Computer Vision Techniques

Neuralink, US 2020/0085508 A1, 3/19/2020

4/28/2024

Background

- Conventional surgical techniques - prohibitively expensive, limit BCI innovation (cannot sequentially implant large # of electrodes into brain)
- Conventional robotic surgery - inferior to human surgeons in terms of precisely positioning implants, target tissues, insertion needles (due to glare, lighting, reflective elements)
- Robotic surgery system - use fluorescence of certain elements, special lighting, computer vision techniques for bio-compatible electrodes in biological tissue using robotic assemblies

Outline

- **Goal**: Discuss computer vision techniques in connection with robotic surgery system (implantable device engagement + targeting + insertion verification subsystems)

Outline

- **Embodiments**:
    - Target Components:
        - System for implanting a device – Front & Side Views
        - Inserter head with needle for inserting probe
    - Implantable Device Engagement Components:
        - Probe device stage with cartridge-pillbox assembly
        - Needle and engagement component illuminated by white light
        - Engagement component fluorescing in response to irradiation
        - Needle and Engagement Component taken using Red Light
    - Electrode Implantation:
        - Insertion Needle and Pincher on Needle Pincher Cartridge
        - Implantation of Electrodes in a Target Tissue Proxy Substance
        - Example of Electrodes Implanted in Brain Tissue
    - Insertion Verification Components:
        - Example Verification Components of a System for Robotic Surgical Implantation
    - Robotic Surgical Implantation Techniques:
        - Flowcharts for Device Engagement and Robotic Surgical Implantation
        - Robotic Surgical Implantation (including Targeting, Verification)
        - Example Computing System for Robotic Surgery guided by Computer Vision
        - Example Components of Computing System for Robotic Surgery guided by Computer Vision

Robotic System for implanting a device – Front View

- See “Device Implantation using Cartridge” for more detail

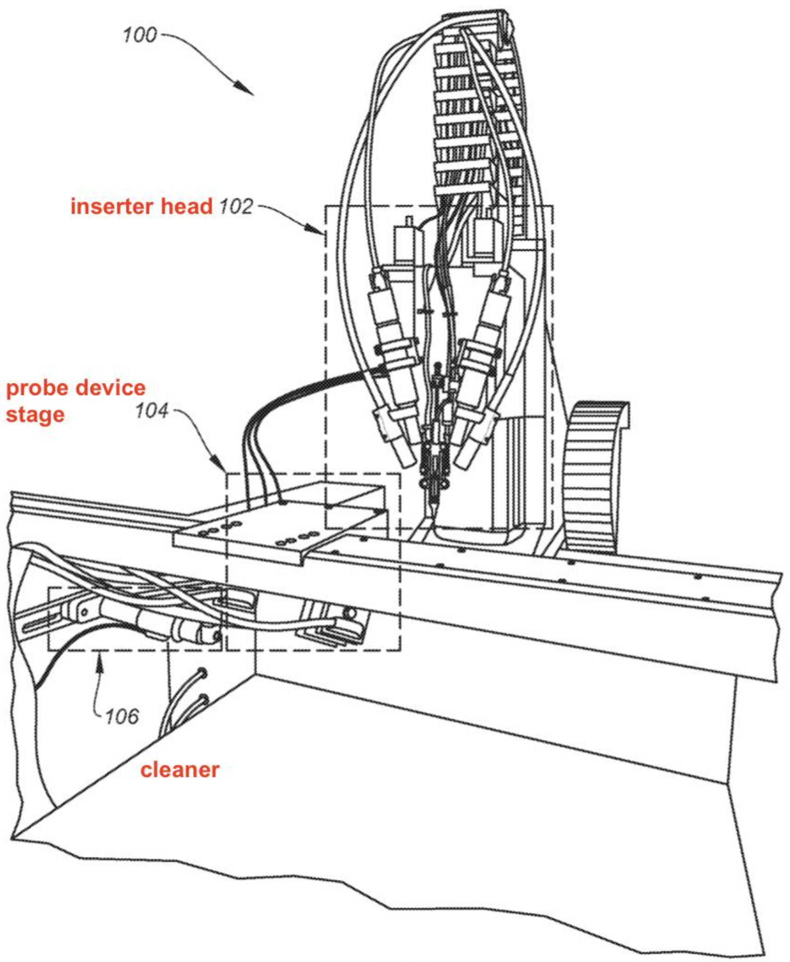


FIG. 1A

Robotic System for implanting a device – Side View

- See “Device Implantation using Cartridge” for more detail

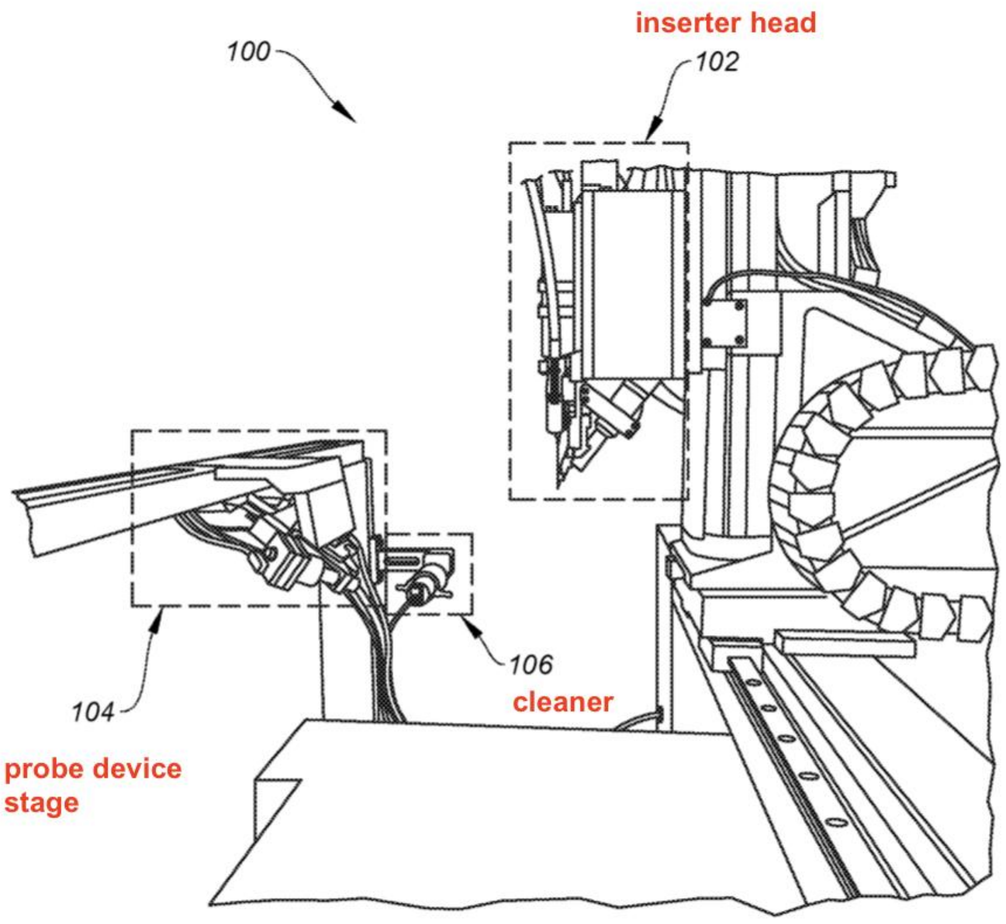


FIG. 1B

Inserter head with needle for inserting probe

- See “Device Implantation using Cartridge” for more detail

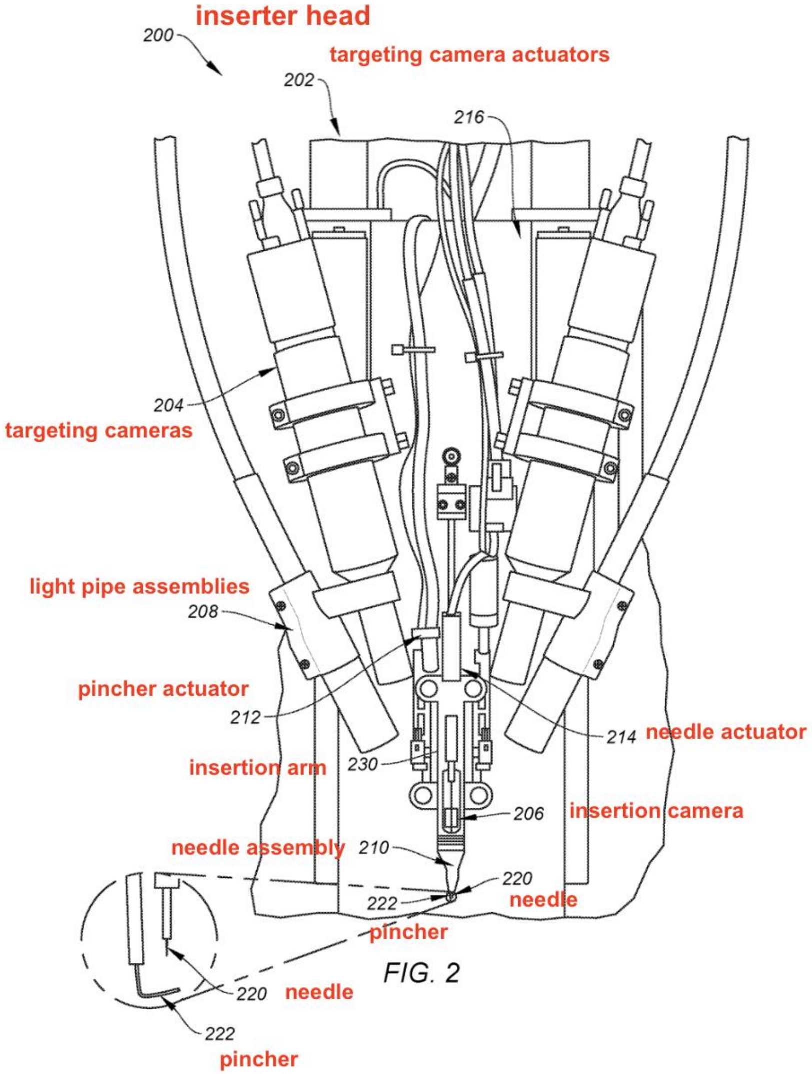


FIG. 2

Probe device stage with cartridge-pillbox assembly

- See “Device Implantation using Cartridge” for more detail

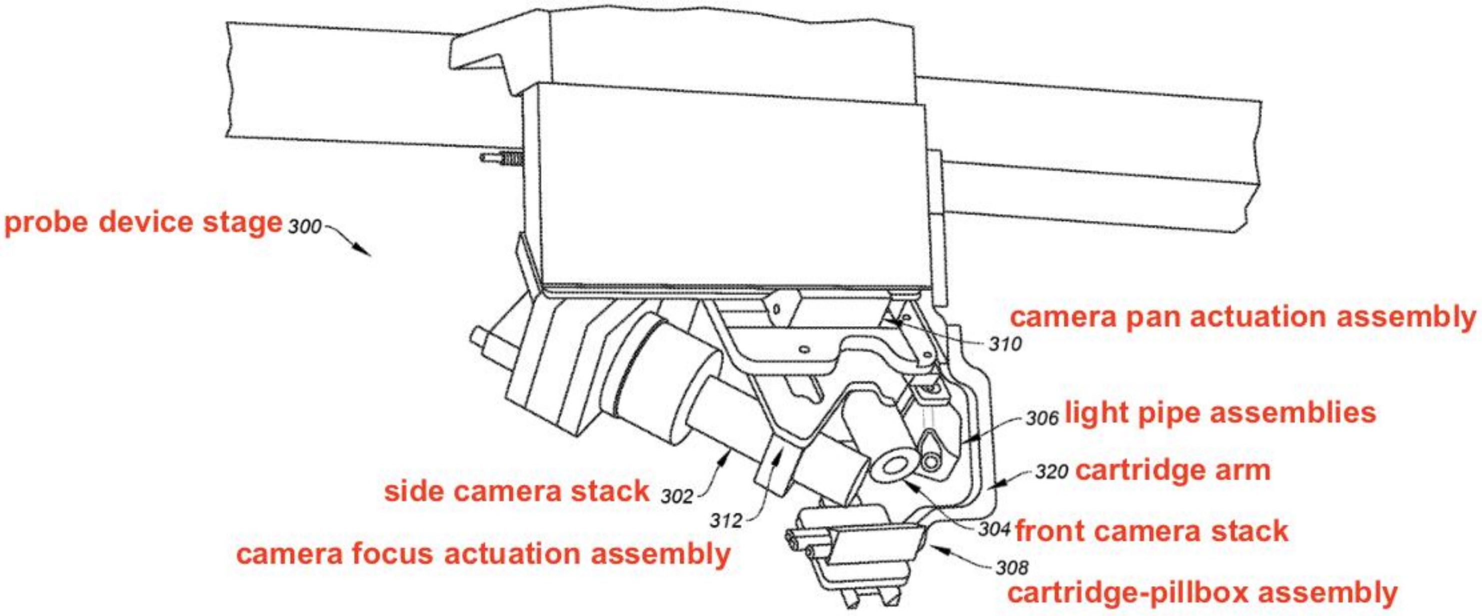


FIG. 3

Needle and Engagement Component illuminated by white light

- Both needle & engagement component appear **blurry**
- **Difficult** for system to **discern loop of engagement component**
- Needle appears **dimly lit**
- May **not** be able to determine positions/orientations of needle & engagement component to engage them
- **Prone** to erroneous detections of needle & engagement component

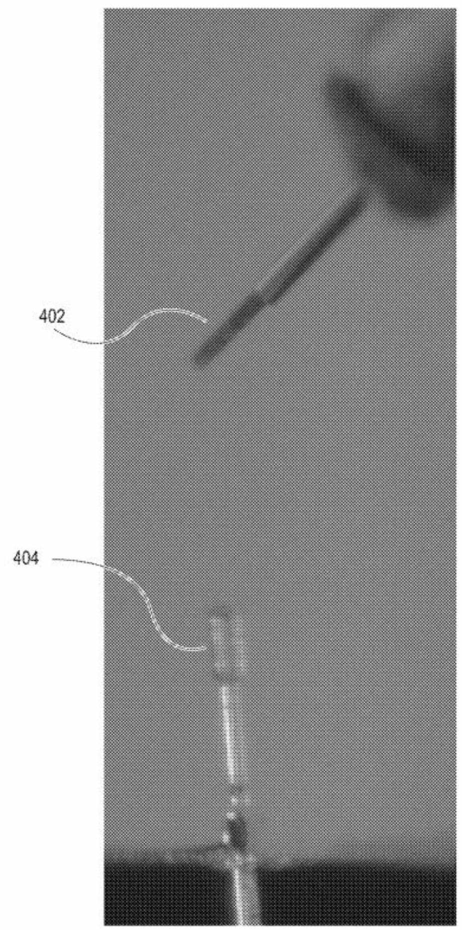


FIG. 4

Engagement component fluorescing green light in response to irradiation

- **Engagement component fluoresces green light** in response to irradiation at near-UV wavelengths (405nm)
- Appears much more sharper than in figure 4 - system can locate engagement component more accurately
- Color data may help identifying the engagement component

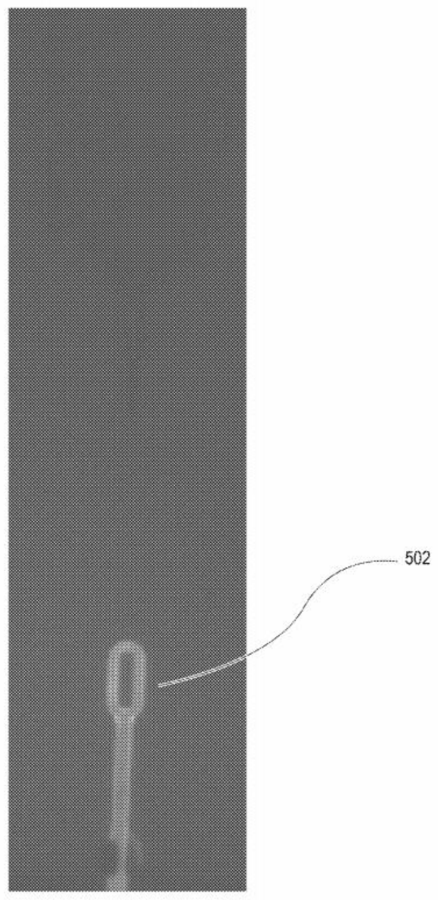


FIG. 5

Needle and Engagement Component taken using Red Light

- **Red light** provdes **technical advantage** - reflects more strongly and clearly from metal with needle
- Appears **sharper** than in figure 4
- Red light with **red backing** - enable cameras to resolve images with **very defined edges** on needle tip
- Uses **red light** to detect **position/orientation of needle**
- **Avoids erroneous** detections, false positives, and false negatives
- Note: images can be in color (may be helpful for identification)

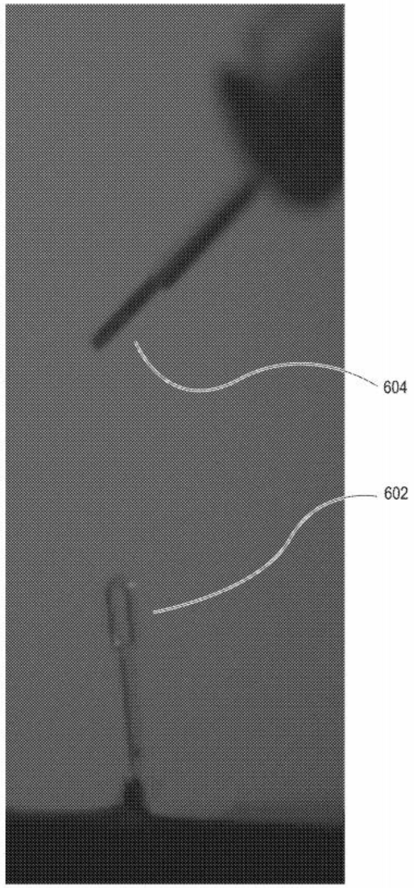


FIG. 6

Insertion Needle and Pincher on Needle Pincher Cartridge (NPC)

- **NPC**:
  - Portion of inserter head that makes **direct contact with brain**
  - Can be **replaced mid-surgery** in under minute
  - Milled from 40μm diameter tungsten-rhenium wire-stock electrochemically etched to 24m diameter along inserted length

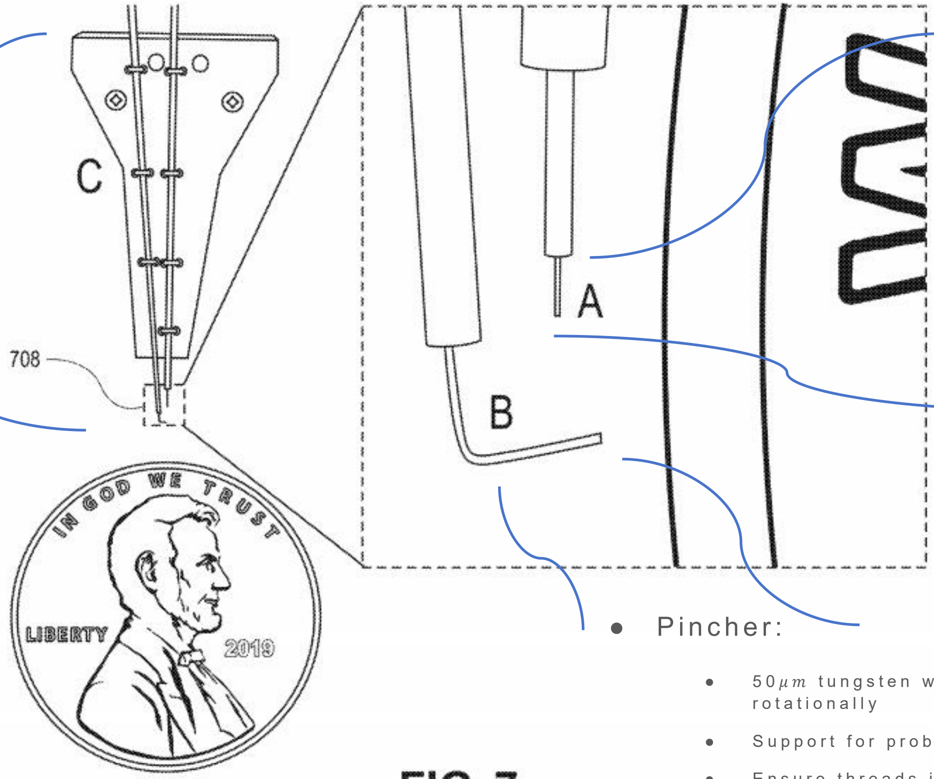


FIG. 7

- Tip of needle:
  - **Engage with engagement component** of electrode for **transporting and inserting individual threads**
  - **Penetrade meniges** and **brain tissue**
  - Driven by **linear motor** that allows **variable insertion speeds** & **rapid retraction acceleration** (up to 30K mm/s^2) to encourage separation of probe from needle

