conduct a Raman setup (step **1216**) which is further explained in **Figure 11B**.

Figure 11E discloses data acquisition steps of the system user workflow as presented in **Figures 10** (step **1008** and step **1010**), **11B** (step **1132**), and **11D** (step **1212**). As seen in **Figure 11E**, the process initiates at step **1220**. The sample is moved underneath the OCT scanner in step **1226**. An OCT image is subsequently acquired in step **1228**. The image is then displayed on a Review page of the biopsy system user interface in step **1230**.

Next, the sample is moved with the selected points of interest underneath the Raman probe (step **1232**). Thereafter, a Raman spectrum graph is acquired (step **1234**). The Raman spectrum is displayed in the biopsy system software for review (step **1236**). Once one point has been scanned, the system moves the sample to an the next selected point for Raman scanning (step **1240**). This process repeats itself (i.e., steps **1232**, **1234**, **1236** and **1240**) until all the selected points are scanned.

The next step is to save and / or export the data (step **1242**). Alternatively, the image display on the OCT user interface (step **1230**) may be directly saved (step **1242**). Once the saving is completed, the acquisition is phase is completed (step **1244**).

In further embodiments of **Figure 11E**, once the process is initiated (step **1220**), there is an option to remove the OCT background (step **1222**) where artifacts may be removed from the background of the OCT image. Once this is completed, the OCT background is captured (step **1224**) and is subtracted from the acquired OCT image of the sample which will result in a cleaner image. After the OCT background is captured (step **1224**), the process reverts back to the original placement of the OCT sample (step **1226**).

The multi-modal imaging system disclosed herein is ideally contemplated for use in pathology labs, however, a person skilled in the art may apply this system to other similar uses. For example, beyond applications in

pathology, this device may also be used in research and development activities for investigating response of various tissues to different types of optical probes and correlating such data from various types of optical probes.

5 In addition to combining OCT modules and Raman modules in the multi-modal imaging system disclosed herein, a person skilled in the art may contemplate other imaging modalities that can be added into the biopsy system. For example, a person skilled in the art may envision that a 3D optical scanner or probe may be incorporated into the existing multi-modal imaging system. A 3D scanner will provide a surface contour scan of the tissue sample. Surface
10 contours will provide an actual 3D image of the sample under white light conditions and provide the distance of the probe **Pi** to the sample which will assist in the alignment of the probe **Pi** during the alignment process. Furthermore, the surface contour can be used to segment out the tissue surface in the OCT image, as well as the sample area within the camera image. Mapping a pixel location on a 2D display to the 3D sample surface requires
15 knowledge of the height of the sample at the pixel location, so a 3D surface profile aids in providing accurate registration between user interface and sample coordinates. In addition, having a 3D scan of a sample allows for sample correlation between multiple scanning sessions performed on the same sample. While the teachings described herein are in conjunction with various
20 embodiments for illustrative purposes, it is not intended that these teachings be limited to such embodiments. On the contrary, the teachings described and illustrated herein encompass various alternatives, modifications, and equivalents, without departing from the embodiments, the general scope of which is defined in the appended claims.
25

Except to the extent necessary or inherent in the processes themselves, no particular order to steps or stages of methods or processes described in this disclosure is intended or implied. In many cases the order of process steps may be varied without changing the purpose, effect, or import of the methods
30 described.

WHAT IS CLAIMED IS:

1. A modular system for organic sample analysis of organic samples, comprising:
 - a sample stage including a support platform and a motorized positioning mechanism mounted on said support platform, and a sample holder mounted on said motorized positioning mechanism upon which a sample is placed;
 - a probe support rack mounted on said support platform;
 - two or more bio-imaging probes mounted on said probe support with said bio-imaging probes arranged in a pre-defined geometry with respect to each other and at least one bio-imaging probe having a field of view independent of all other bio-imaging probes; and
 - a computer controller connected to said motorized positioning mechanism and said two or more bio-imaging probes, said computer controller being programmed with instructions for instructing said motorized positioning mechanism to move said sample holder having the sample located thereon to positions in the field of view of each bio-imaging probe where the sample can be analyzed individually by each of said bio-imaging probes, said computer controller including a storage means for storing imaging data from each of said bio-imaging probe, and said computer controller being programmed with instructions for spatially correlating imaging data of a selected volume of interest with the imaging data obtained from at least one other bio-imaging probe and storing said spatially correlated imaging data in said storage means.
2. The modular system according to claim 1 wherein said computer controller includes a user interface to facilitate a user obtaining, using a designated bio-imaging probe, imaging data of the sample to be visually displayed, and used by an input selection means for selecting a volume of interest of the sample to be imaged by said at least one additional bio-imaging probe.
3. The modular system according to claim 2 wherein said user interface is configured to allow the user to select a single volume of a tissue sample to be

probed by the two or more bio-imaging probes, or to allow the user to select multiple volumes independent of each other to be probed by the two or more bio-imaging probes.

4. The modular system according to any one of claims 2 and 3 wherein said computer controller includes pre-defined algorithms that facilitate sample analysis by executing pre-determined sequence of selections of sample volumes of interest, sample positioning steps, data acquisitions by the bio-imaging probes, and data analysis.

5. The modular system according to any one of claims 2 to 4 wherein said computer controller includes machine learning algorithms based on information about the one or a plurality of samples previously acquired.

6. The modular system according to any one of claims 4 to 5 wherein said computer controller is connected to a distant computer system and where said distant computer system contains a user interface and where said user interface can be operated by a distant user who can control the computer controller within the modular system that controls the sample analysis.

7. The modular system according to any one of claims 2 to 6 wherein said computer controller is programmed with instructions to assign imaging data acquired at a certain point in the field of view of a selected bio-imaging probe to visually display imaging data of the designated probe.

8. The modular system according to any one of claims 1 to 7 wherein at least one of said bio-imaging probes is a 3D scanner, and wherein said computer controller is programmed with instructions to display a 3D profile on a two dimensional computer display.

9. The modular system according to any one of claims 1 to 7 wherein at least one of said bio-imaging probes is a 3D scanner, and wherein said computer controller is programmed with instructions to display a 3D profile on a three dimensional computer display.

10. The modular system according to any one of claims 8 and 9 wherein said 3D profile is a surface profile of said sample and where said surface profile of said sample is stored by said computer controller as a set of coordinates relative to said 3D scanner.

11. The modular system according to any one of claims 8, 9, and 10 wherein operation of said 3D scanner is based on one of these systems: time-of-flight, triangulation, structured light, modulated light, stereoscopic systems, and photometric systems.

12. The modular system according to claim 3 wherein said designated bio-imaging probe is one of a visible light camera and an infrared camera.

13. The modular system according to claim 12 including a pair of lasers fixed at a predetermined geometry with each other and said designated probe such that two laser beams emitted by the pair of lasers intersect within the field of view of the designated bio-imaging probe, and wherein said user interface is configured to receive input from the user to activate the motorized positioning mechanism to move it and display movement of the sample and to stop movement of the sample when the two laser beams intersect at a location of interest in the sample, said computer controller being programmed with instructions to calculate, based on coordinates of the location of interest at a point where the two laser beams intersect, a distance to move the motorized positioning system to place the location of interest in a predetermined location within the field of view of each bio-imaging probe in order to acquire imaging data of the location of interest by each bio-imaging probe and to spatially correlate the imaging data acquired by each bio-imaging probe.

14. The modular system according to any one of claims 1 to 13 wherein the two or more bio-imaging probes are optical probes.