- Pincher:
  - 50μm tungsten wire bent at tip, driven axially & rotationally
  - Support for probes during transport
  - Ensure threads inserted along needle path
  - Engagement & insertion - rotate to pinch the neck of electrode loop against cannula tip of needle as NPC peels electrode thread off parylene backing, drive thread to insertion site of target tissue
  - Robotic assembly - drive thread to tissue, needle extends through cannula & enter thru tissue
  - Electrode & loop remains in tissue as needle retracts

Implantation Process of Electrodes in a Target Tissue Proxy Substance

- Needle inserts first thread (holds plurality of electrodes)
- Insert second thread with second plurality of electrodes

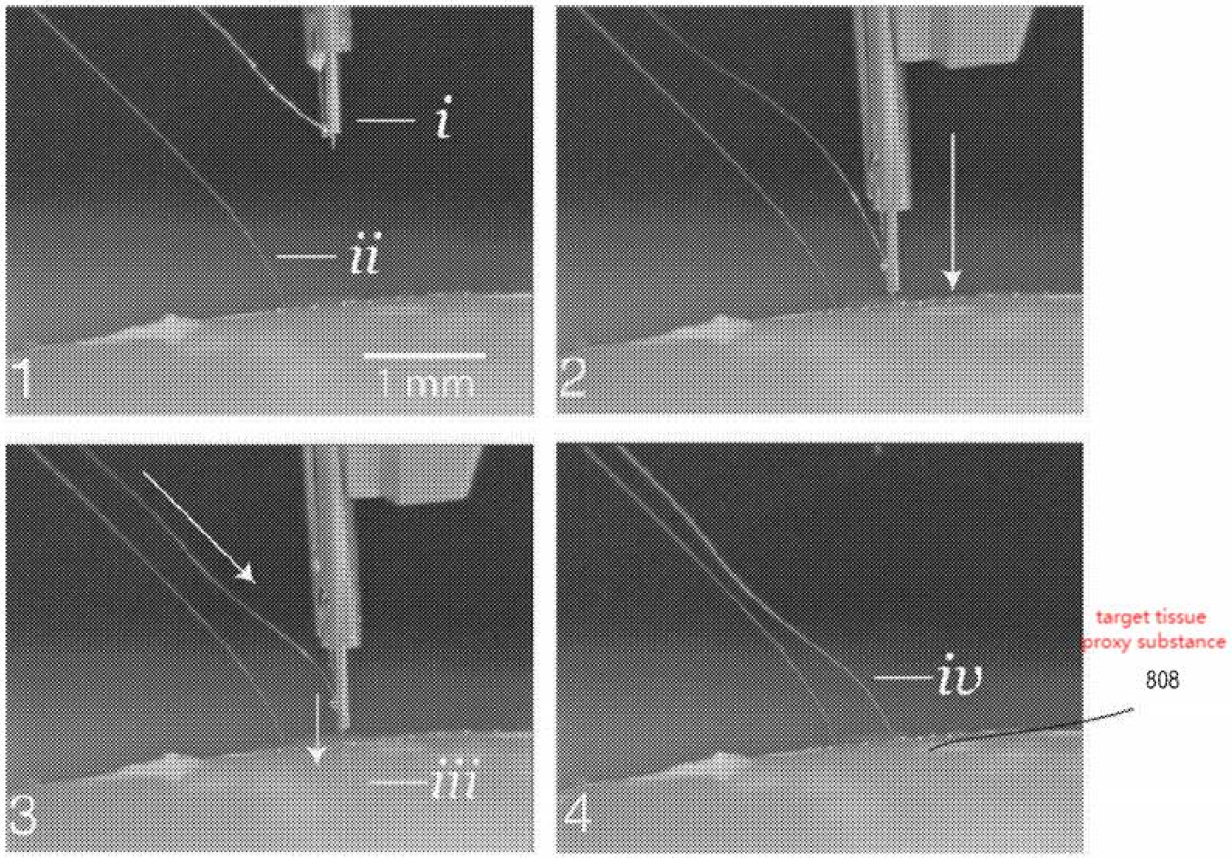


FIG. 8

Example of Electrodes Implanted in Brain Tissue

- 96 polymer threads, 32 electrodes/thread
  - 5-50μm thread width, **nominal thread thickness 4-6μm**, length ~20mm
- **Thin Hair: 60μm thick (12-15x thicker than threads)**
- Small size, greater flexibility, greater biocompatibility
- Probes can remain implanted for long periods of time without triggering immune responses, minimize tissue displacement

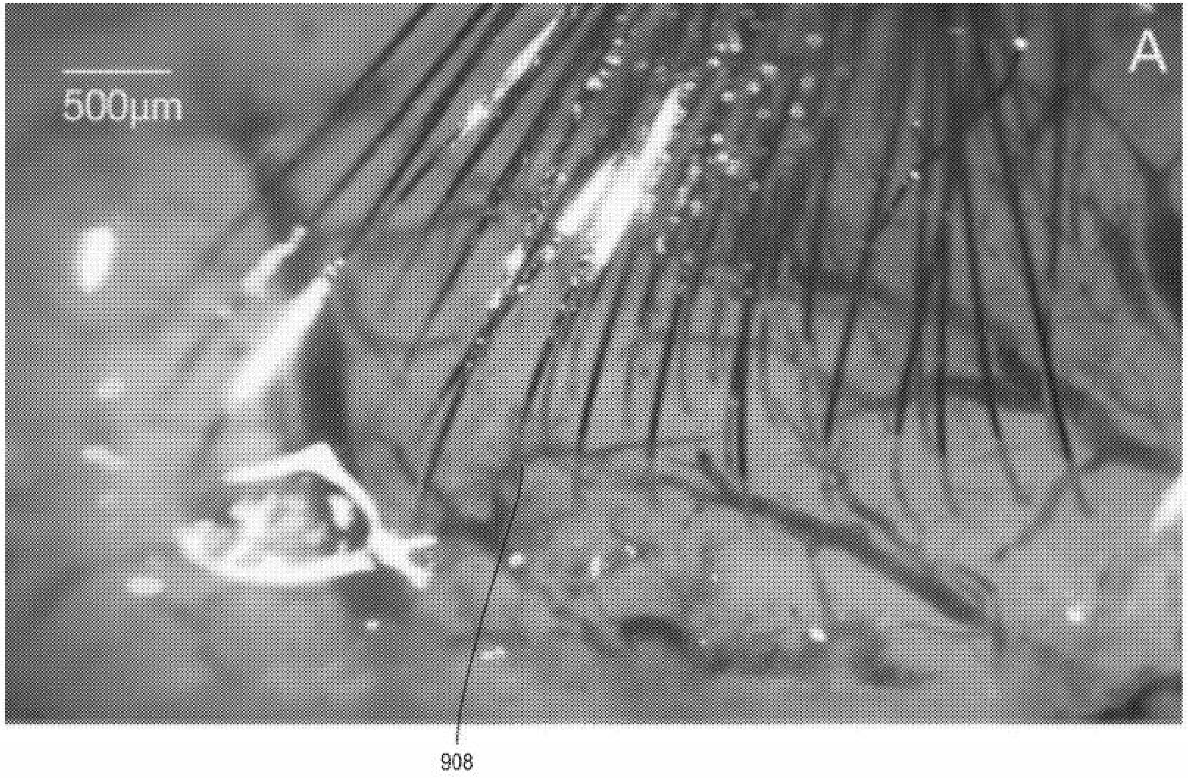
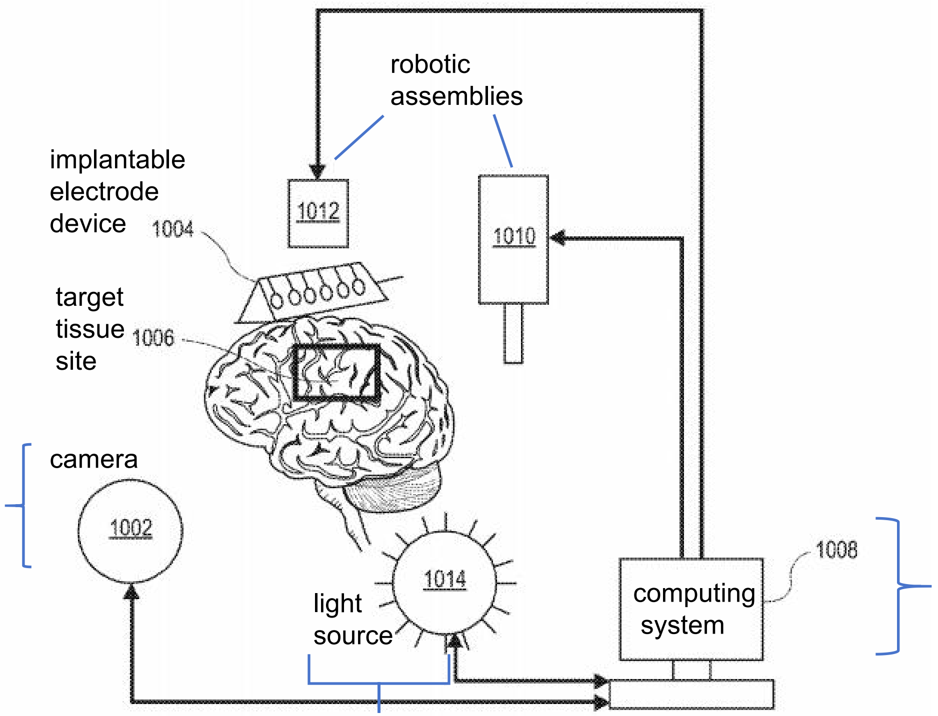


FIG. 9

Example Verification Components of a System for Robotic Surgical Implantation

- capture light fluoresced to generate 3D map of plurality of electrodes in target tissue site



illuminate implantable electrode device with light of wavelength to fluoresce device & its wires

FIG. 10

- process images from cameras via CV heuristic to determine implantable electrode device and/or insertion needle
- send further instructions to robotic assemblies (ex. correct positioning implantation of electrode device
OR
no further motions needed, robotic surgery proceed to next stage)

Device Engagement and Robotic Surgical Implantation

Note: The following diagrams may involve more components (e.g., cameras, illumination components, computing system, etc.) but are not shown for simplicity

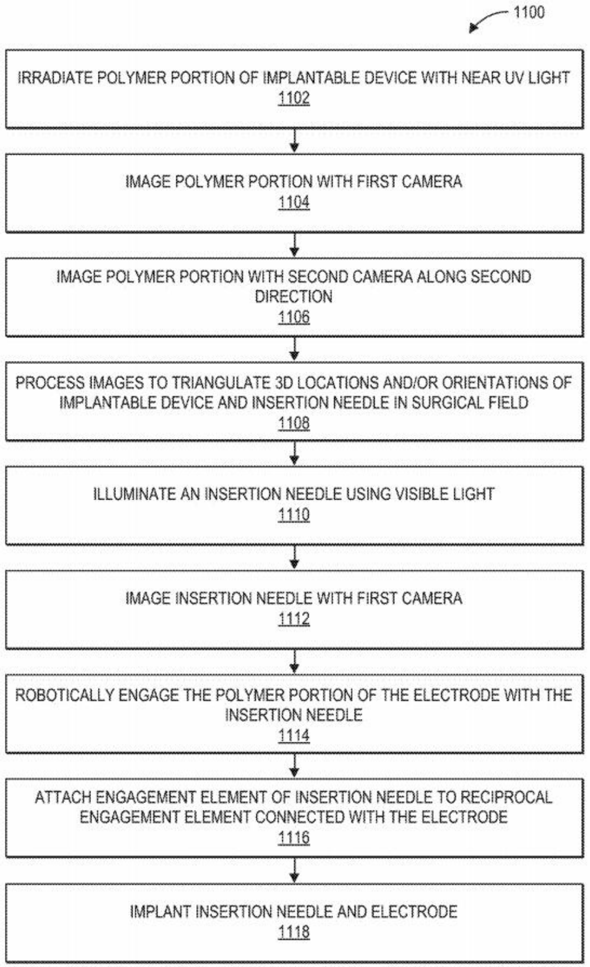
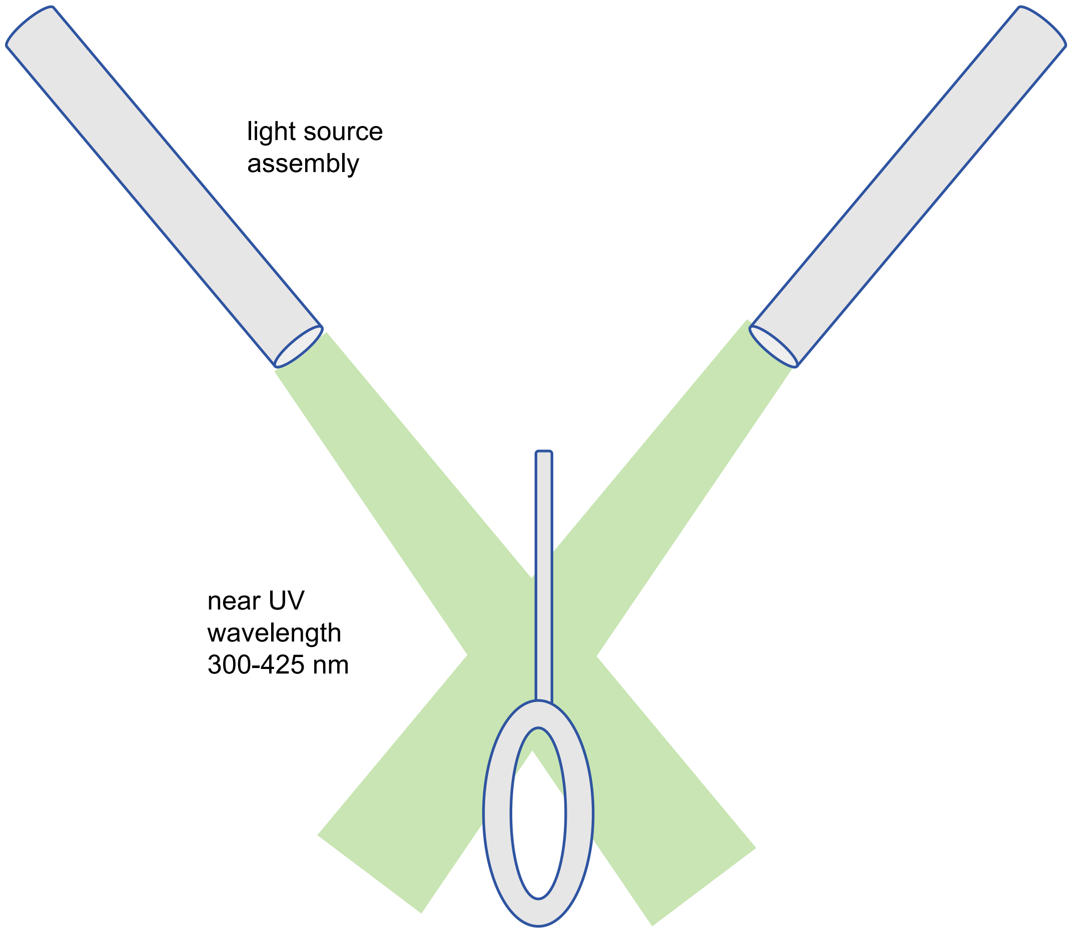


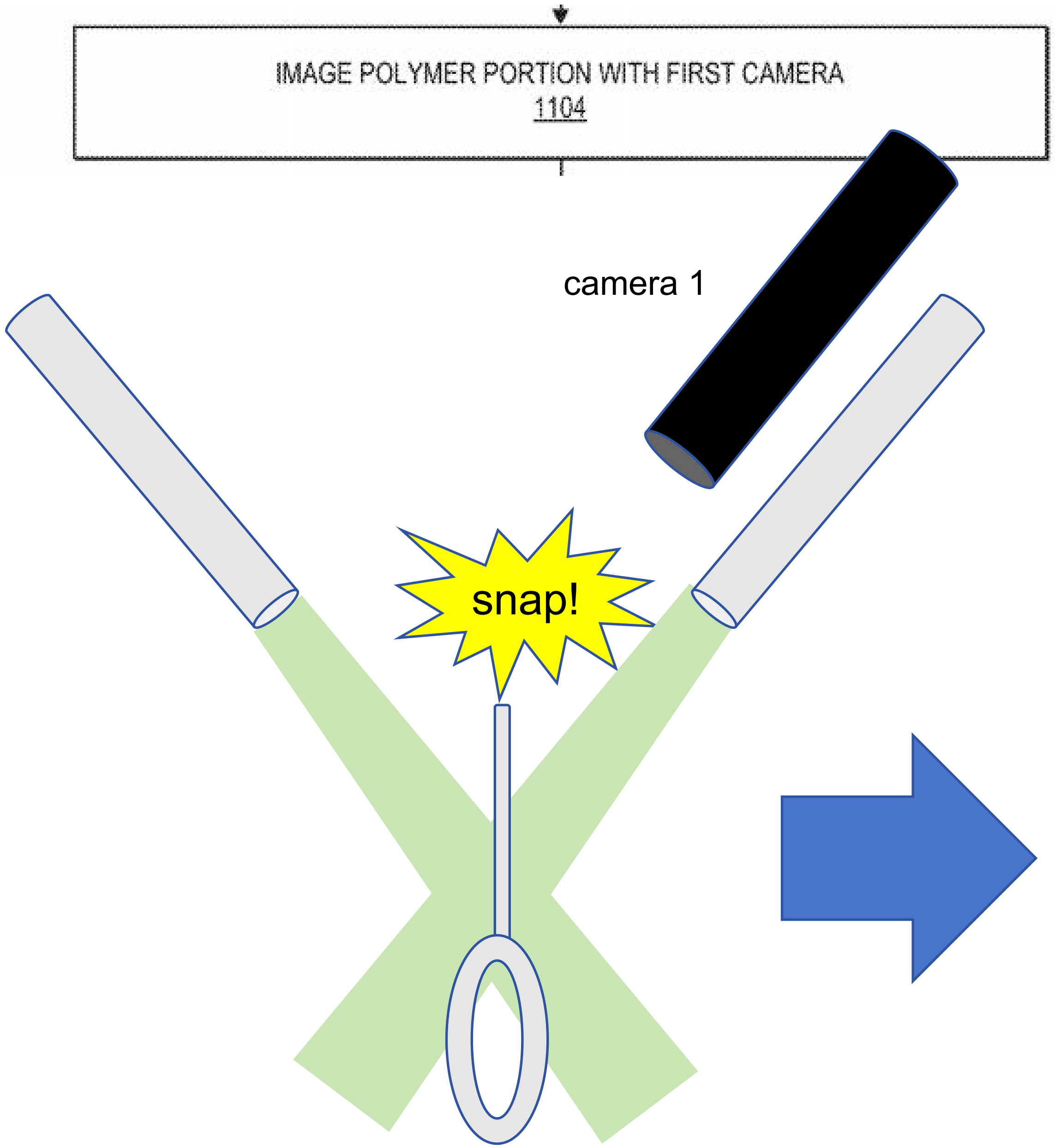
FIG. 11

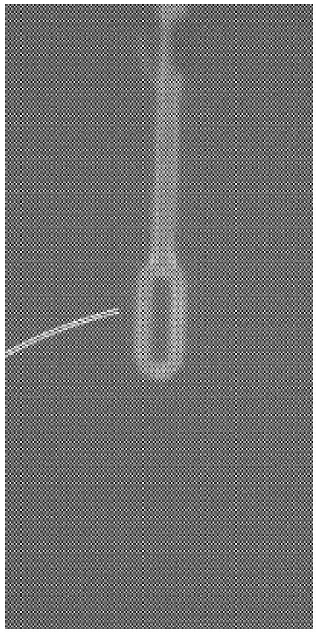
Step 1:

IRRADIATE POLYMER PORTION OF IMPLANTABLE DEVICE WITH NEAR UV LIGHT
1102



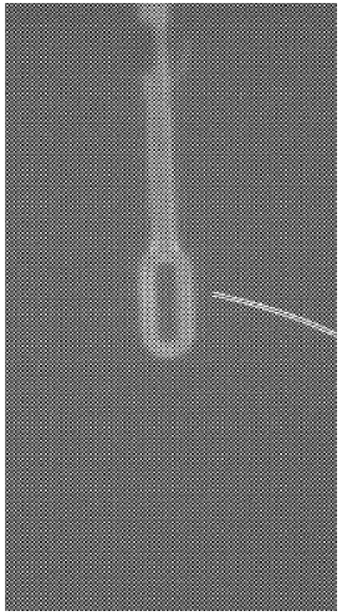
Step 2:

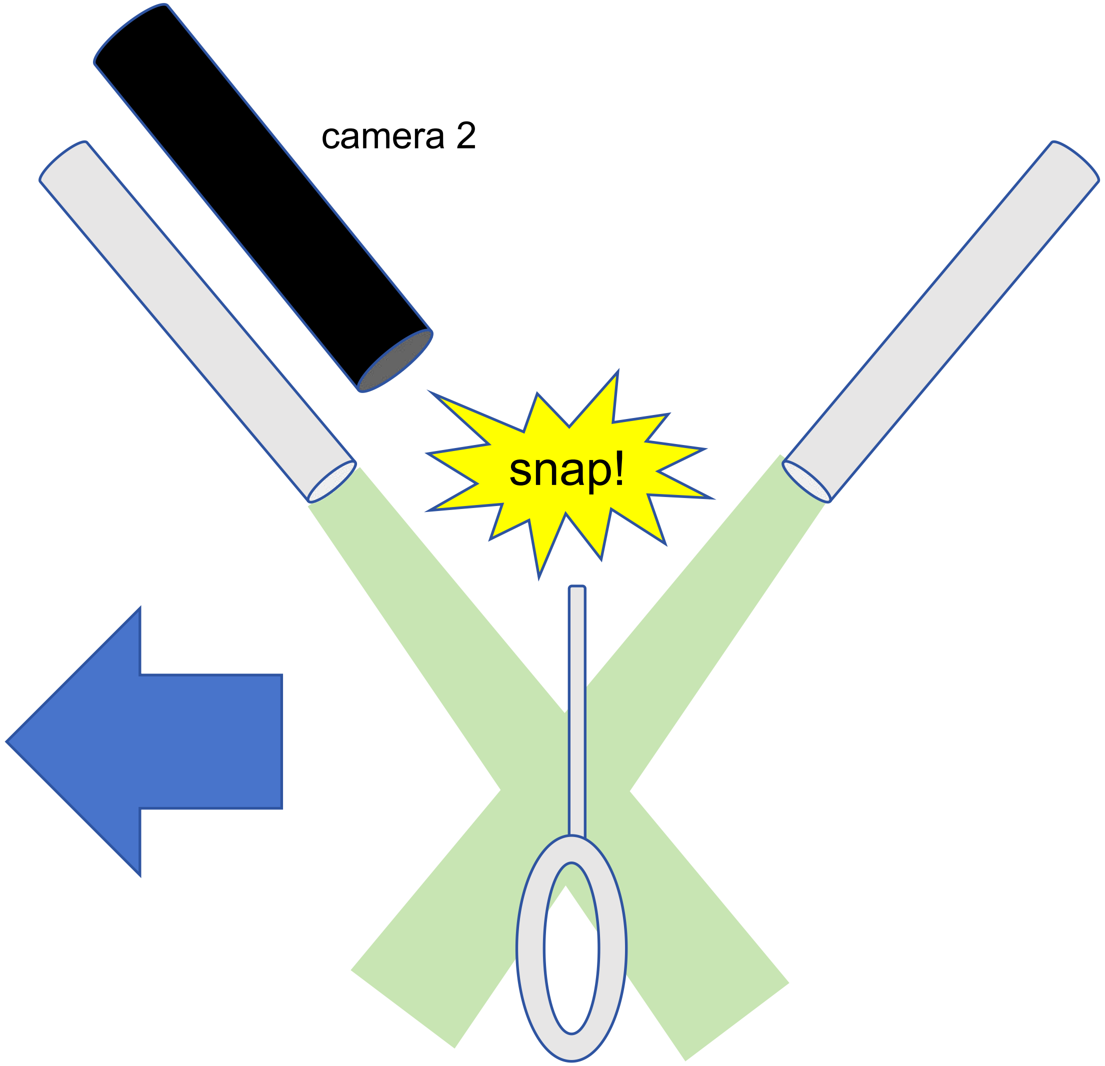




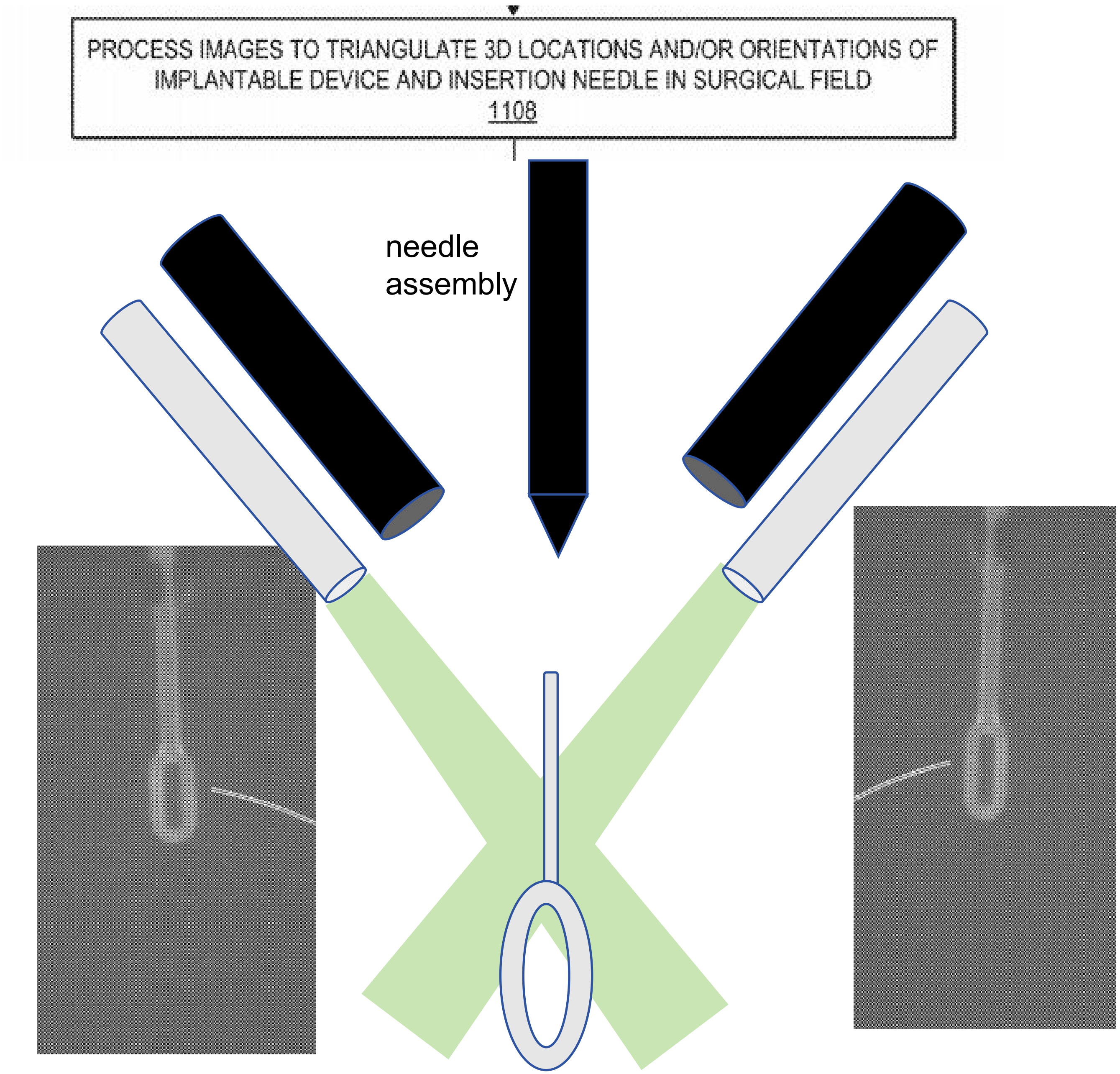
Step 3:

IMAGE POLYMER PORTION WITH SECOND CAMERA ALONG SECOND DIRECTION
<u>1106</u>

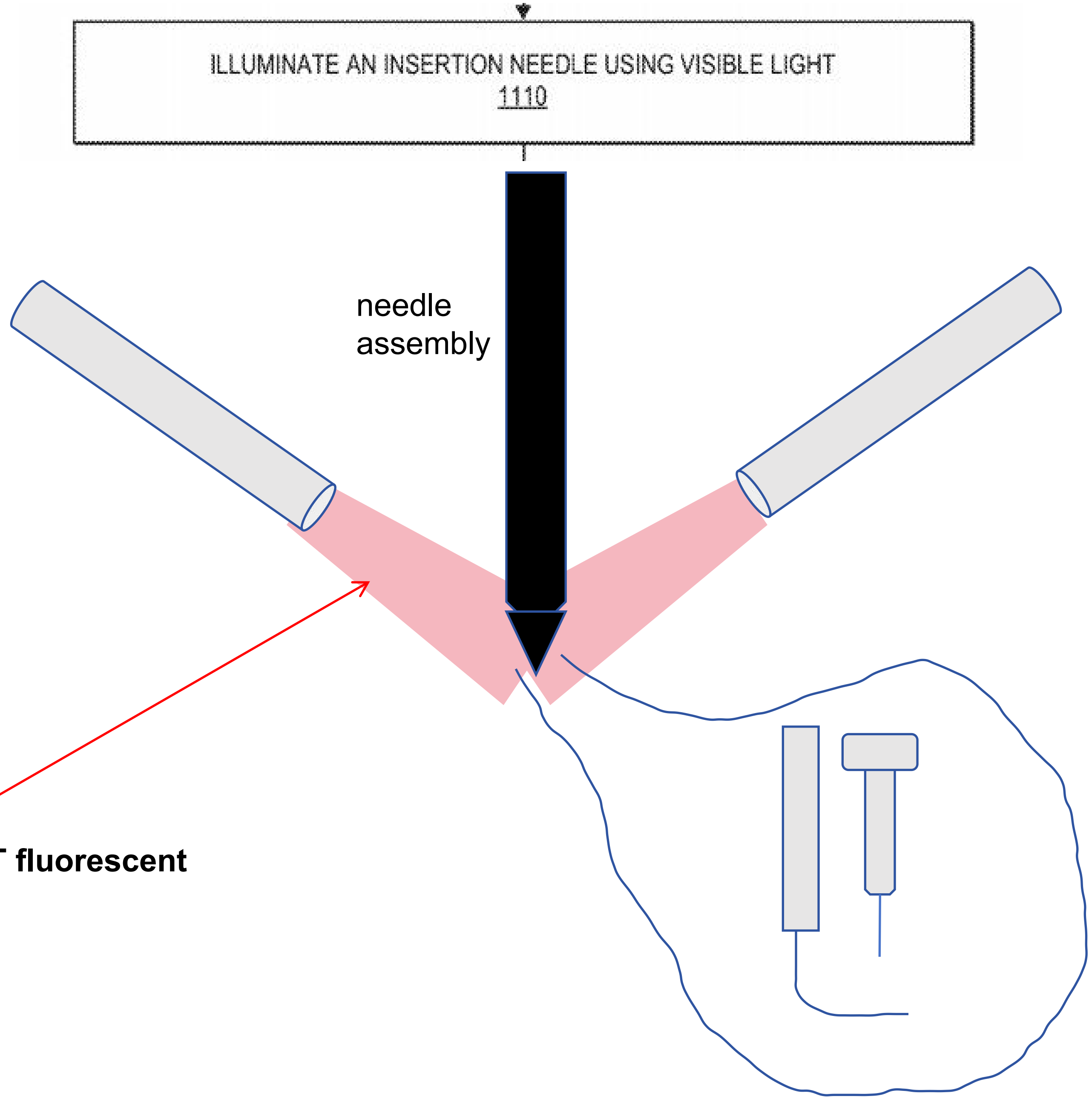




Step 4:

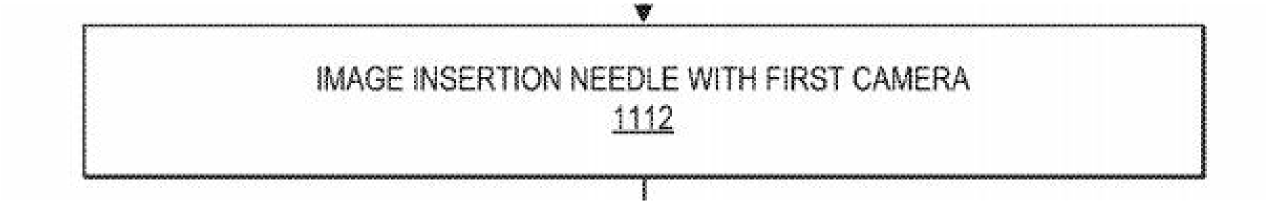

PROCESS IMAGES TO TRIANGULATE 3D LOCATIONS AND/OR ORIENTATIONS OF IMPLANTABLE DEVICE AND INSERTION NEEDLE IN SURGICAL FIELD
1108
needle assembly

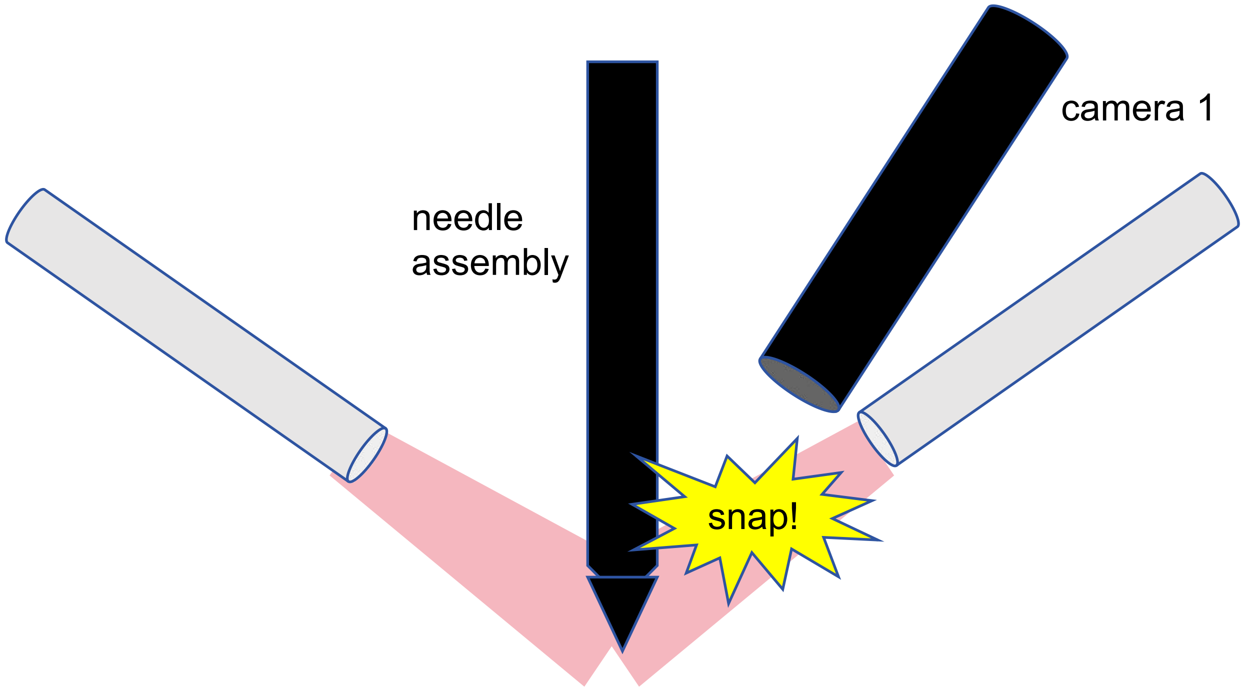
Step 5:

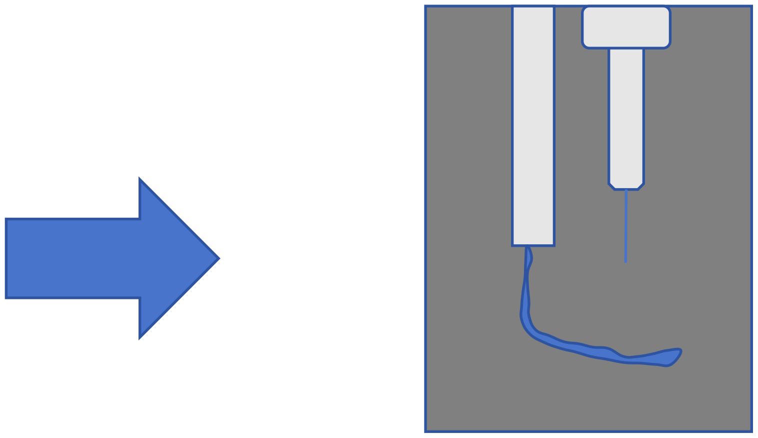


VISIBLE light - NOT fluorescent
(e.g., red)

Step 6:



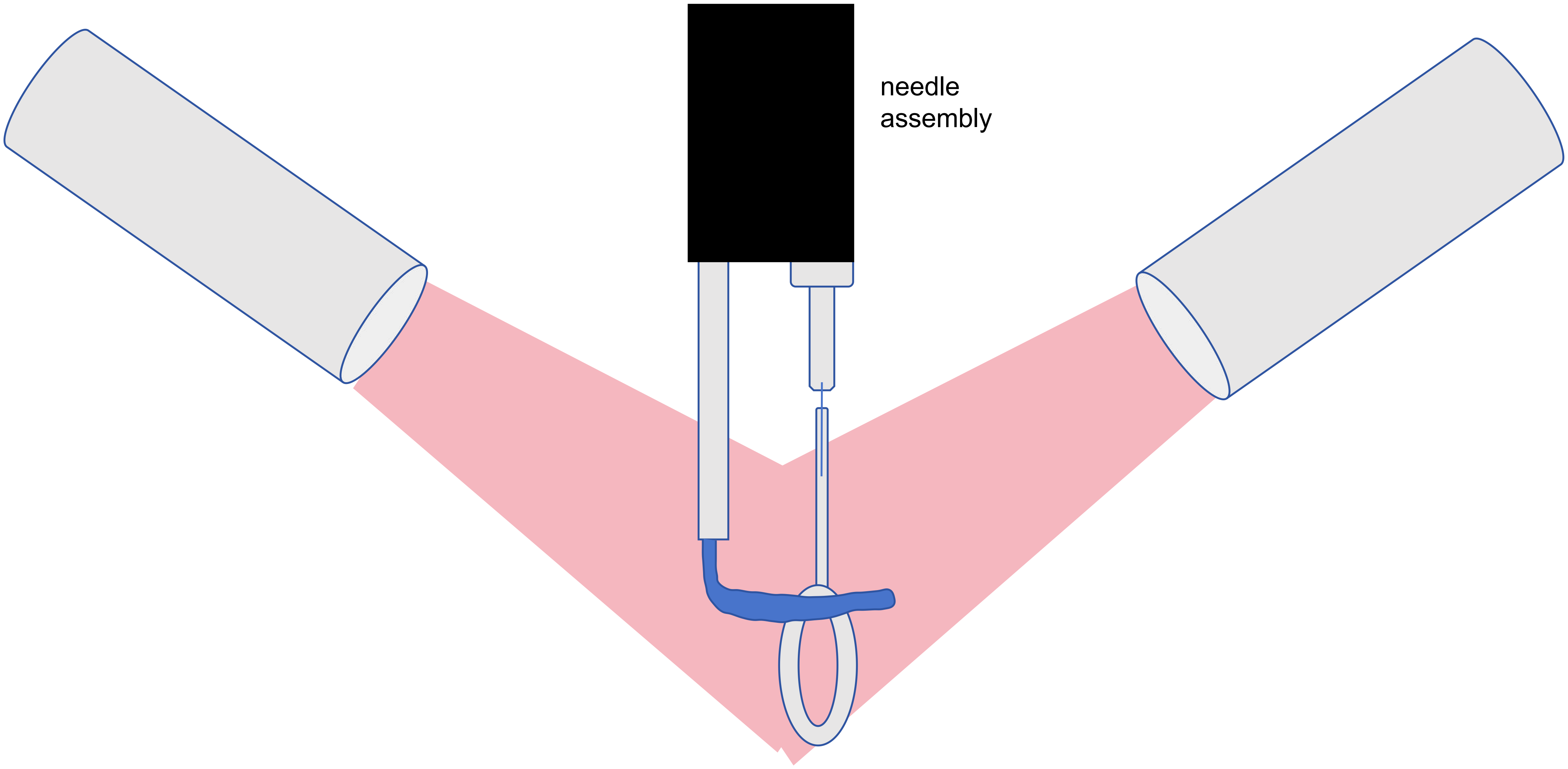




Note: real image not
available for show

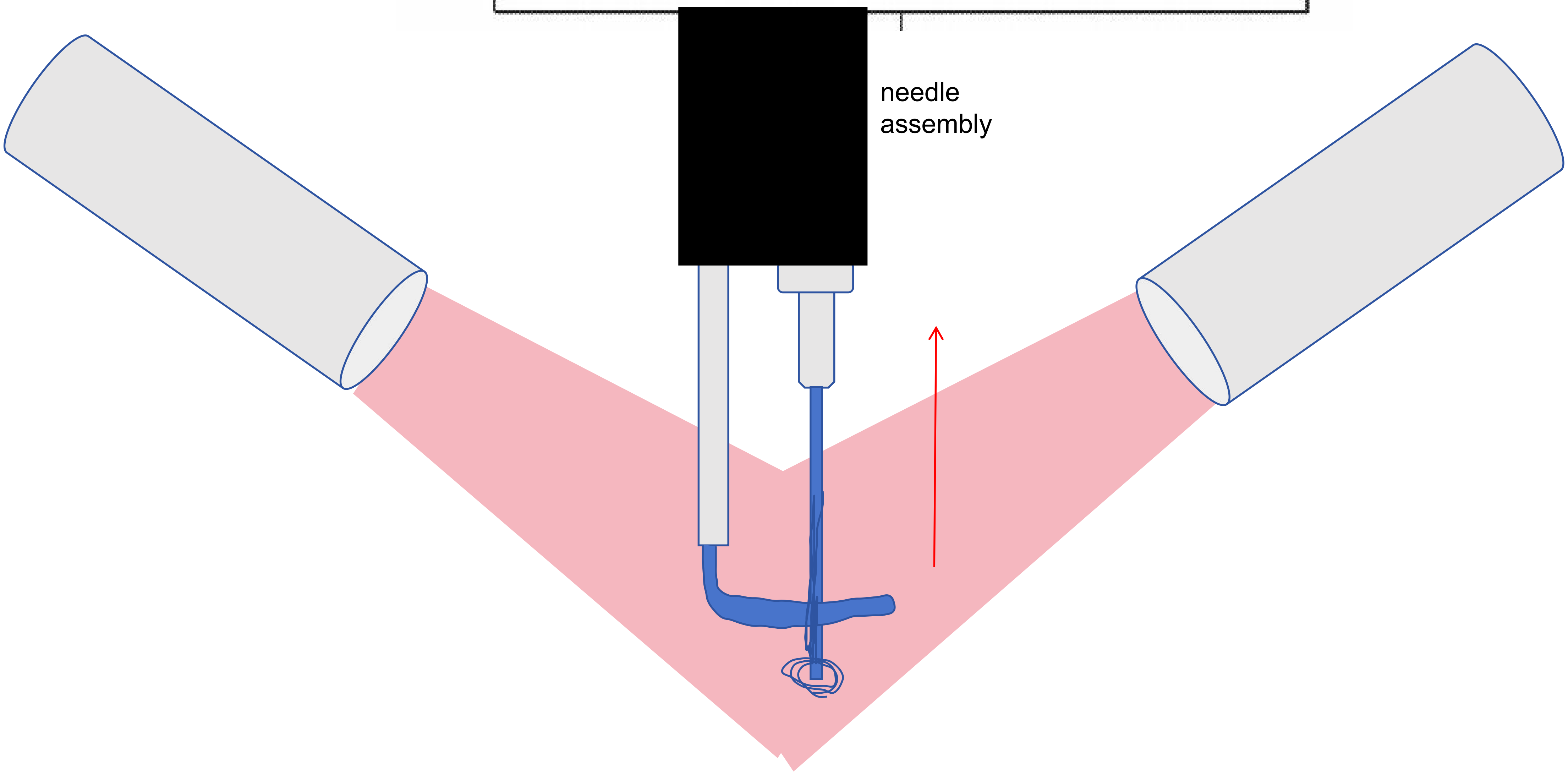
Step 7:

ROBOTICALLY ENGAGE THE POLYMER PORTION OF THE ELECTRODE WITH THE INSERTION NEEDLE
1114

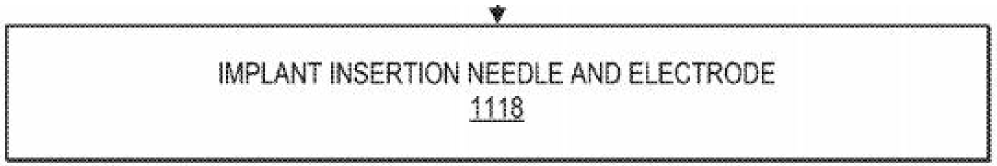


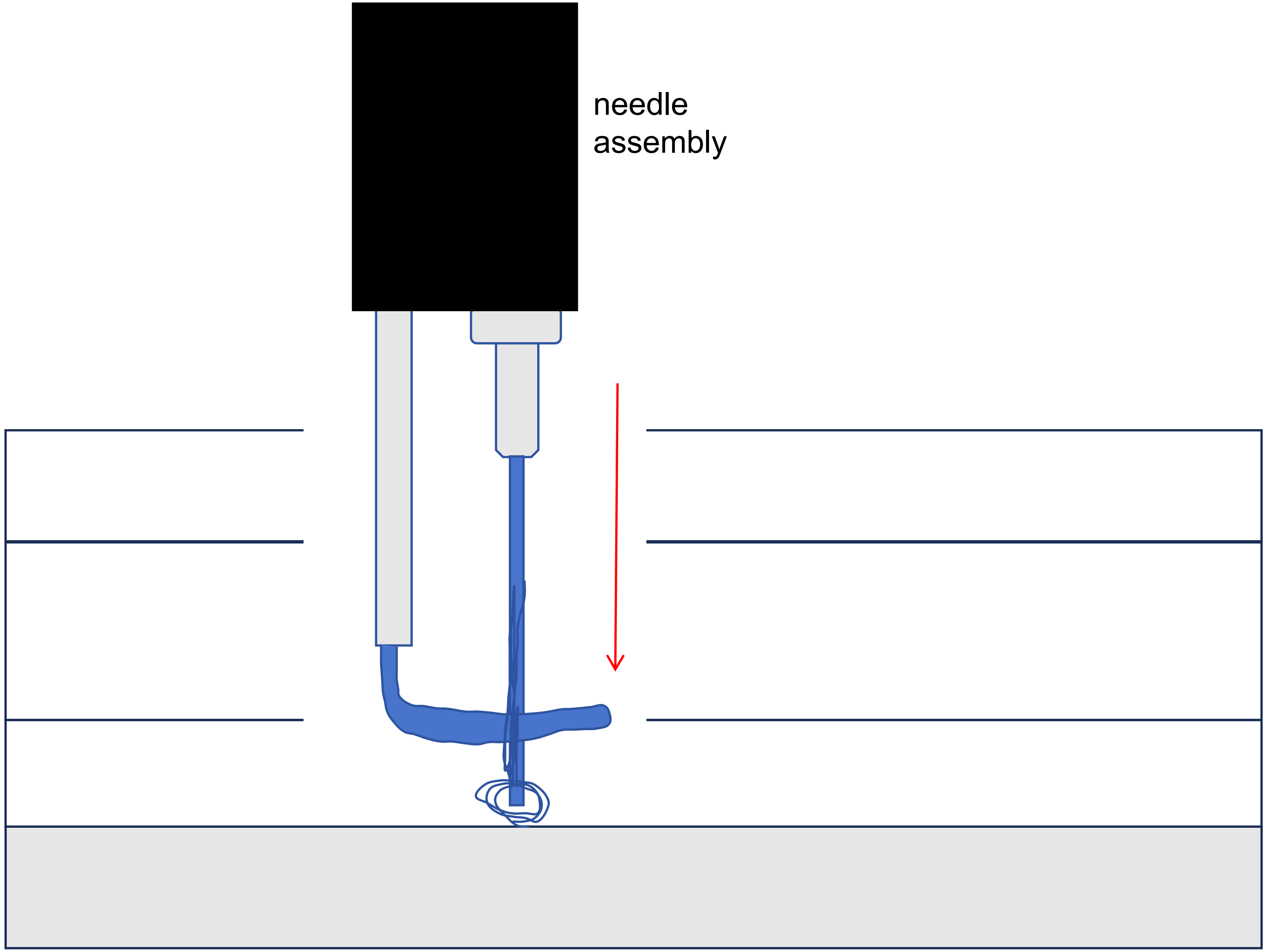
Step 8:

ATTACH ENGAGEMENT ELEMENT OF INSERTION NEEDLE TO RECIPROCAL ENGAGEMENT ELEMENT CONNECTED WITH THE ELECTRODE
1116



Step 9:


IMPLANT INSERTION NEEDLE AND ELECTRODE
1118


needle
assembly

Robotic Surgical Implantation

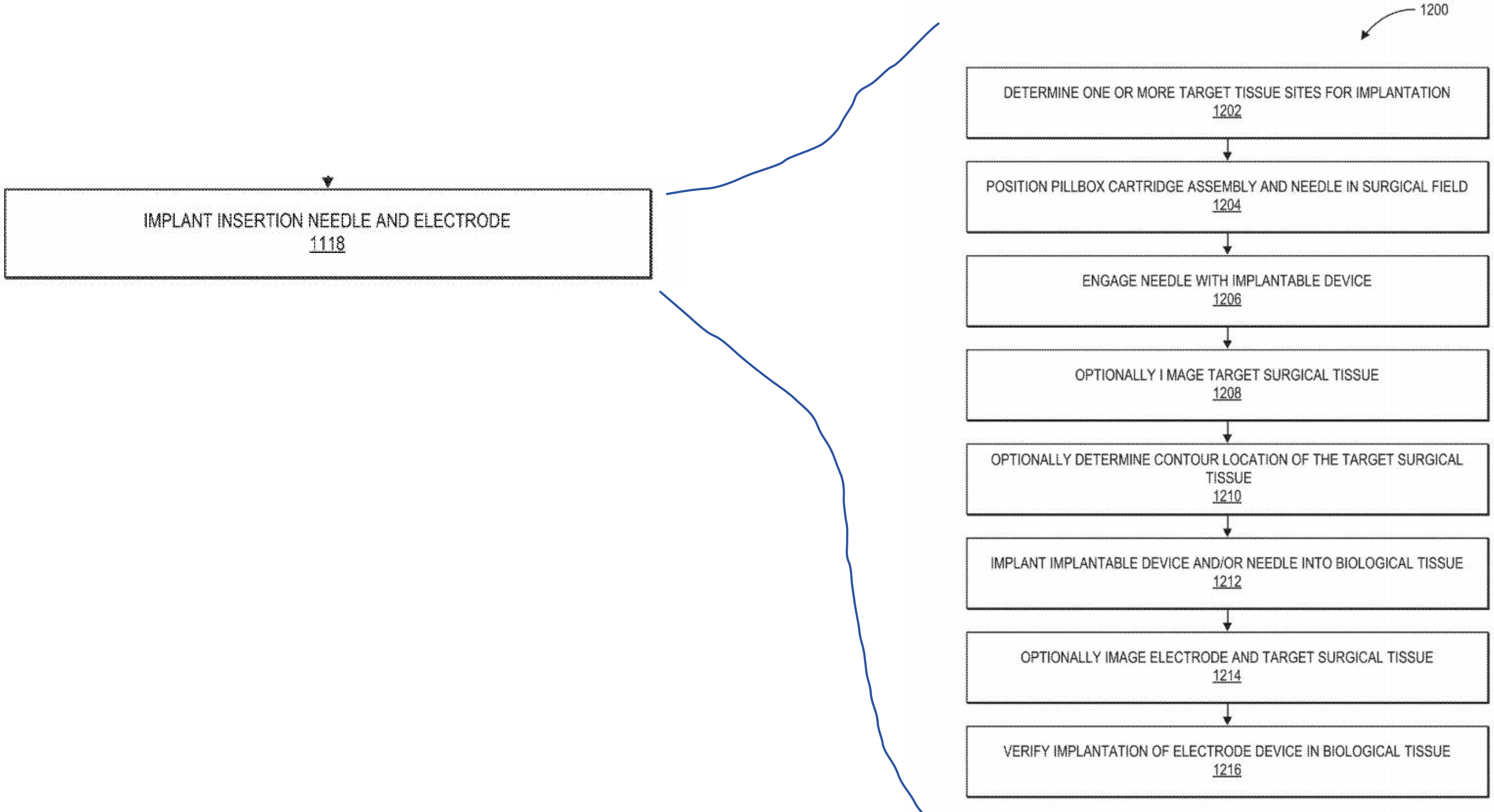
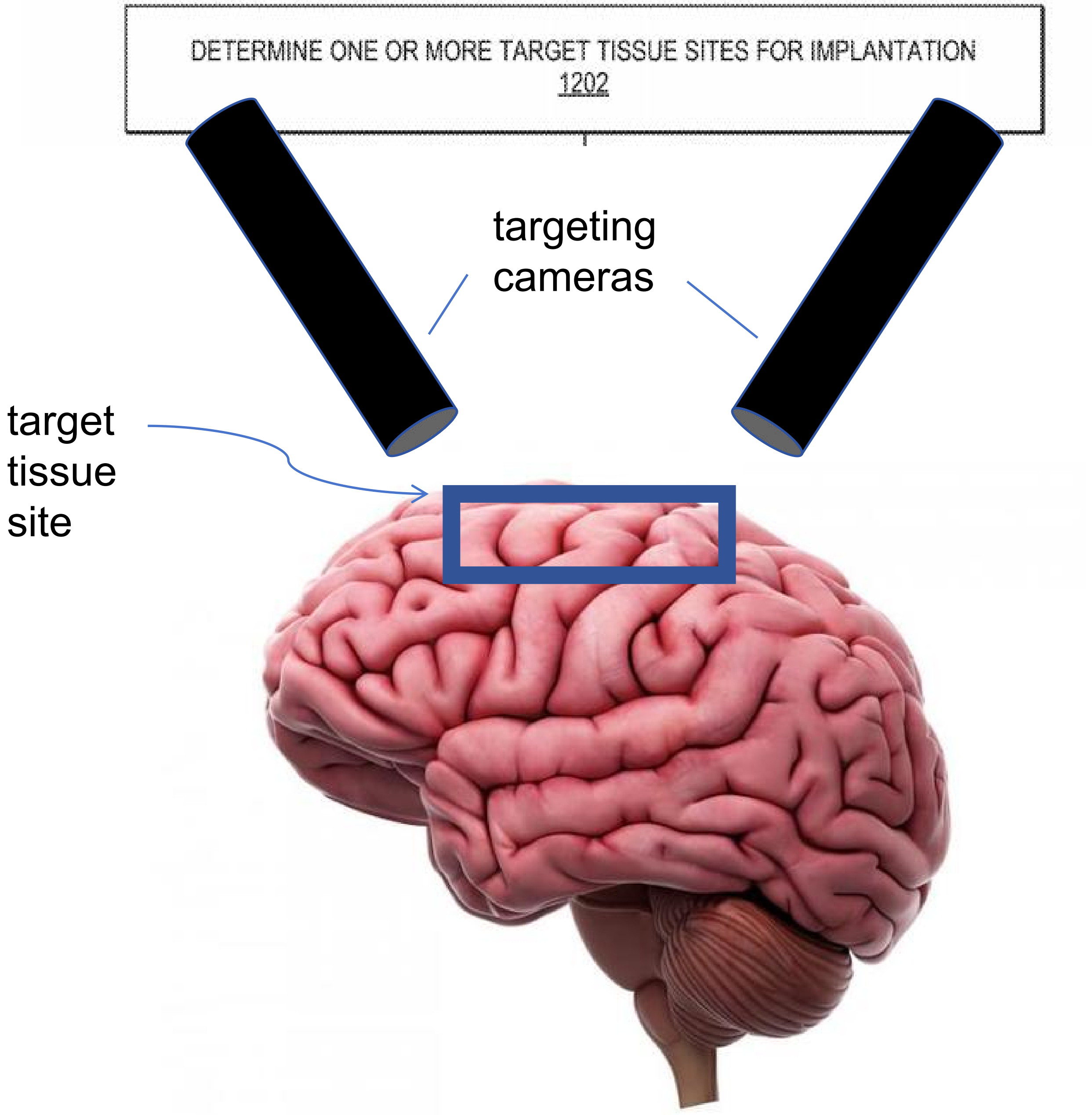
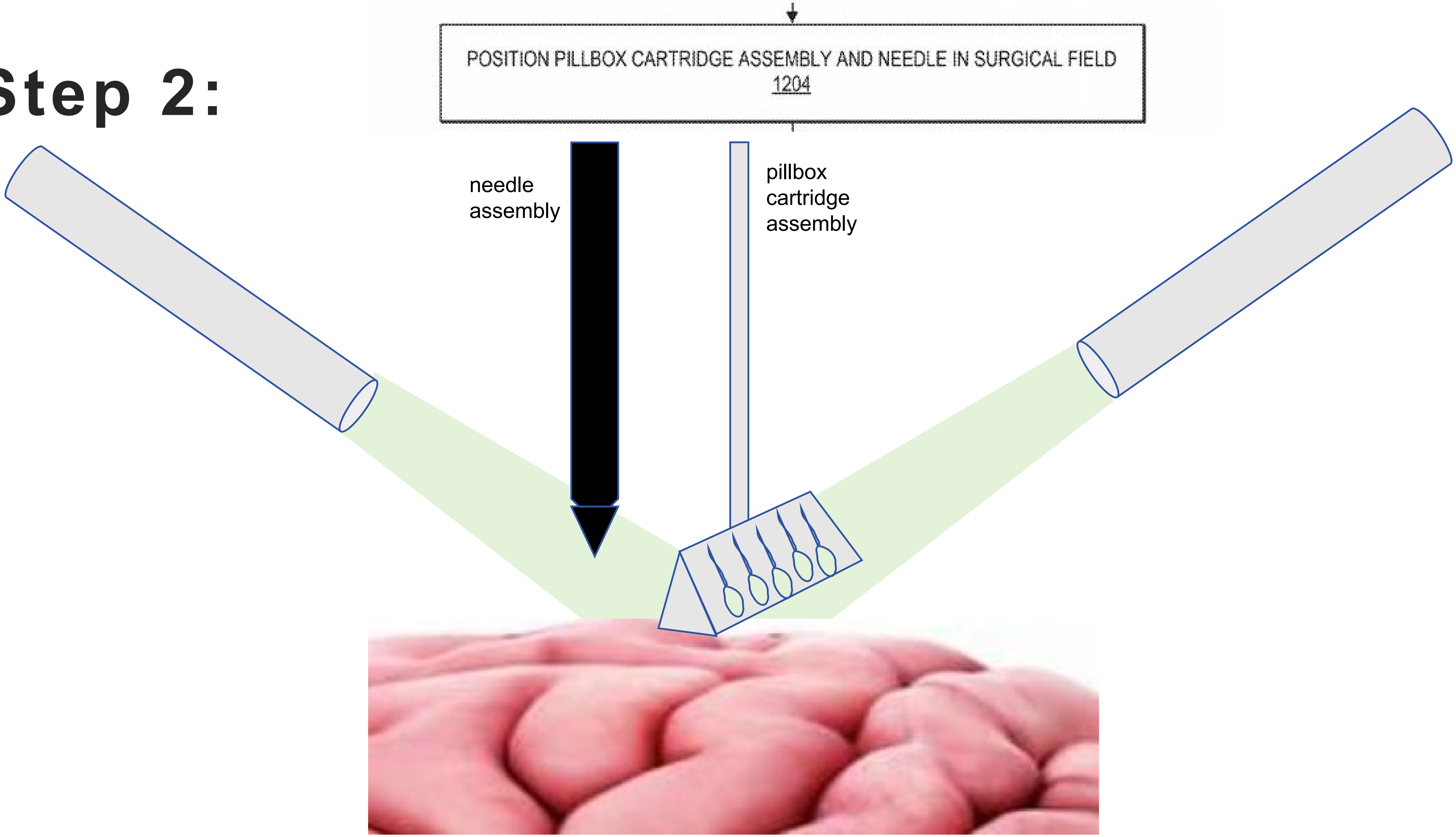