15. The modular system according to claim 14 wherein said two or more optical probes are any one of a spontaneous Raman probe, an optical

coherence tomography (OCT) probe, a polarization sensitive optical coherence tomography (PS-OCT) probe, fluorescent probe, stimulated Raman scattering (SRS) probe, short wavelength infrared (SWIR) camera, light microscope, coherent anti-Stokes Raman scattering (CARS) probe, hyperspectral imaging (HIS) probe, fluorescence lifetime imaging microscopy (FLIM) probe, diffuse reflectance probe, second harmonic imaging probe, and third harmonic imaging probe.

16. The modular system according to any one of claims 14 to 15 wherein said optical probes and positioning mechanism are enclosed in an enclosure.

17. The modular system according to claim 16 wherein said enclosure is temperature controlled.

18. The modular system according to any one of claims 1 to 17 wherein said support platform is mounted on vibration isolators.

19. The modular system according to any one of claims 1 to 18 wherein each of said bio-imaging probes has a field of view independent of all other bio-imaging probes.

20. The modular system according to any one of claims 1 to 19 wherein said organic sample is human tissue, animal tissue, plant tissue, cells, and food samples.

21. The modular system according to any one of claims 16 and 17 wherein said enclosure is a light tight enclosure.

22. The modular system according to any one of claims 16, 17 or 21 including a ventilation system to circulate fresh air into the enclosure.

23. The modular system according to claim 2, wherein at least one of the bio-imaging probes is a white light microscope providing an initial image of at least a portion of the volume of interest, and wherein said user interface is

configured to be used by said input selection means for marking, on an image on a visual display, a portion of the sample surface to be probed with one or more bio-imaging probes.

24. The modular system according to any one of claims 1 to 23 wherein one of said bio-imaging probes comprises an excitation laser, and including a photosensitive material affixed to the sample stage wherein illumination by said excitation laser leaves a mark on said photosensitive material, and wherein said computer controller is programmed with instructions to register the mark on the photosensitive material with at least one other bio-imaging probe.

25. The modular system according to claim 14 including a pinhole registration device including a housing attached to the sample stage, said housing containing a photodiode and a pinhole aperture in a top surface of the housing located above the photodiode, and wherein said computer controller is programmed with instructions to image said pinhole with at least two of said optical probes by moving the pinhole registration device within fields of view of said two optical probes and wherein the computer controller is programmed with instructions to determine positions of said pinhole relative to said optical probes by analyzing images of the pinhole acquired by said optical probes.

26. The modular system according to claim 25 wherein at least one of the optical probes incorporates an excitation laser and where the image of said pinhole is produced by said excitation laser by moving the pinhole registration device across an excitation laser beam and detecting a maximum photo-diode signal, and storing a location of the pinhole registration device at the location of the detected maximum photo-diode signal.

27. The modular system according to any one of claims 1 to 26 where said sample is a biopsy tissue sample of a patient, and wherein said computer controller is programmed with instructions to store previously acquired data related to said biopsy tissue sample comprising patient identification data, spatial coordinates of a biopsy sample acquisition point in the anatomy of the patient, and time of the biopsy sample acquisition.

28. A method under computer control of organic sample analysis, comprising,

a) in any order:

i) affixing two or more bio-imaging probes to a probe support rack which is mounted on a support platform, said two or more bio-imaging probes being mounted in a pre-defined geometry with respect to each other and at least one bio-imaging probe having a field of view independent of all other bio-imaging probes,

ii) placing an organic sample on a sample holder, the sample holder being mounted on a motorized positioning mechanism; and

b) initiating a computer controller connected to said motorized positioning mechanism and the two or more bio-imaging probes for instructing the motorized positioning mechanism to move the sample holder having the sample located thereon to positions in the field of view of selected bio-imaging probes where the sample is analyzed individually by each of the bio-imaging probes, storing imaging data from each of the bio-imaging probes, and spatially correlating said imaging data of a selected volume of interest with the imaging data obtained from at least one other bio-imaging probe and storing said spatially correlated imaging data in a storage means.

29. The method according to claim 28 including using a designated bio-imaging probe to obtain imaging data of the sample and visually displaying an image of the sample from said imaging data, and from said image, selecting a volume of interest of the sample to be imaged by said at least one additional bio-imaging probe.

30. The method according to claim 29 wherein a user interface is used to select the designated bio-imaging probe among the bio-imaging probes, and wherein an input selection means is used for selecting the volume of interest of the sample to be imaged by said at least one additional bio-imaging probe.

31. The method according to claim 29 or 30 including assigning imaging data acquired at a certain point in the field of view of a selected bio-imaging probe to the visually displayed image data of the designated probe.

32. The method according to claim 30 wherein said user interface is configured to allow a user to select a single volume of a tissue sample to be probed by the two or more bio-imaging probes, or to allow the user to select multiple volumes independent of each other to be probed by the two or more bio-imaging probes.

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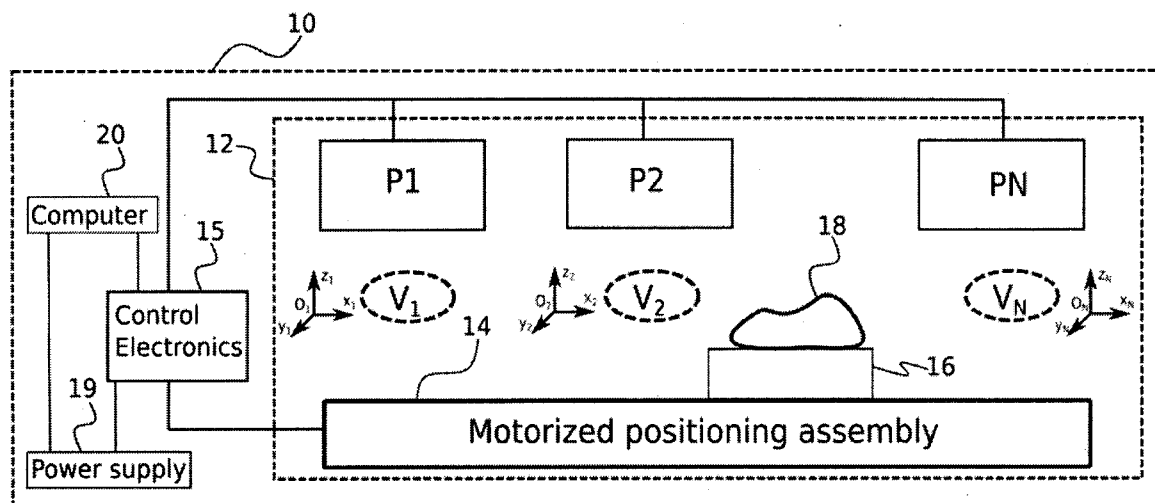


FIGURE 1

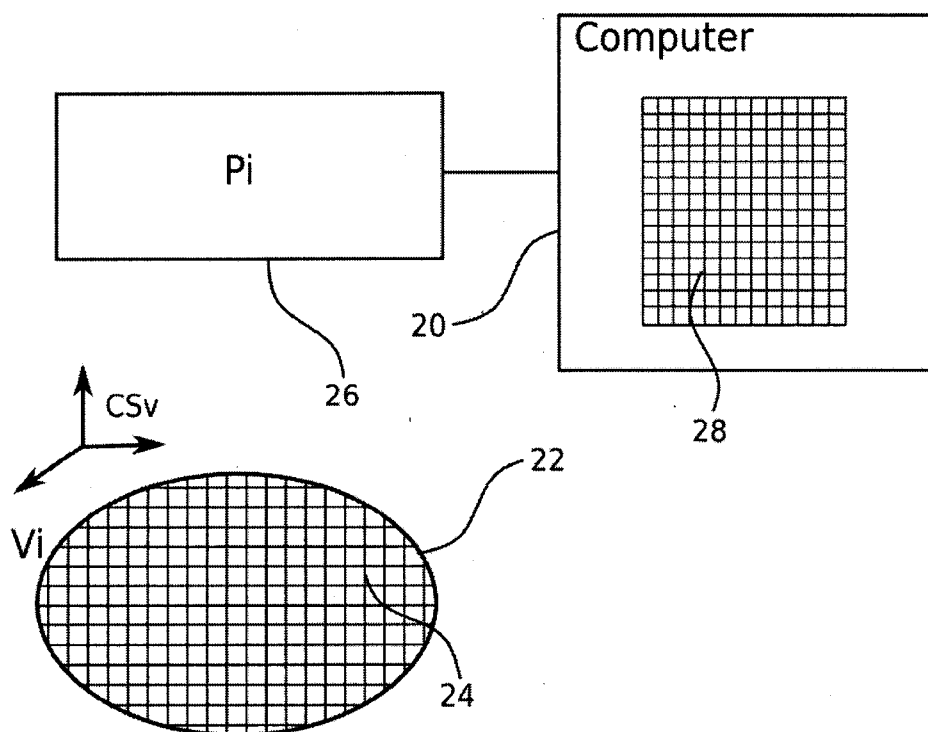


FIGURE 2

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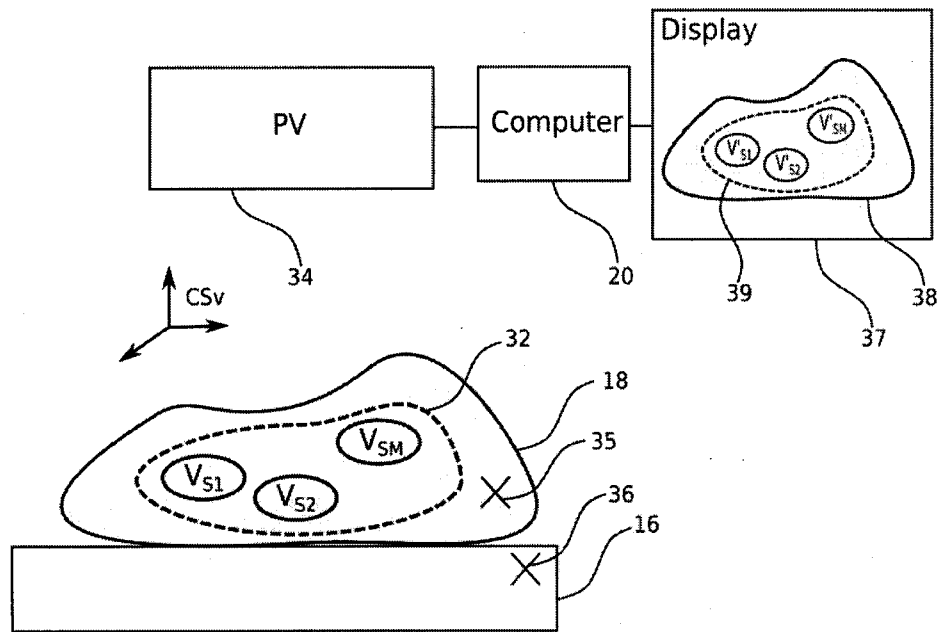


FIGURE 3

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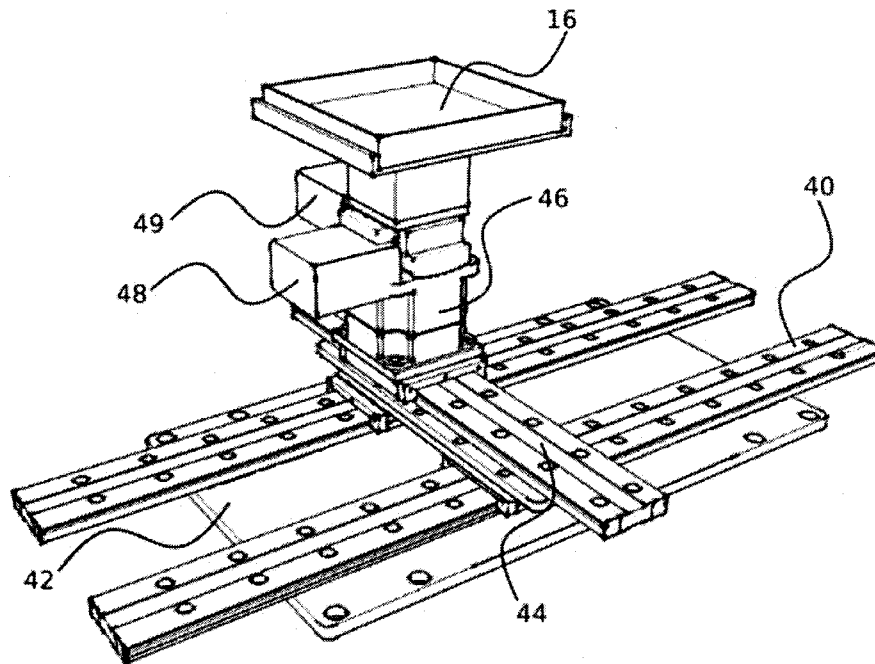


FIGURE 4

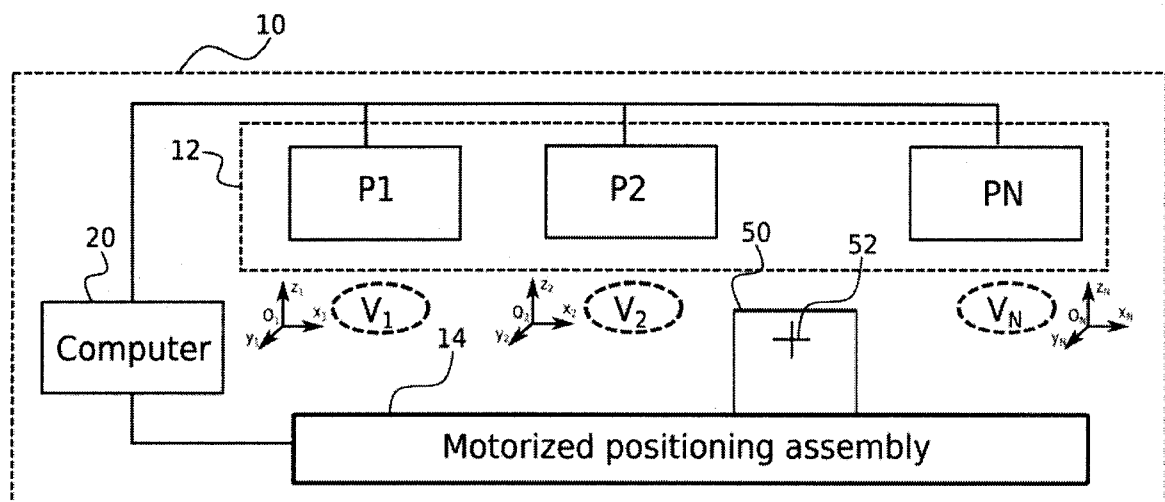


FIGURE 5

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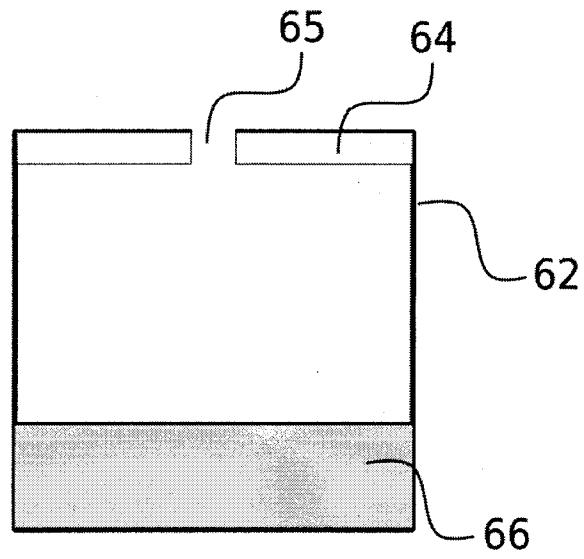