FIG. 12

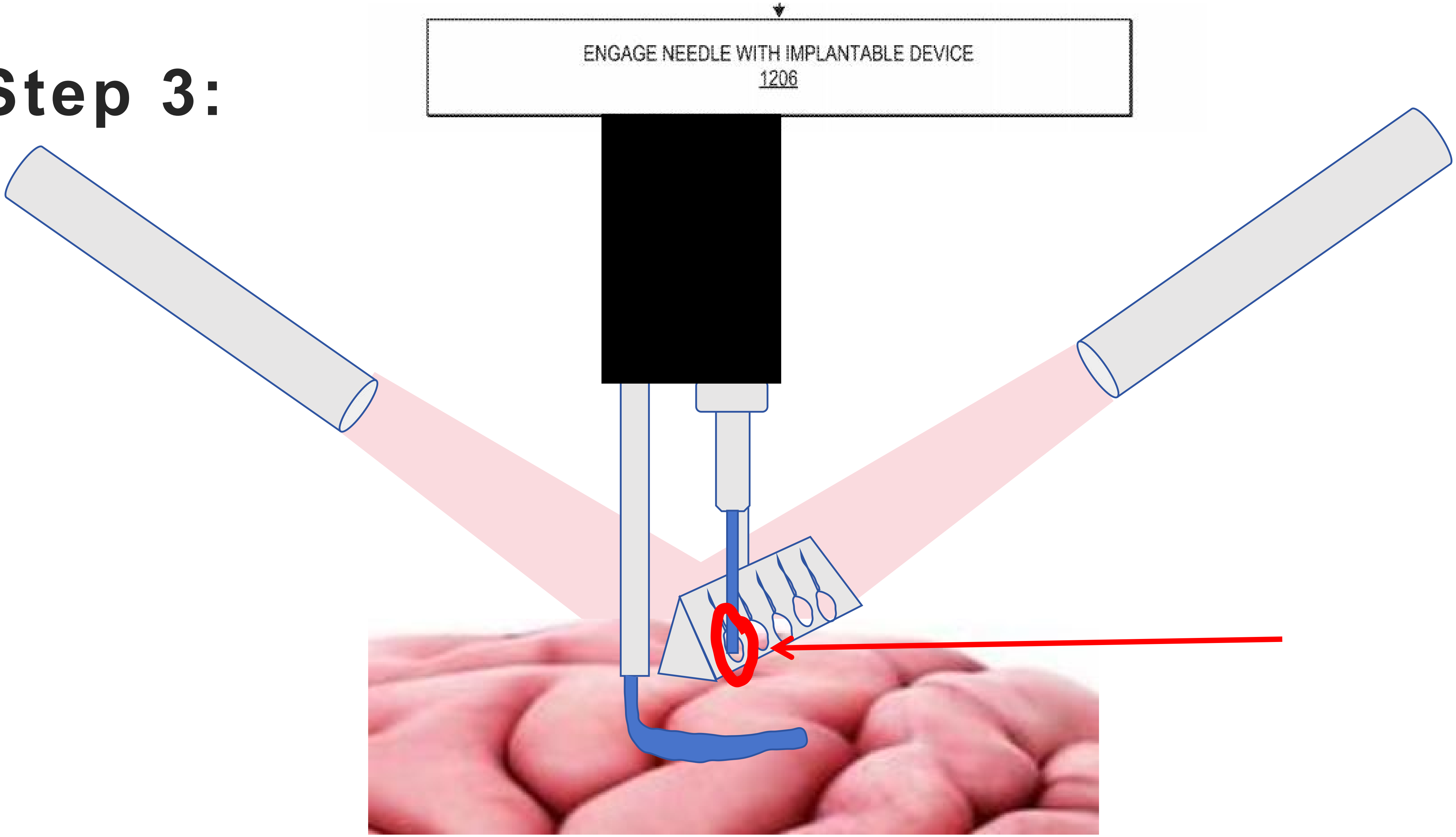
Step 1:


DETERMINE ONE OR MORE TARGET TISSUE SITES FOR IMPLANTATION
1202
targeting
cameras
target
tissue
site

Step 2:

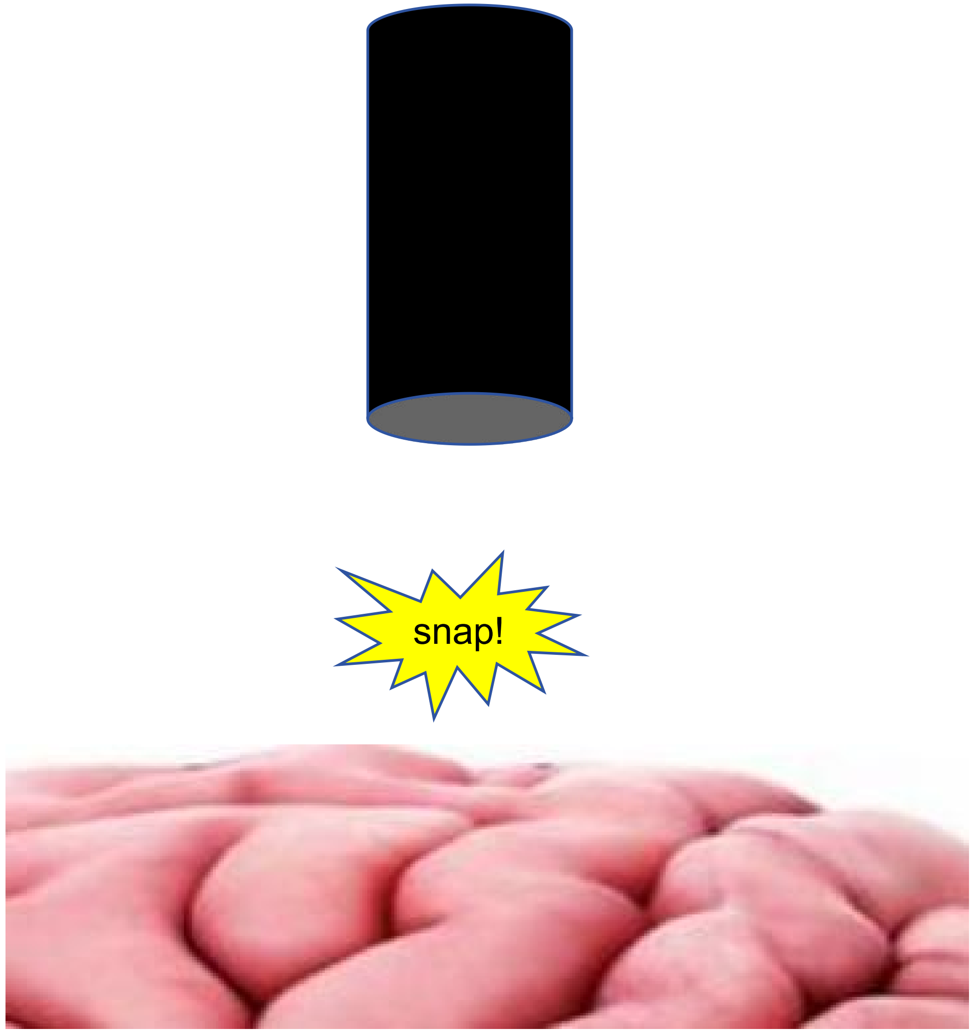

POSITION PILLBOX CARTRIDGE ASSEMBLY AND NEEDLE IN SURGICAL FIELD
1204
needle
assembly
pillbox
cartridge
assembly

Step 3:



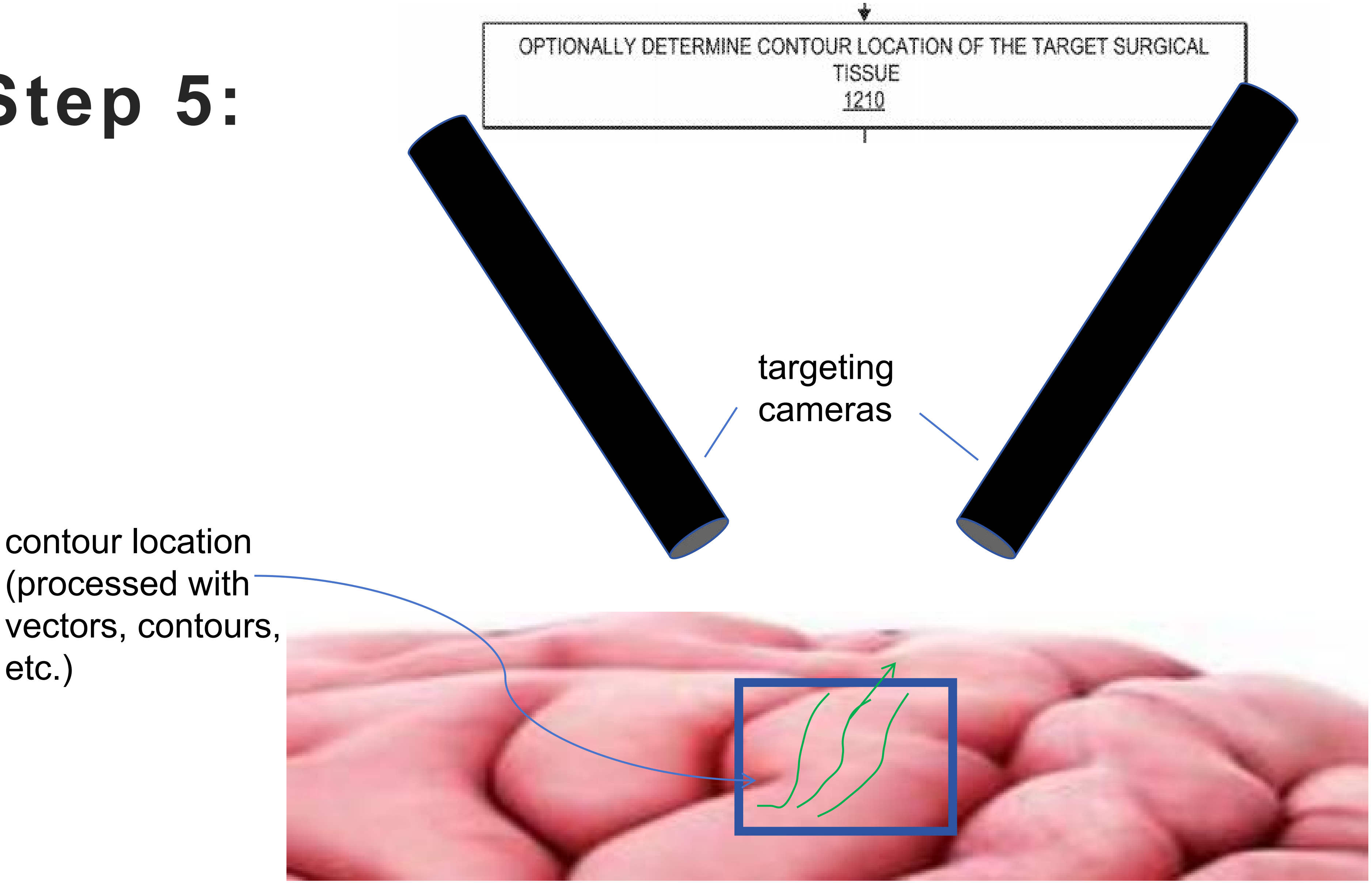
Step 4:

OPTIONALLY I MAGE TARGET SURGICAL TISSUE
1208



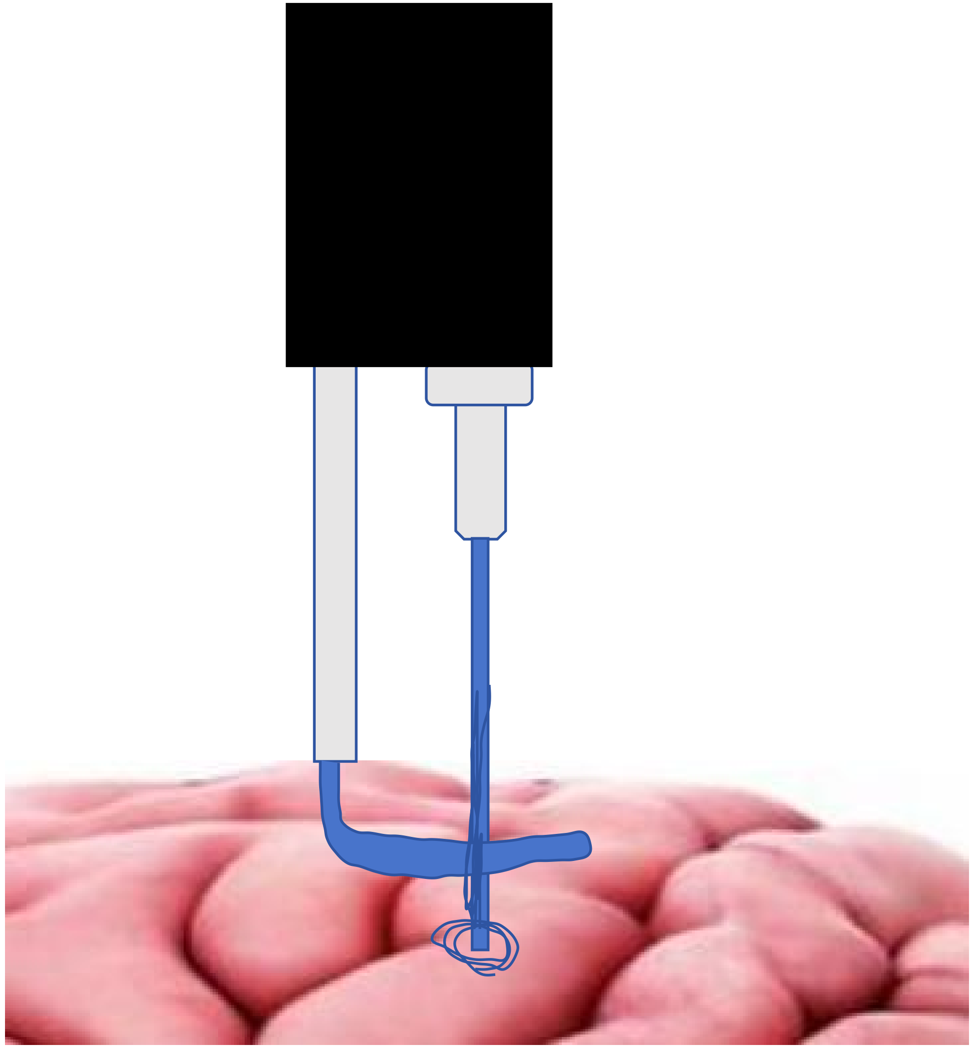
Note: real image not available for show

Step 5:


OPTIONALLY DETERMINE CONTOUR LOCATION OF THE TARGET SURGICAL TISSUE
1210
targeting cameras
contour location (processed with vectors, contours, etc.)