FIGURE 6A

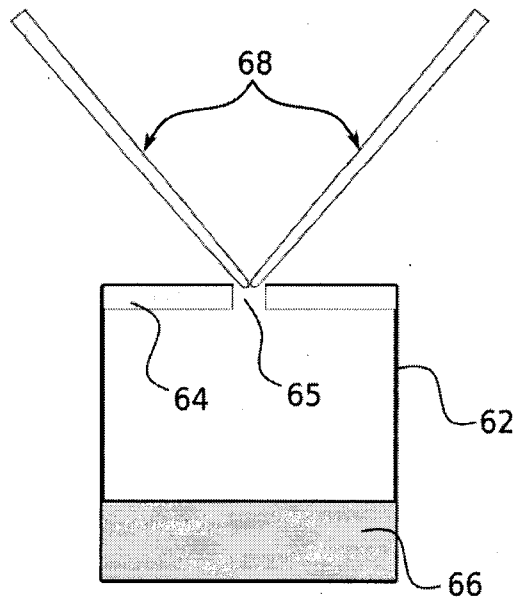


FIGURE 6B

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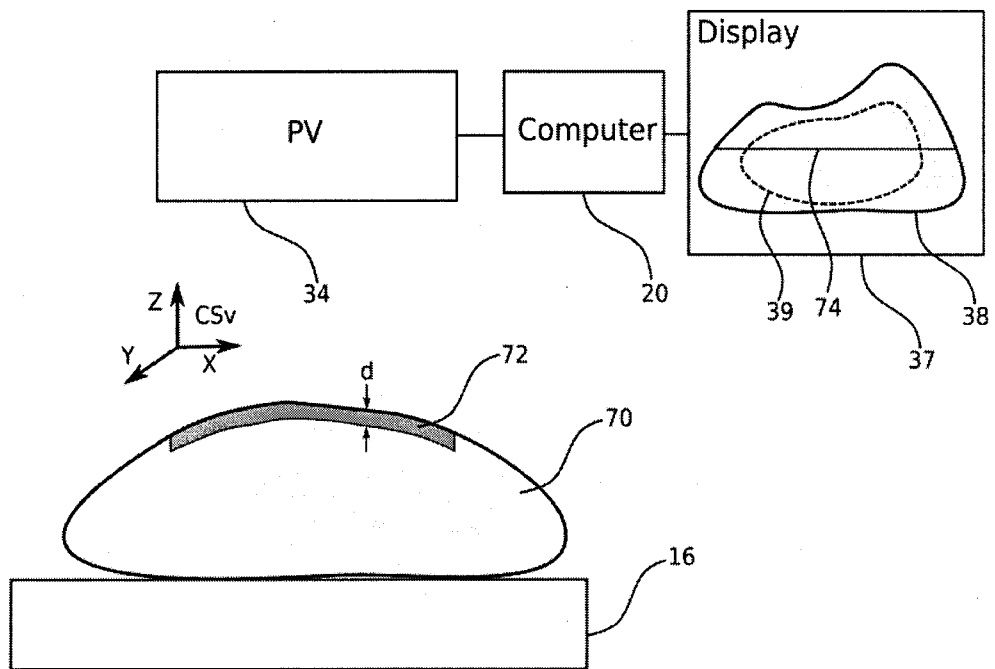


FIGURE 7

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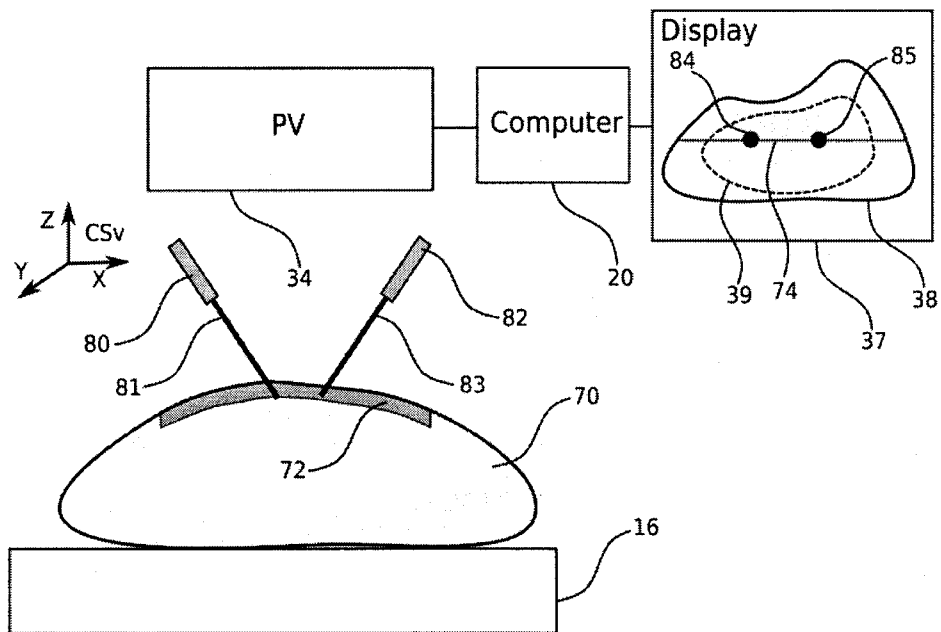


FIGURE 8A

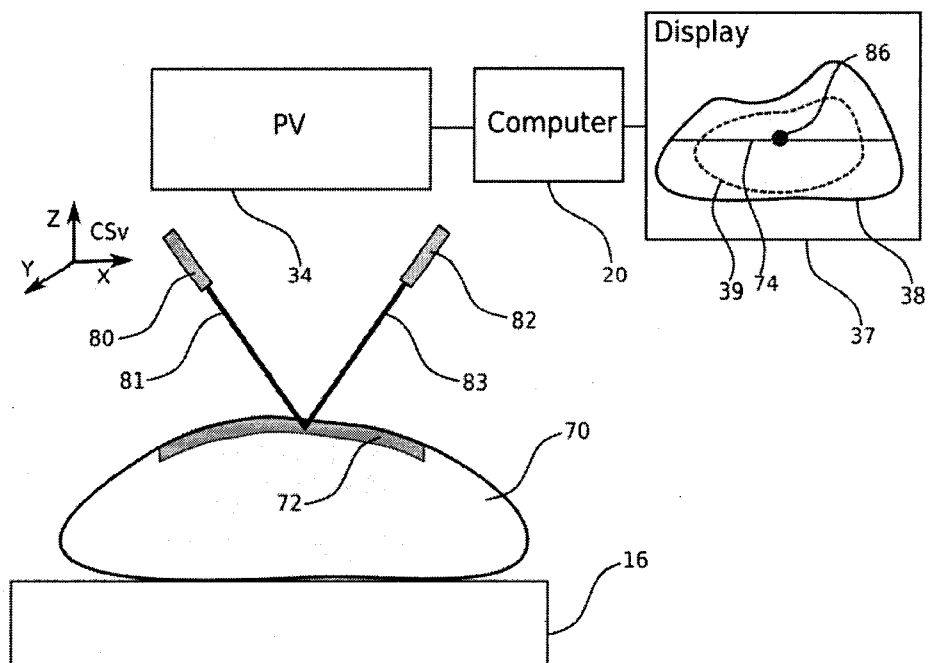


FIGURE 8B

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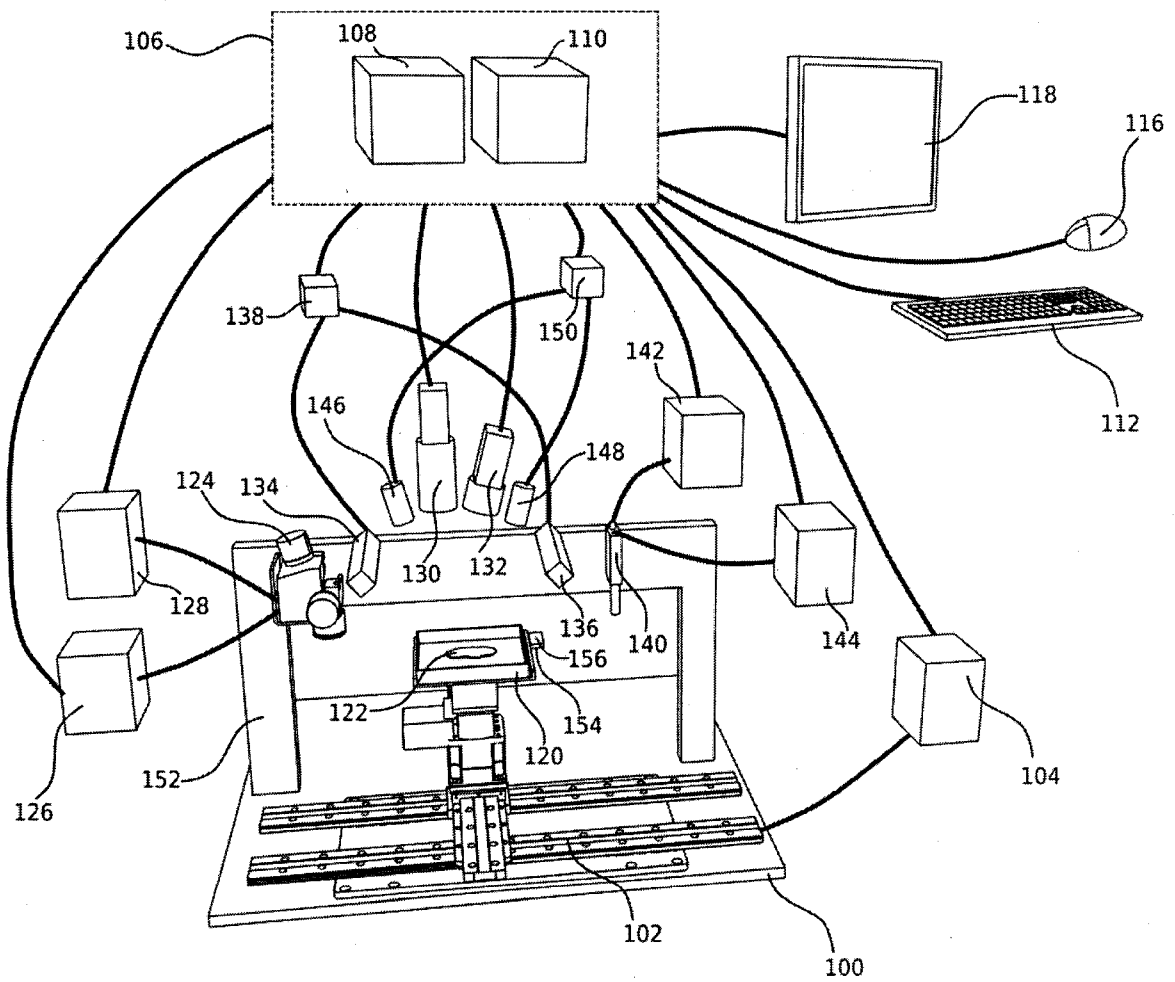


FIGURE 9A

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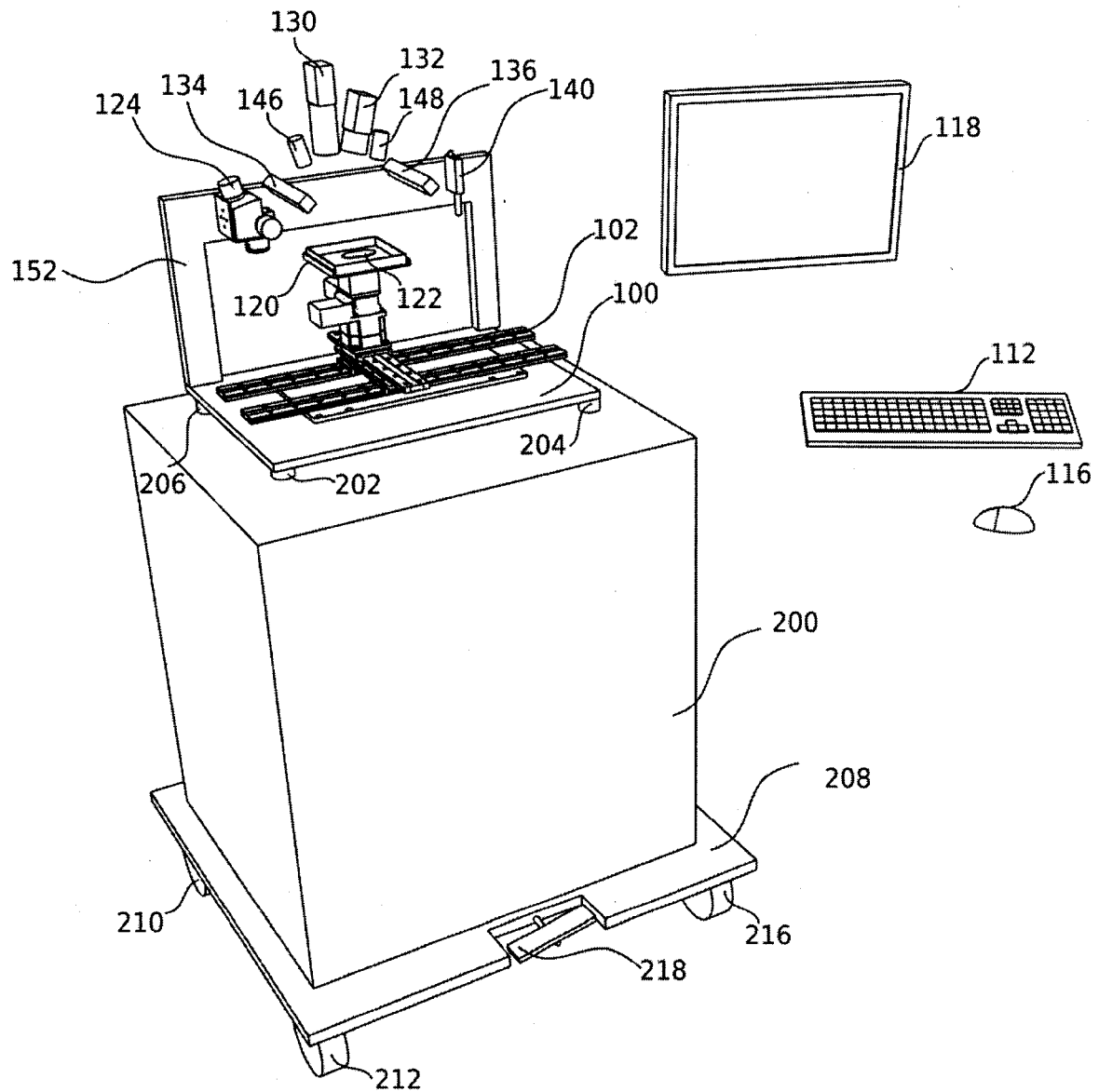