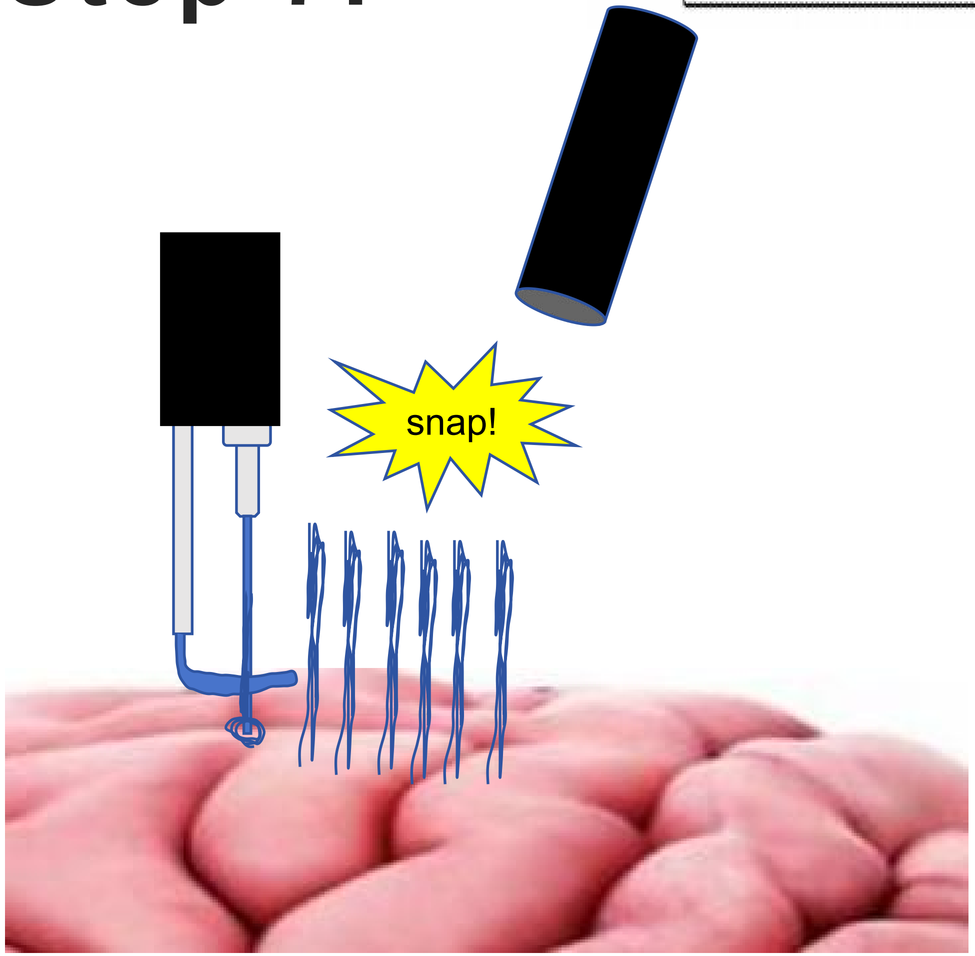
Step 6:

IMPLANT IMPLANTABLE DEVICE AND/OR NEEDLE INTO BIOLOGICAL TISSUE
1212



Step 7:

OPTIONALLY IMAGE ELECTRODE AND TARGET SURGICAL TISSUE
1214



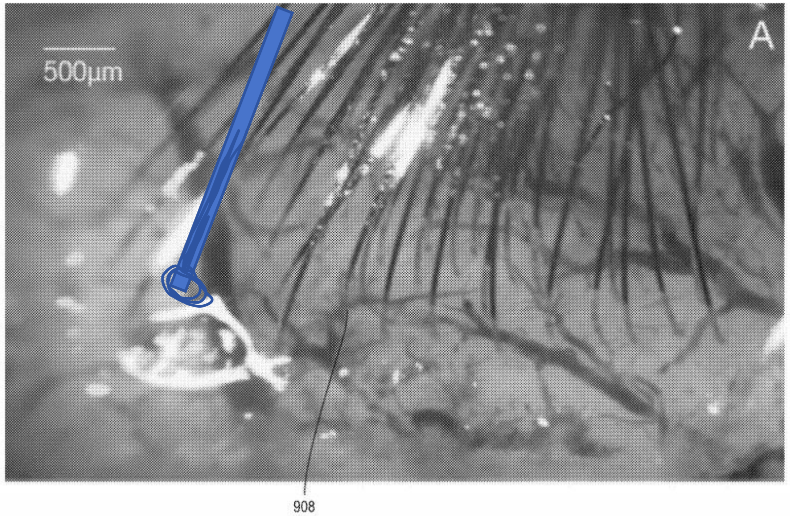


FIG. 9

Step 8:

VERIFY IMPLANTATION OF ELECTRODE DEVICE IN BIOLOGICAL TISSUE
1216

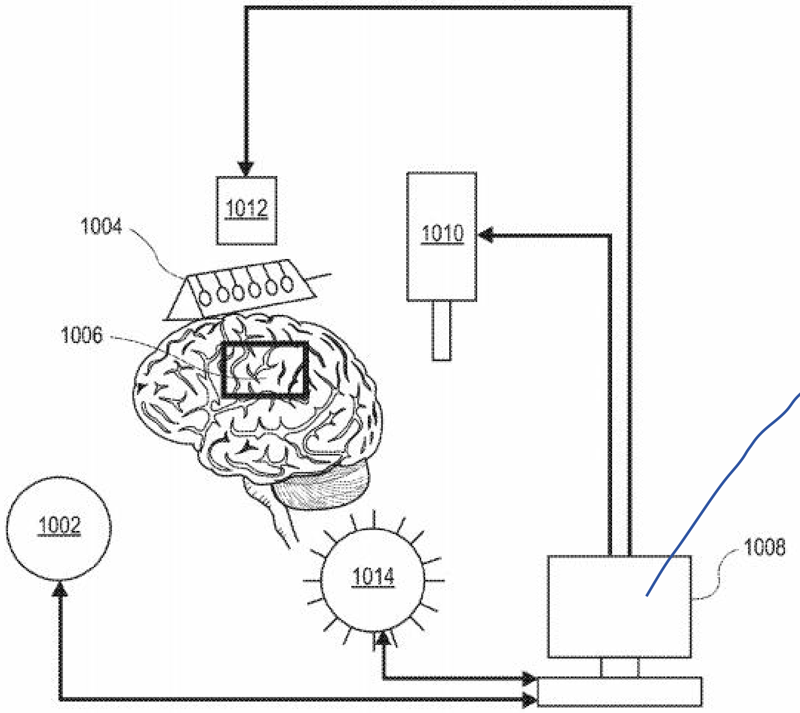


FIG. 10

Verification: computing system determines whether to **end system** or **return to step 4 for further correction**

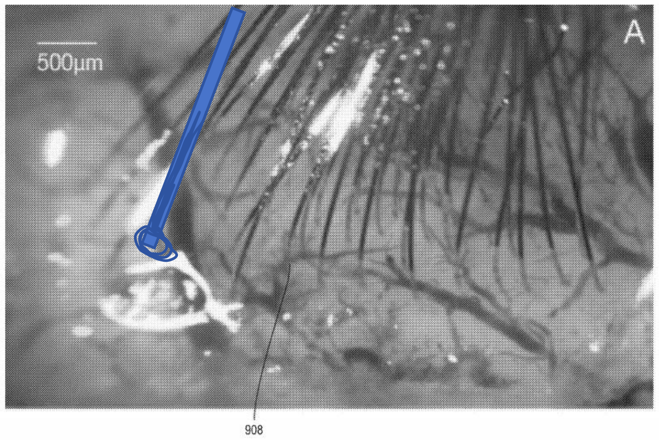


FIG. 9

Targeting during Robotic Surgical Implantation

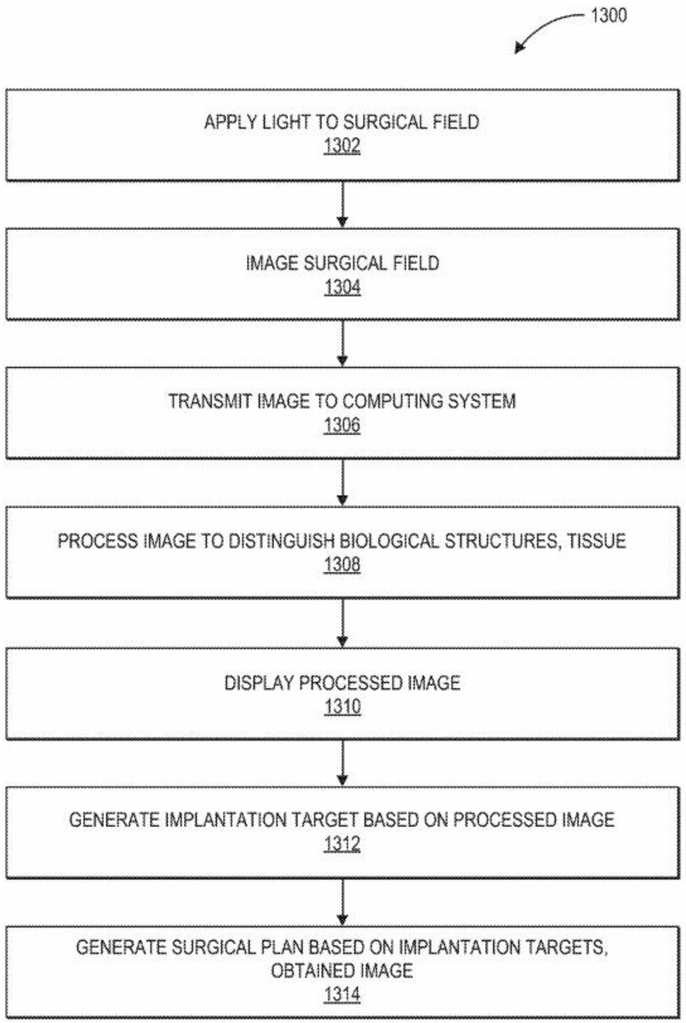
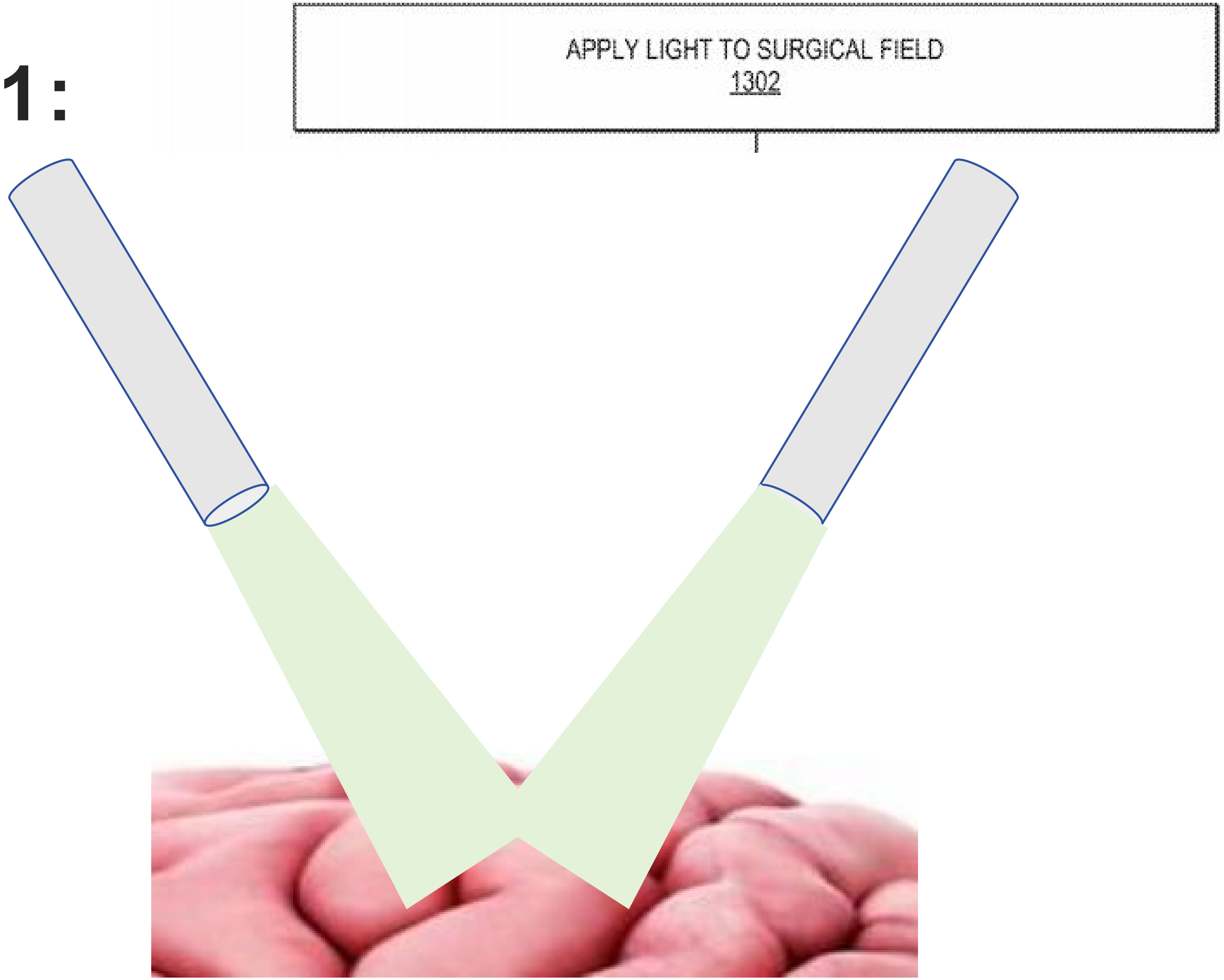
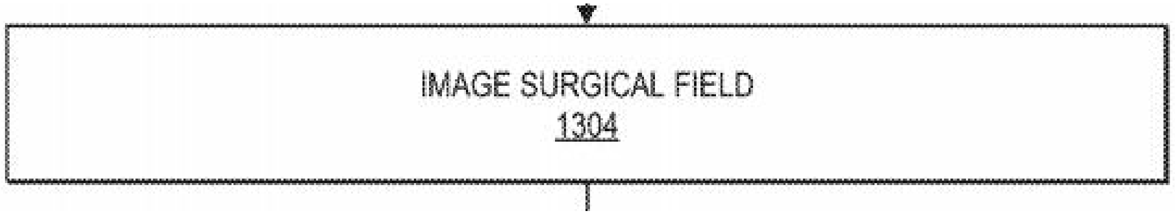


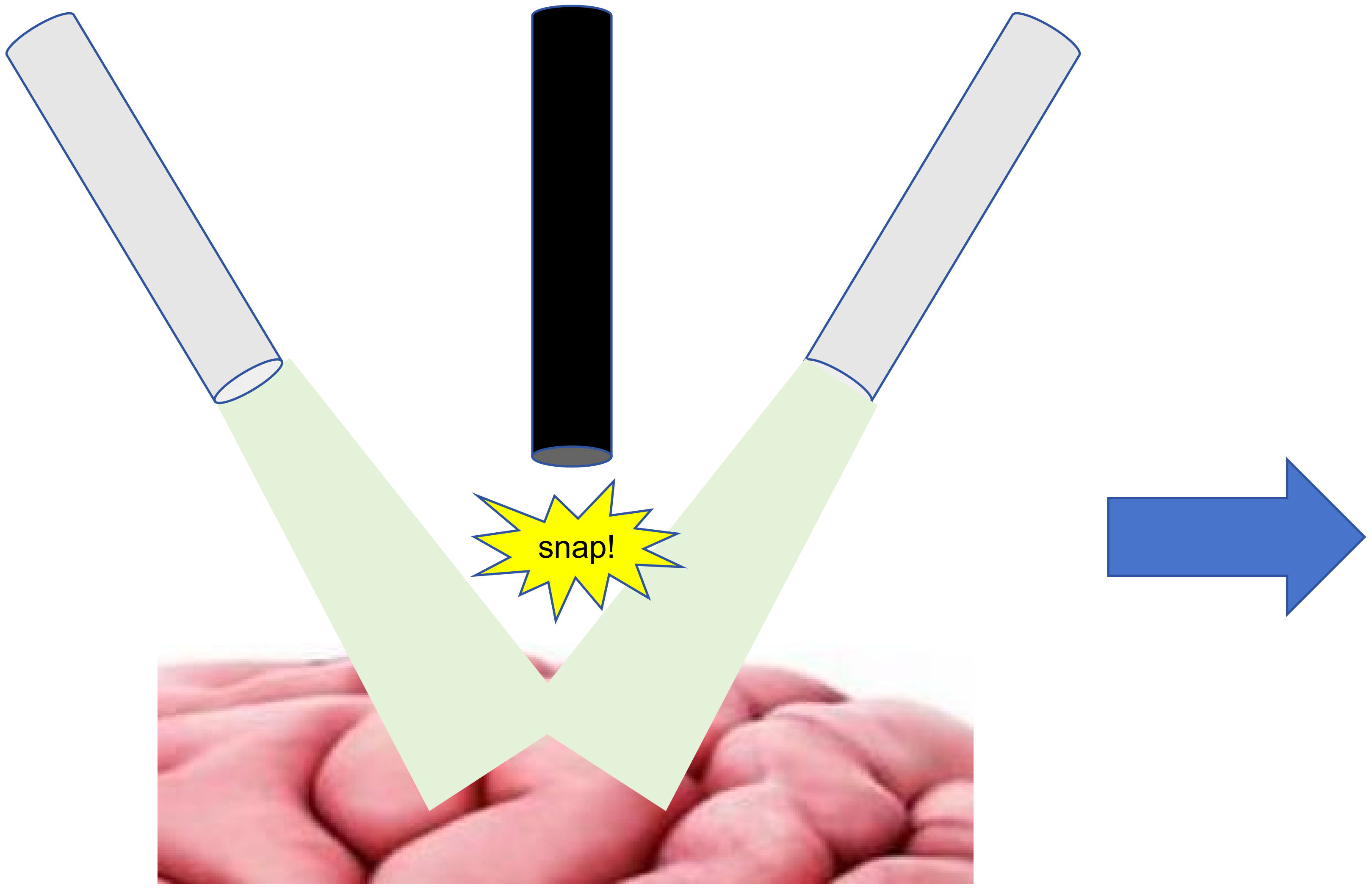
FIG. 13

Step 1:

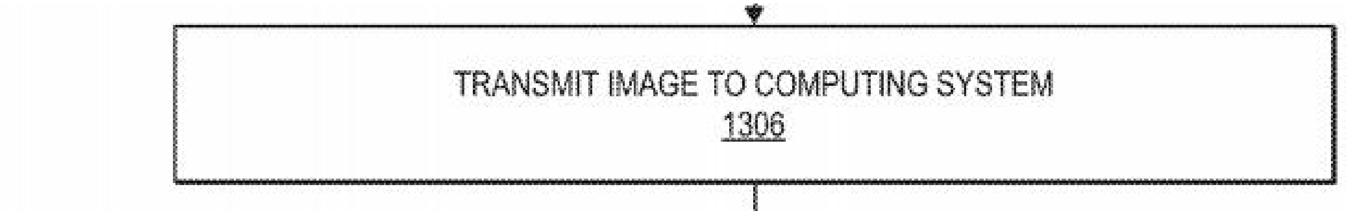


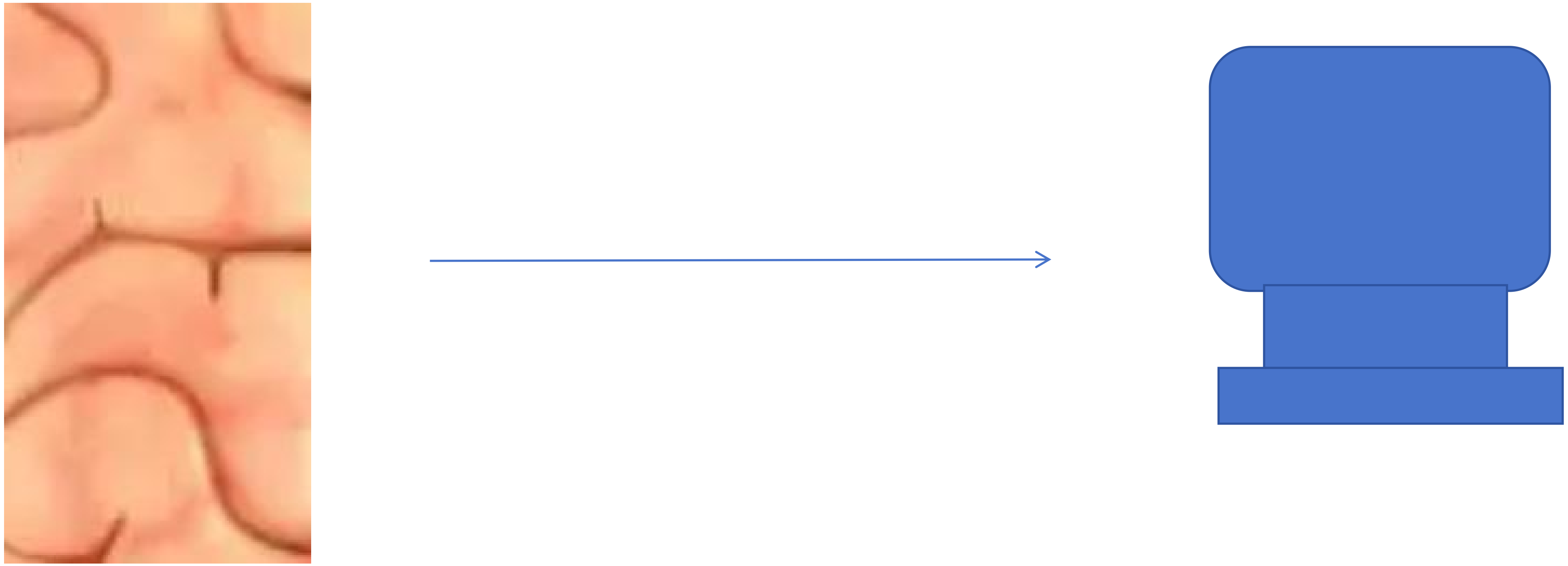
Step 2:





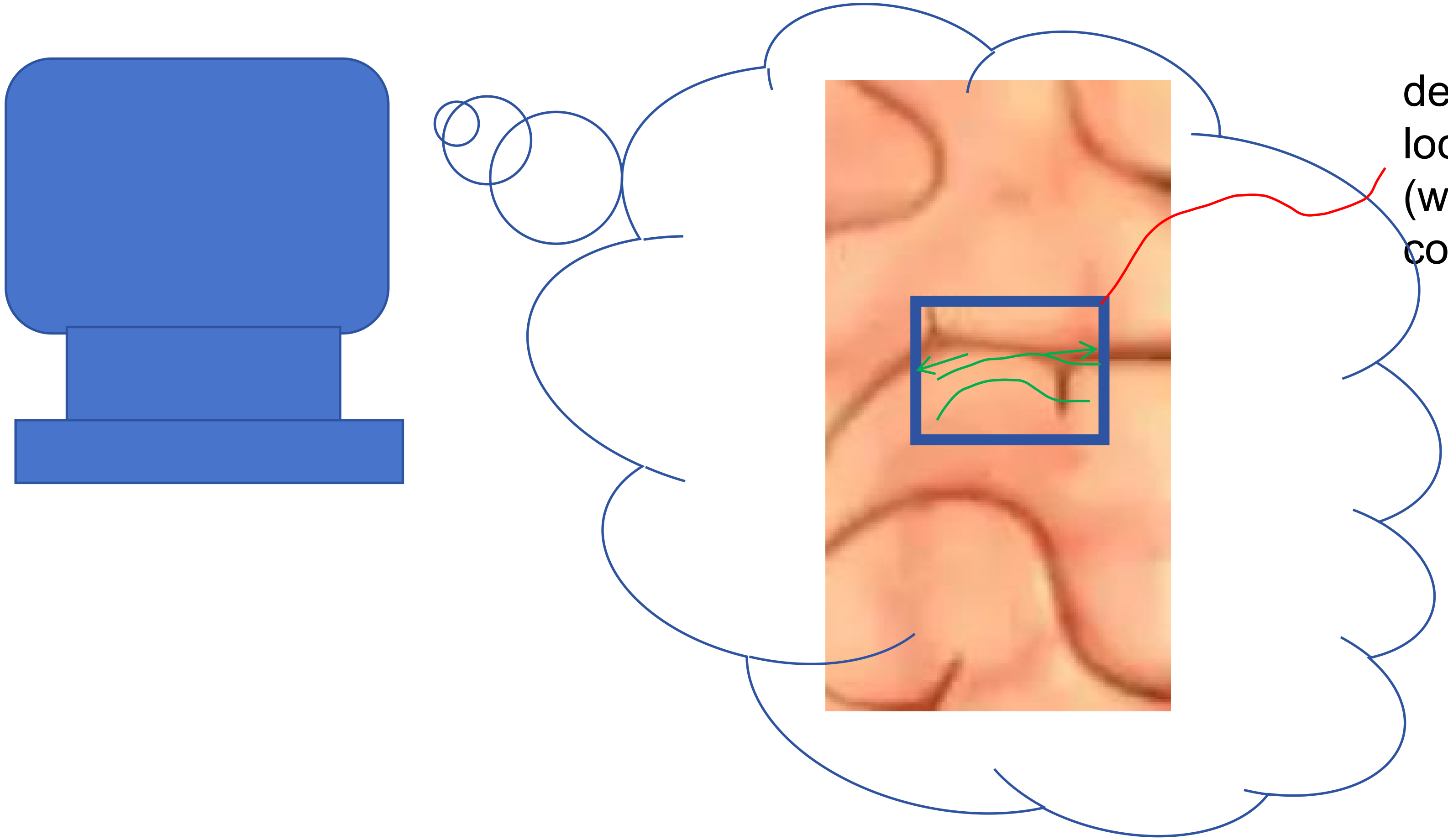
Step 3:





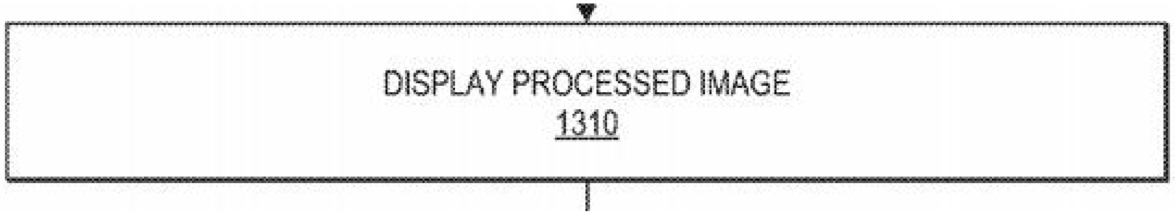
Step 4:

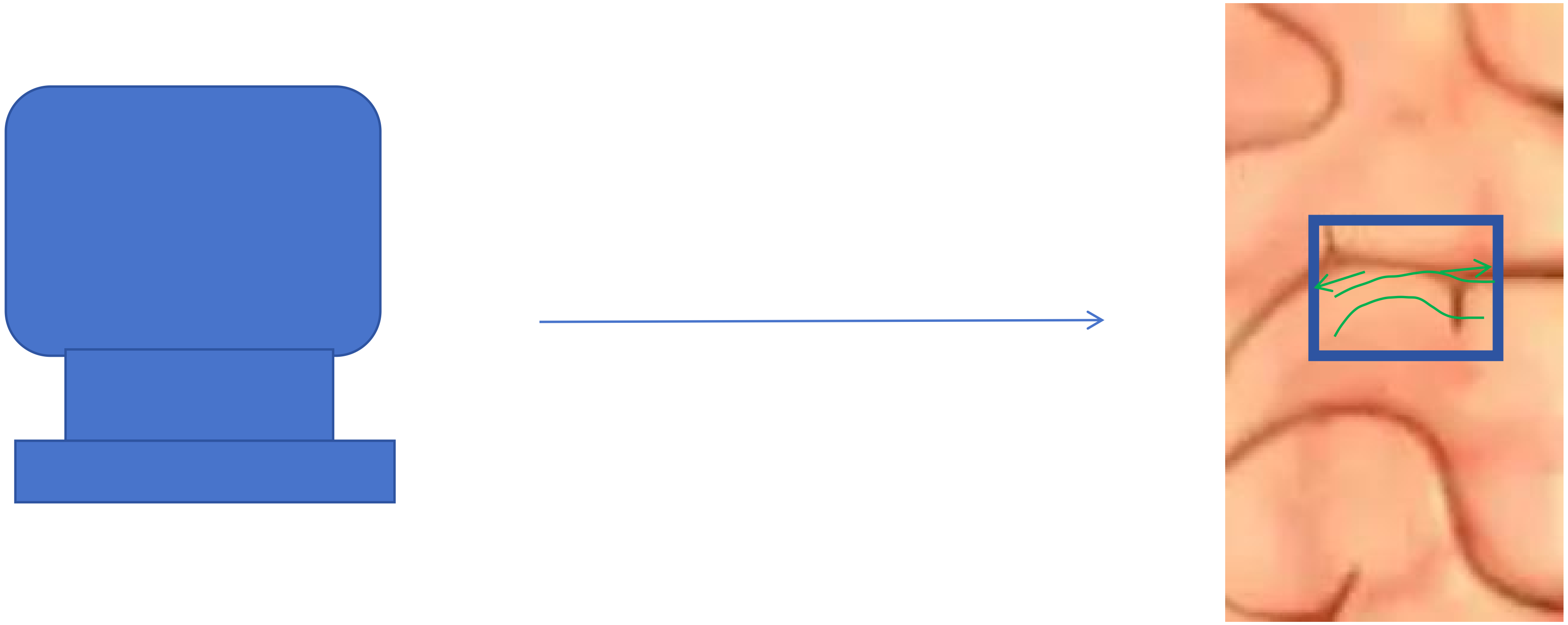
PROCESS IMAGE TO DISTINGUISH BIOLOGICAL STRUCTURES, TISSUE
1308



determine contour location of tissue (with vectors, contour lines, etc.)

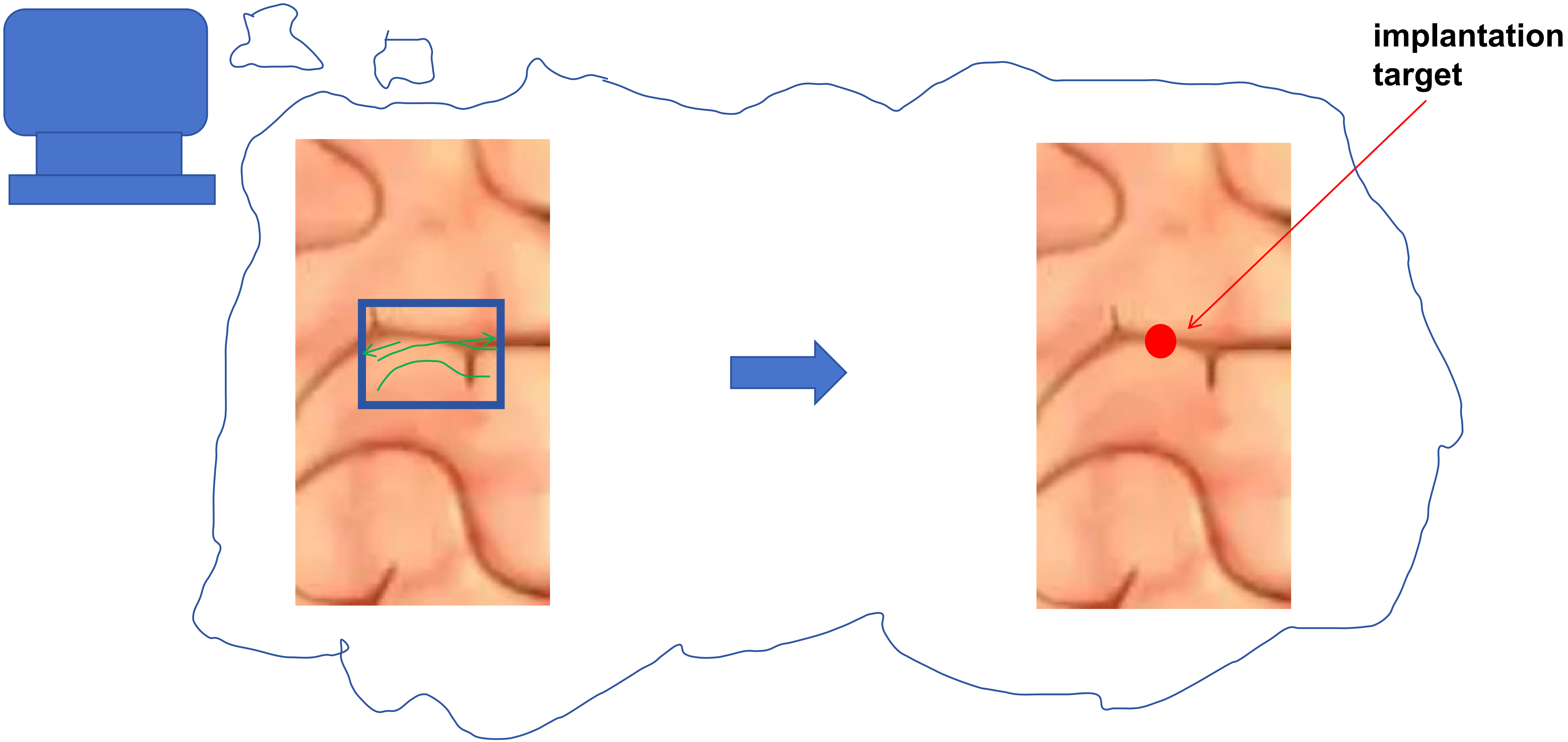
Step 5:





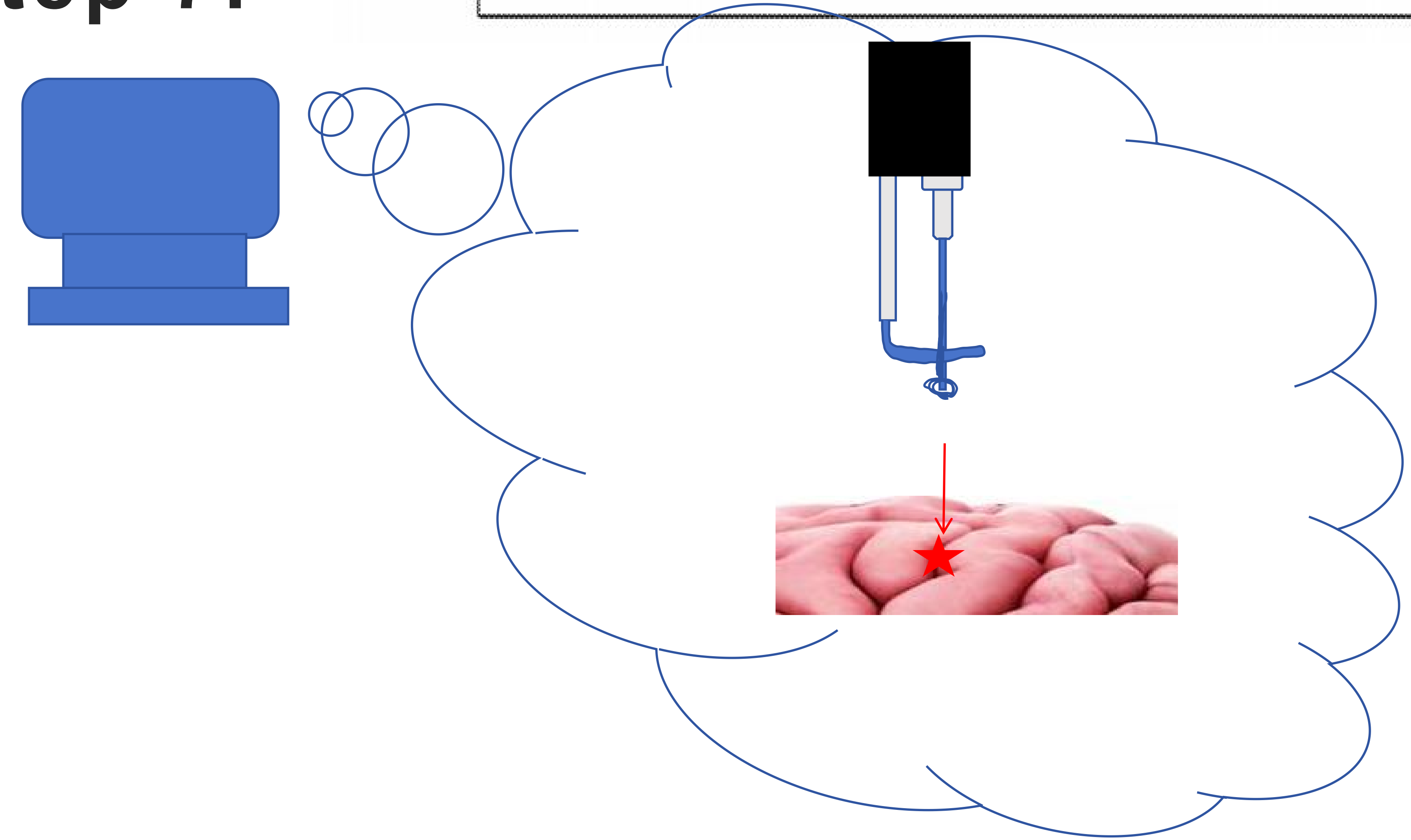
Step 6:

GENERATE IMPLANTATION TARGET BASED ON PROCESSED IMAGE
1312



Step 7:

GENERATE SURGICAL PLAN BASED ON IMPLANTATION TARGETS, OBTAINED IMAGE
1314



(in computer language, of course)

Verification during Robotic Surgical Implantation

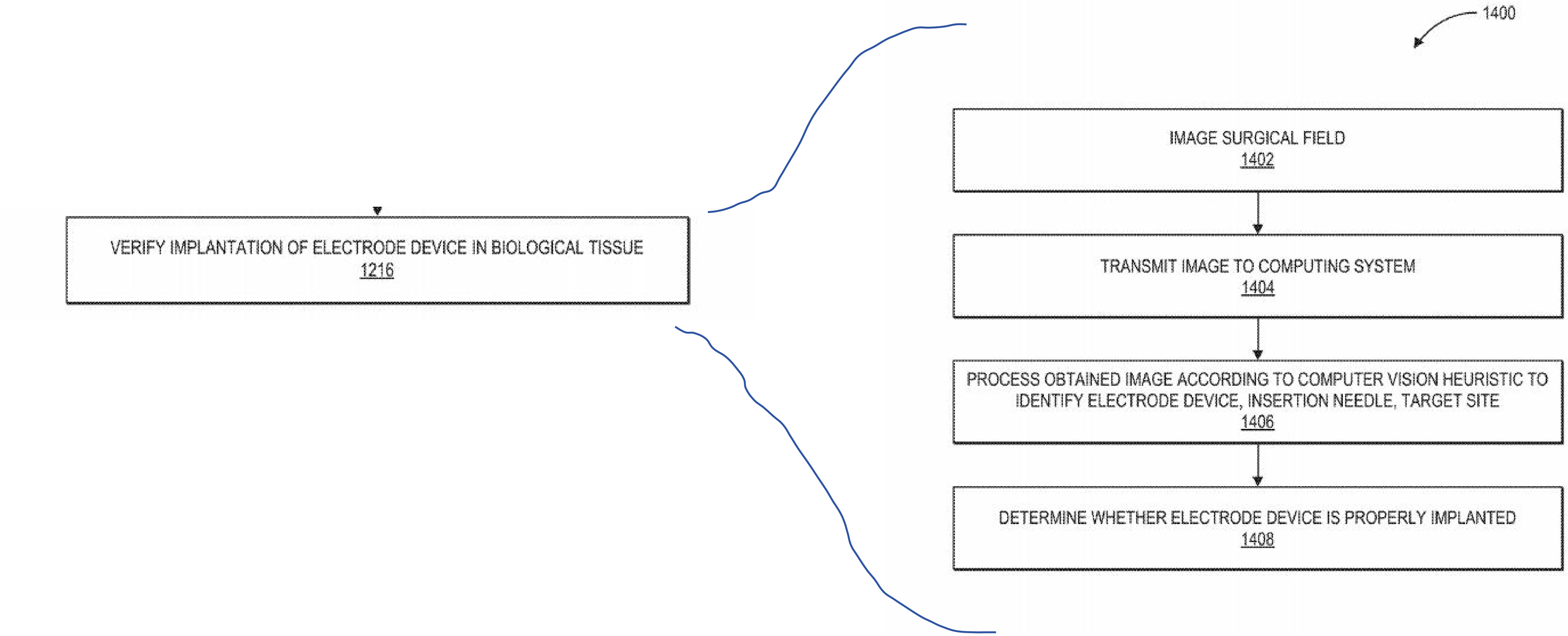
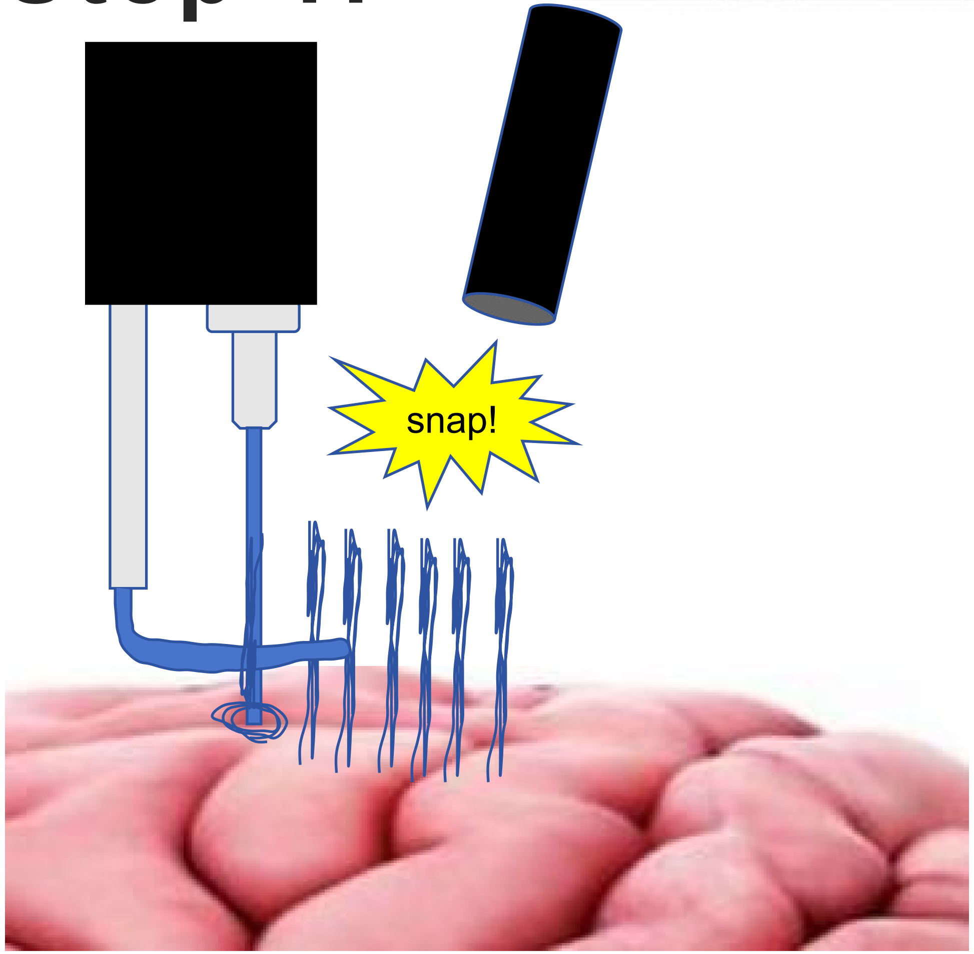