FIGURE 9B

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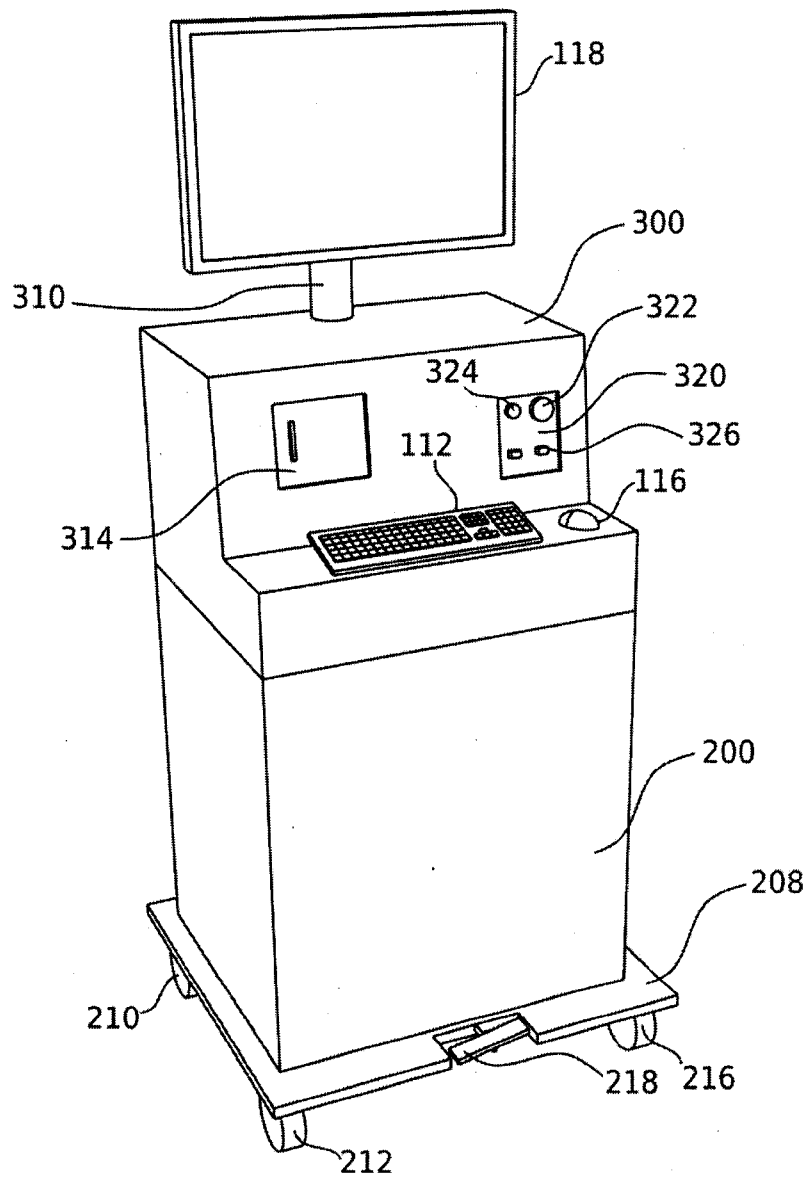


FIGURE 9C

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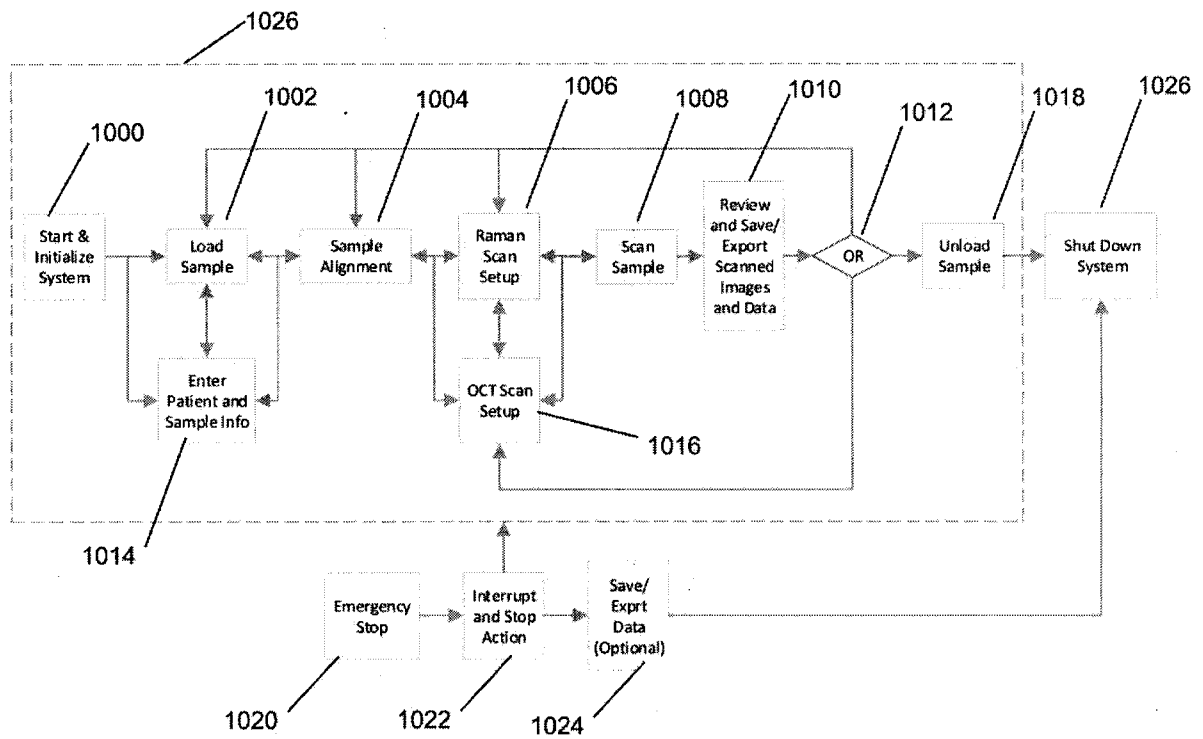


FIGURE 10

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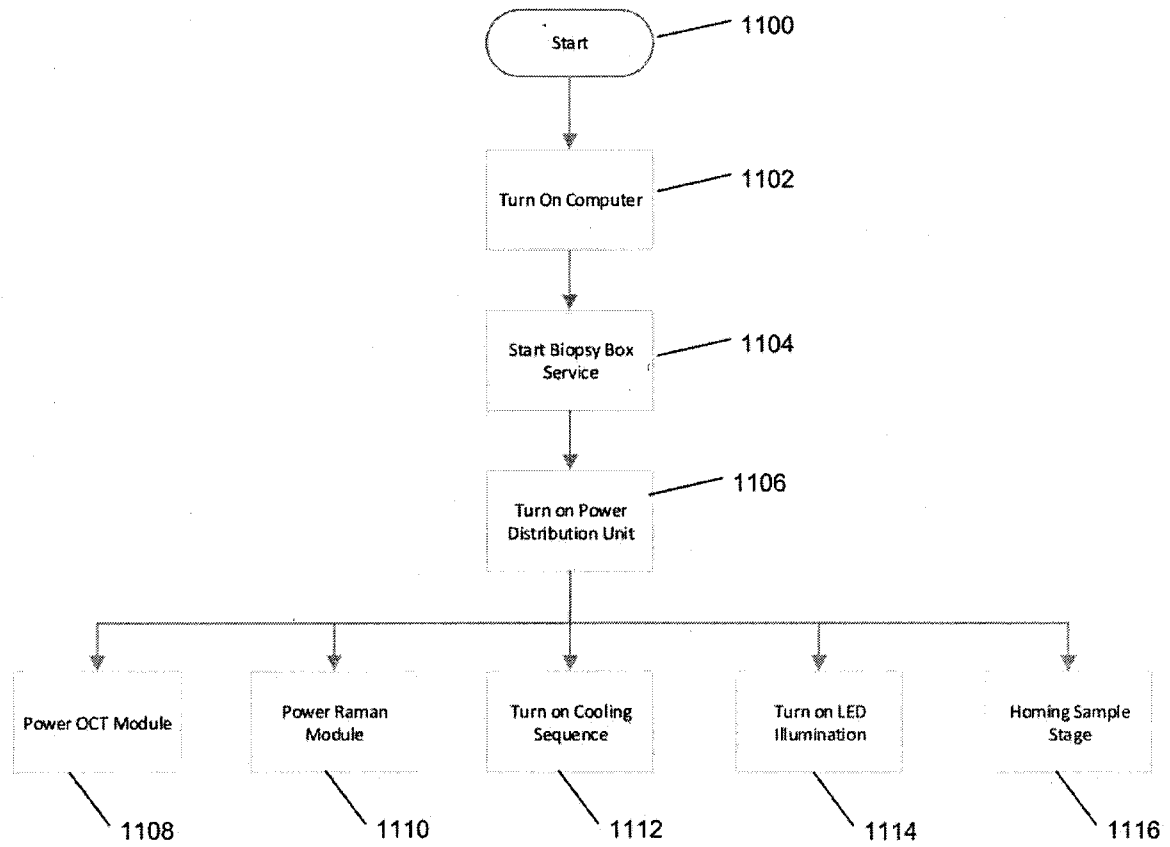


FIGURE 11A

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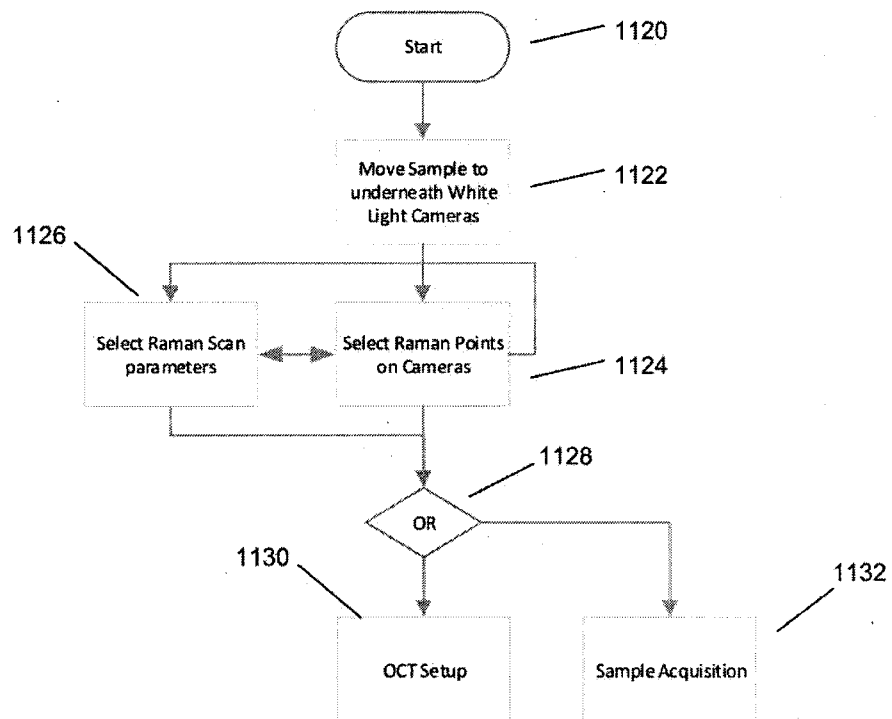
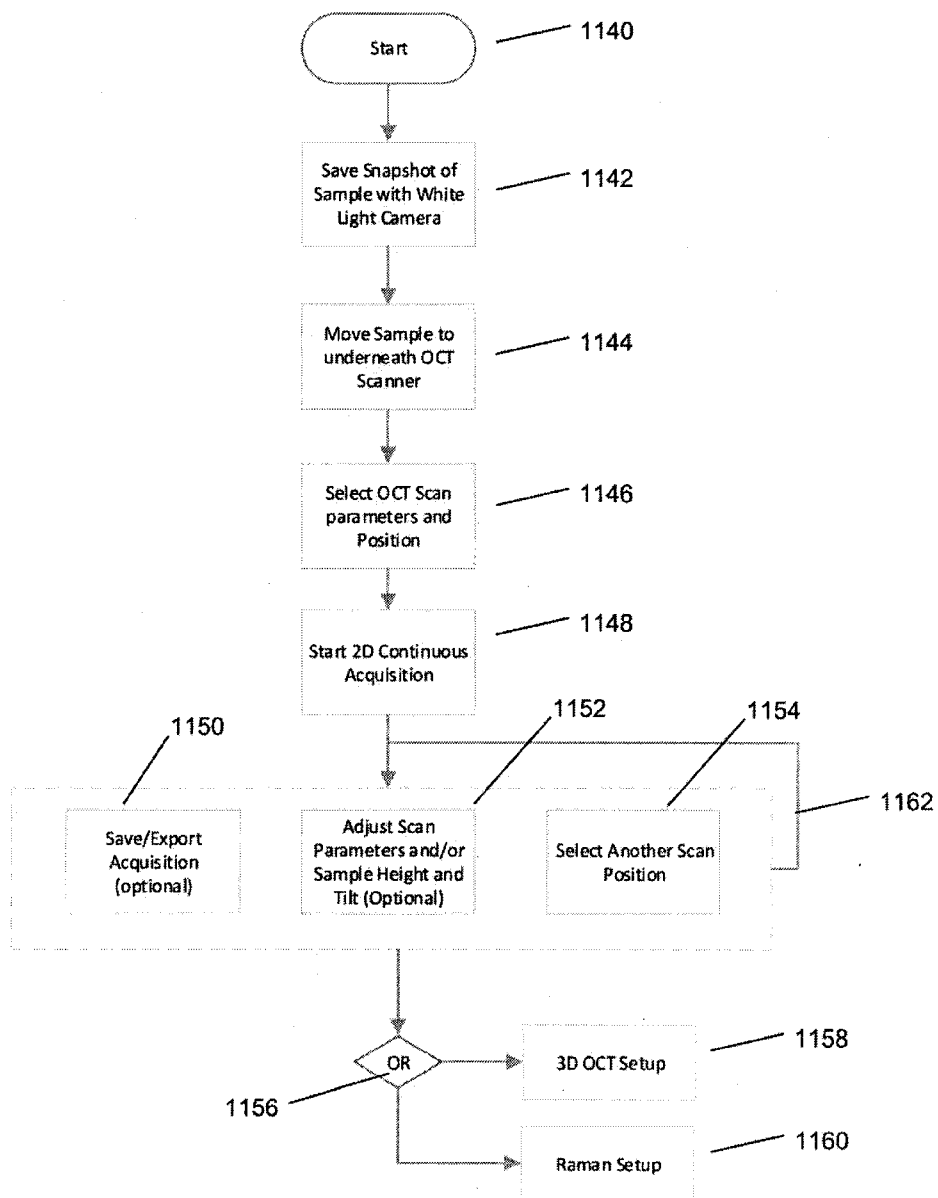


FIGURE 11B

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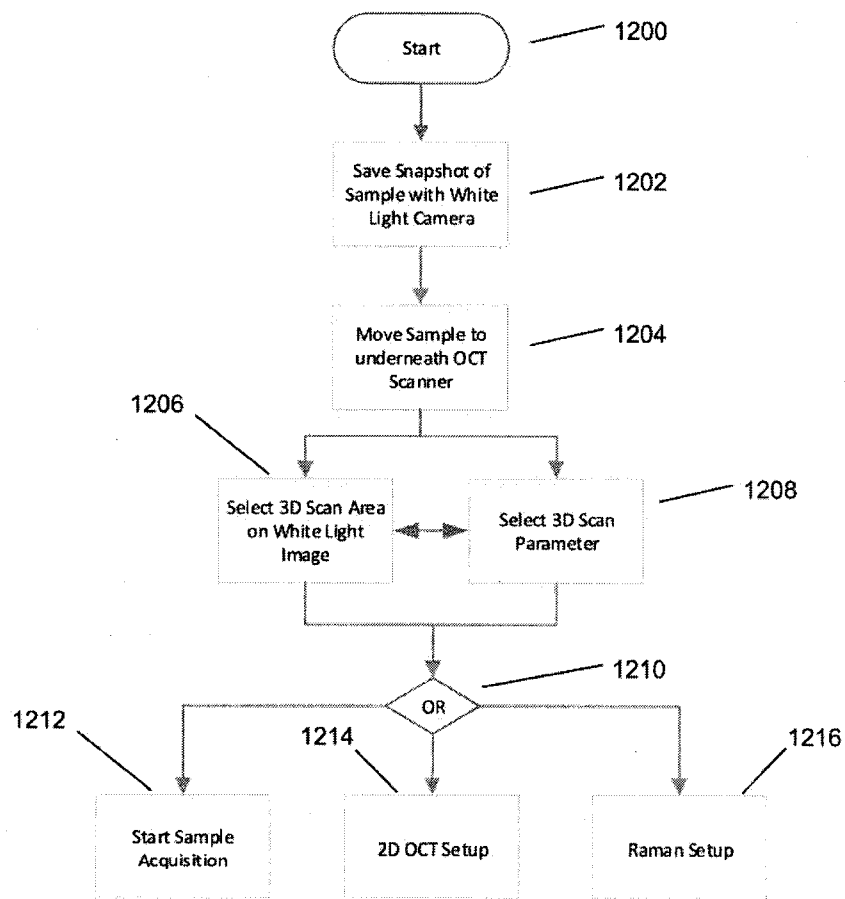


FIGURE 11D

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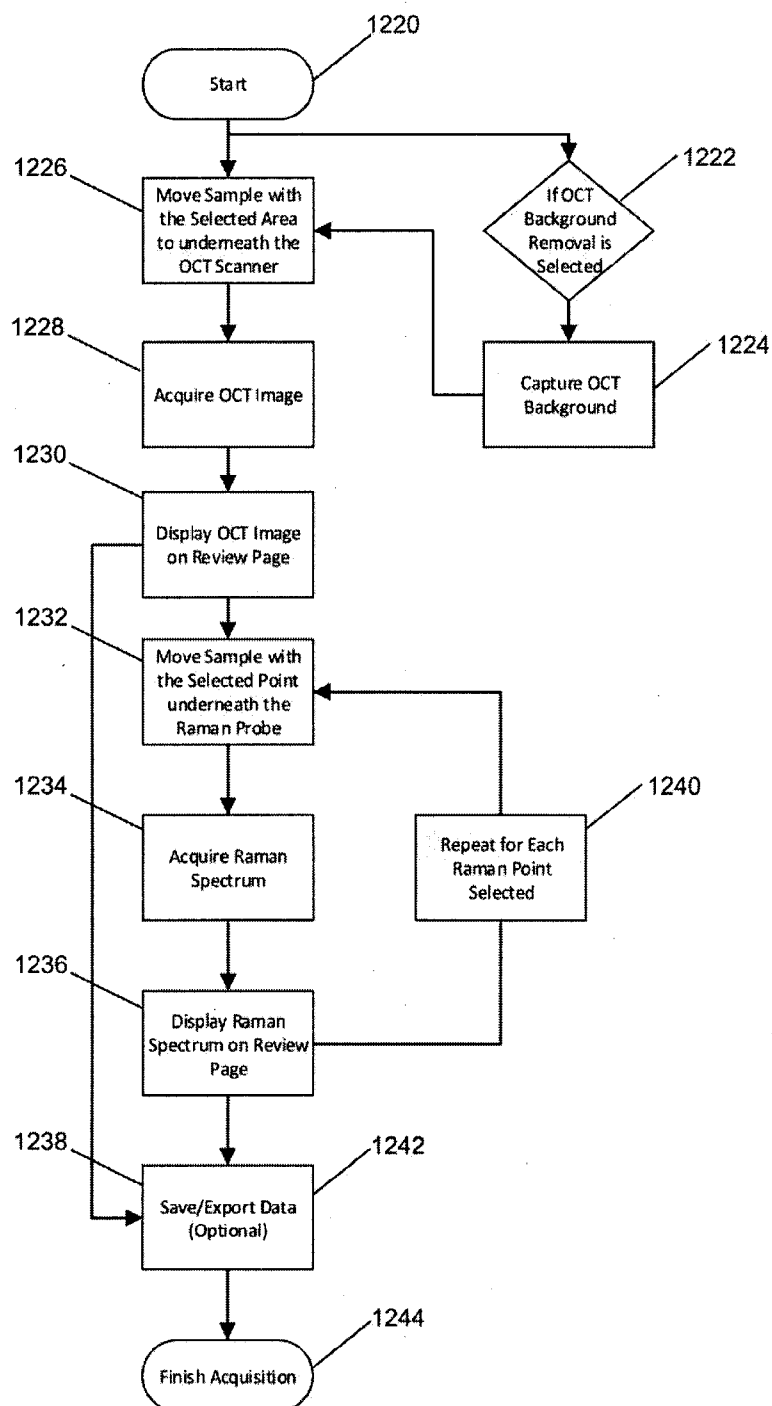


FIGURE 11E