FIG. 14

Step 1:

IMAGE SURGICAL FIELD
1402



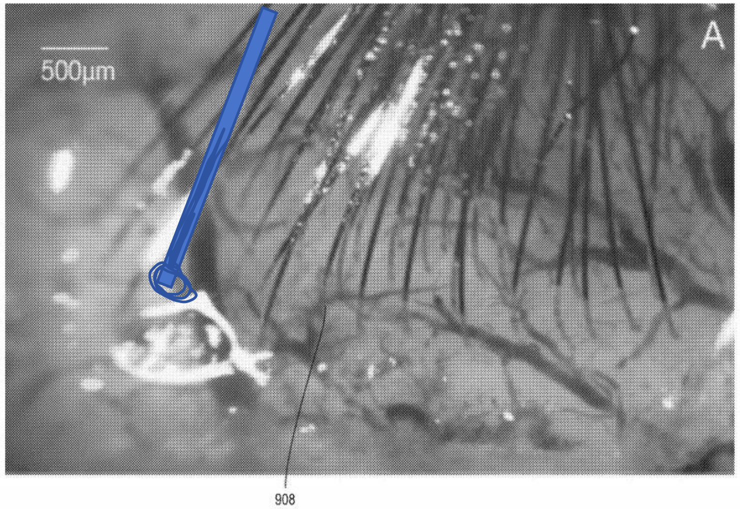


FIG. 9

Step 2:

TRANSMIT IMAGE TO COMPUTING SYSTEM
1404

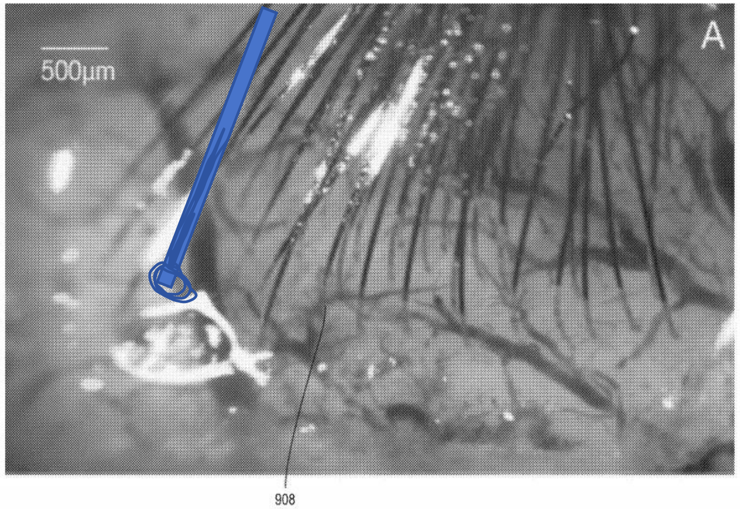
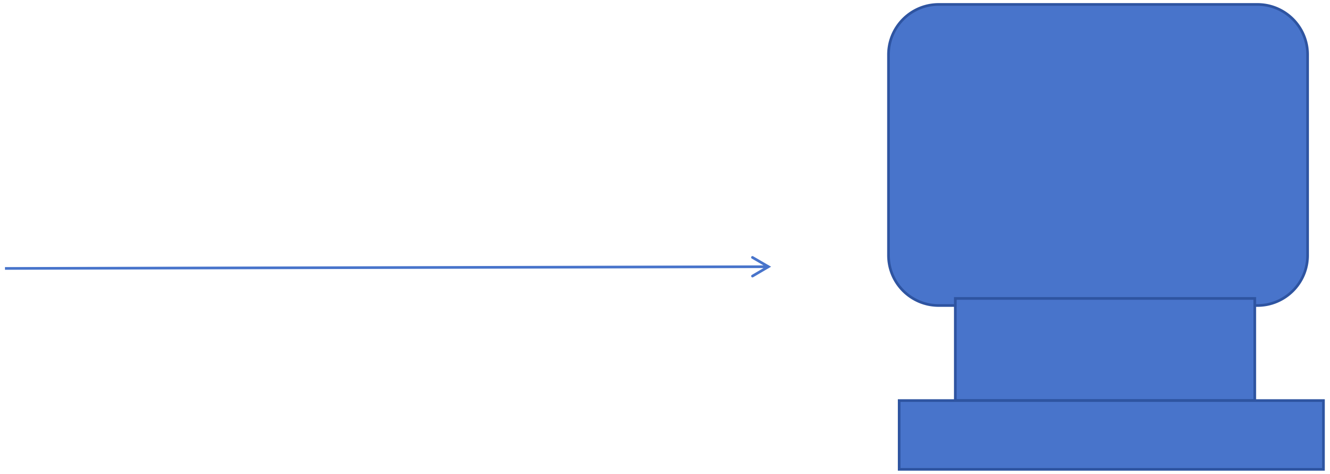


FIG. 9



Step 3:

PROCESS OBTAINED IMAGE ACCORDING TO COMPUTER VISION HEURISTIC TO IDENTIFY ELECTRODE DEVICE, INSERTION NEEDLE, TARGET SITE
1406

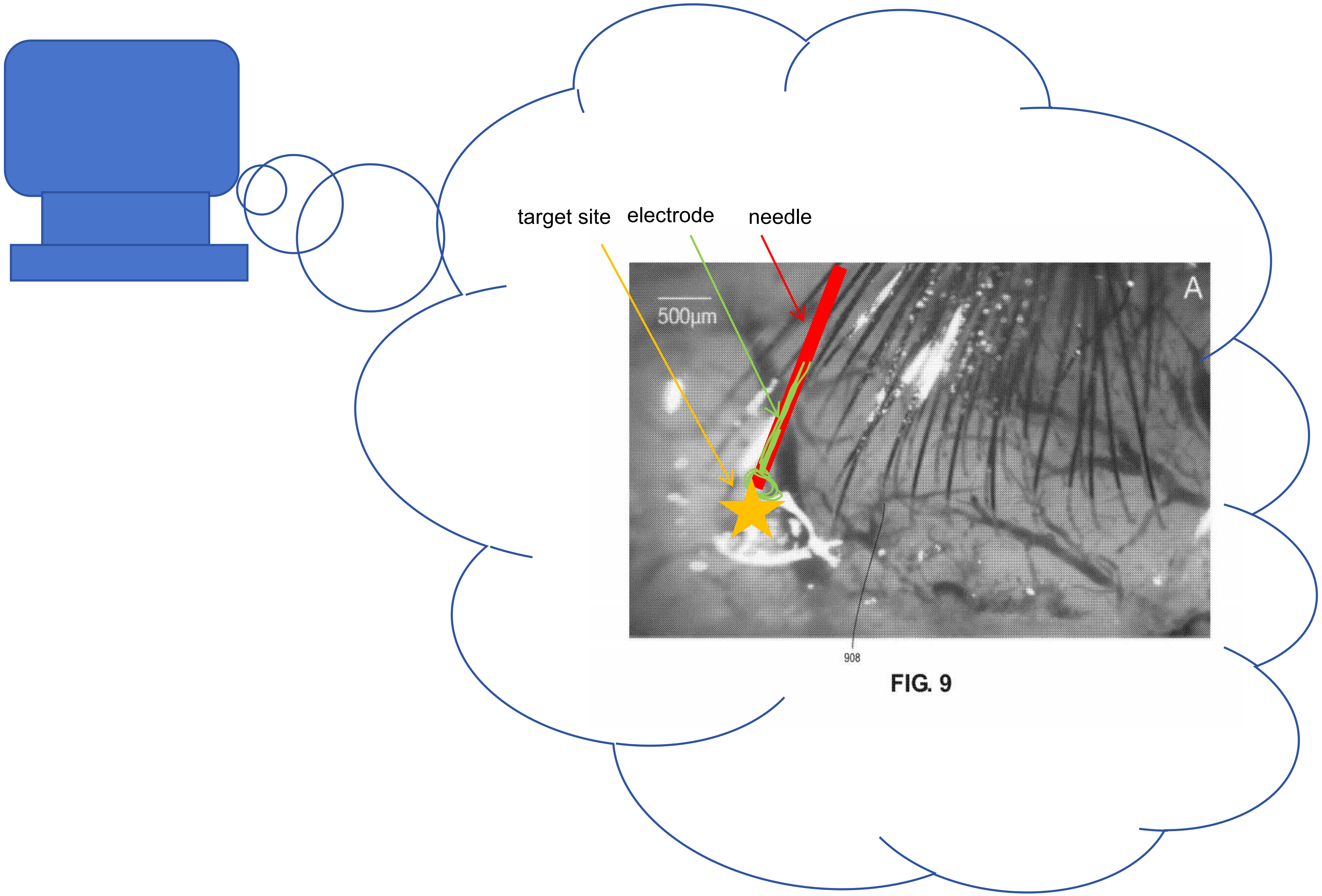


FIG. 9

Step 4:

DETERMINE WHETHER ELECTRODE DEVICE IS PROPERLY IMPLANTED
1408

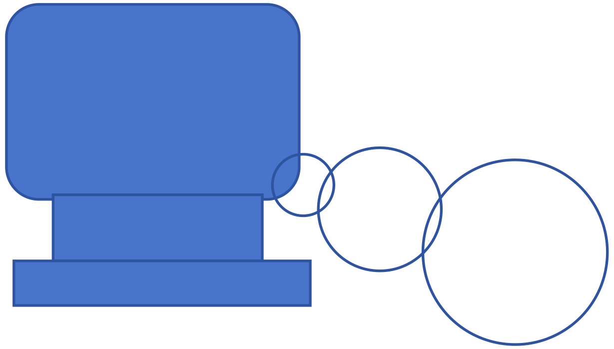


FIG. 9

based on **focusing stack techniques** (focal plane merging, z-stacking) - images of same surgical field have different focal depths

electrode properly implanted!!

Example Computing System for Robotic Surgery guided by Computer Vision

Displays:
e.g., cathode ray tube (CRT), light emitting diode (LED), liquid crystal display (LCD), etc.

Storage:
e.g., magnetic storage, tape, optical disks, etc.

Processors:
- implemented as appropriate in hardware, software, computer-executable instructions, etc.
- e.g., general-purpose computers, microprocessors, ASICs, FPGAs, DSPs, etc.

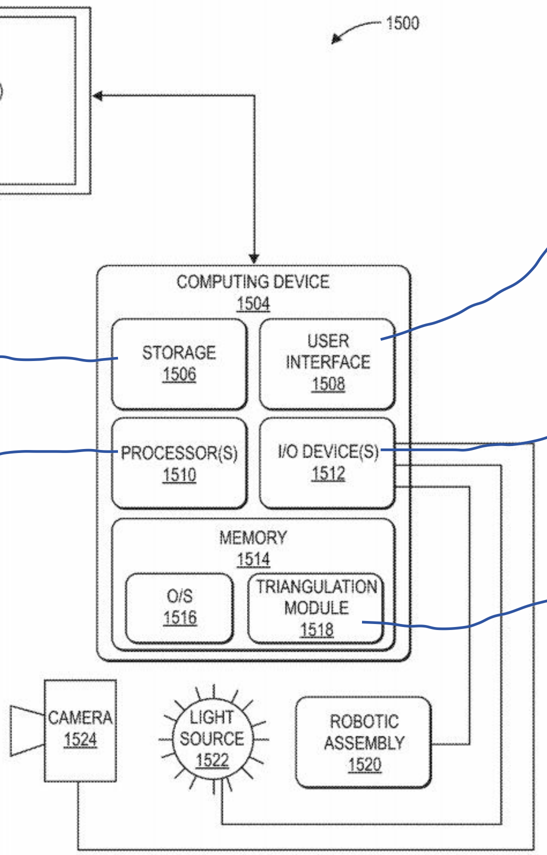


FIG. 15A

User interface:
- Utilized by authentication user to access portions of computable device
- Including GUI, APIs, web-based applications

I/O Devices:
e.g., keyboard, mouse, pen, voice input, touch input, printer, etc.

Triangulation Module:
- Triangulate location of objects - electrodes, needles, target tissue, etc.
- Store program instructions loadable and executable on processors
- Receive/adjust/implement linear combination coefficients for Laplacian estimation based on potentials measured by CRE

Example Components of Computing System for Robotic Surgery guided by Computer Vision

I/O Peripherals:
keyboard,
mouse,
microphone,
printer, etc.

Memory stores
OS, programs,
applications

Communication Peripherals:
Facilitate communication between computer system and any other computer device over communication network (e.g. network interface controller, antenna, modem, etc.)

Processor & Memory:
Can be virtualized and hosted within another cmoputer system of cloud network/data center

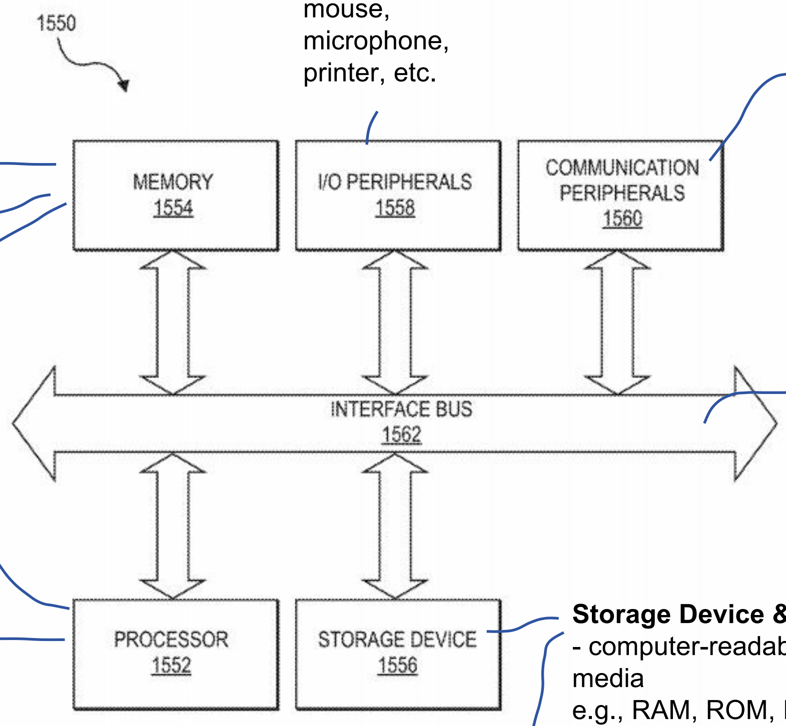


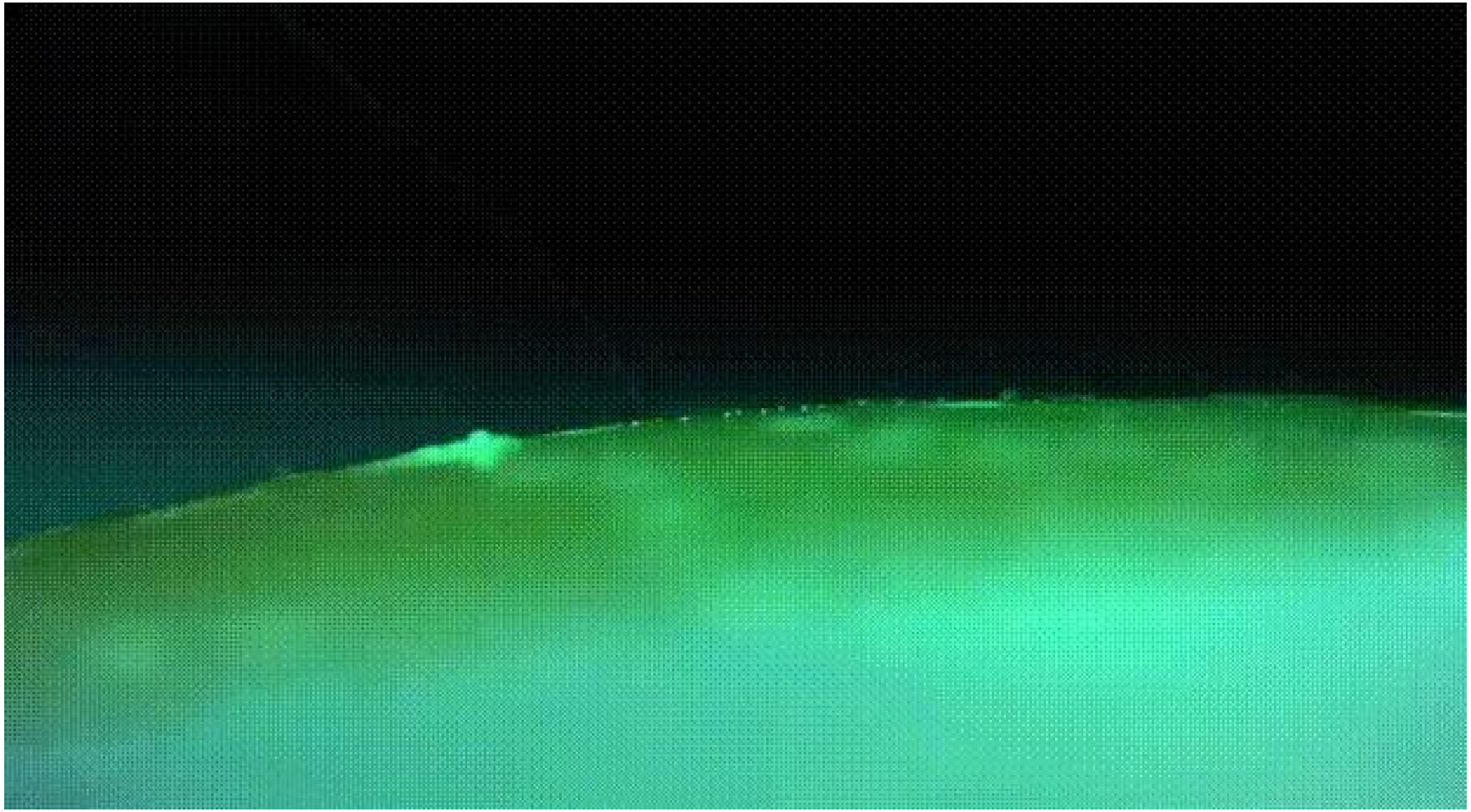
FIG. 15B

Interface Bus:
Communicate, transmit, transfer data, controls, command along various components

Processor:
- Execute stored instructions
- e.g., microprocessor, logical processing unit, DSP, etc.

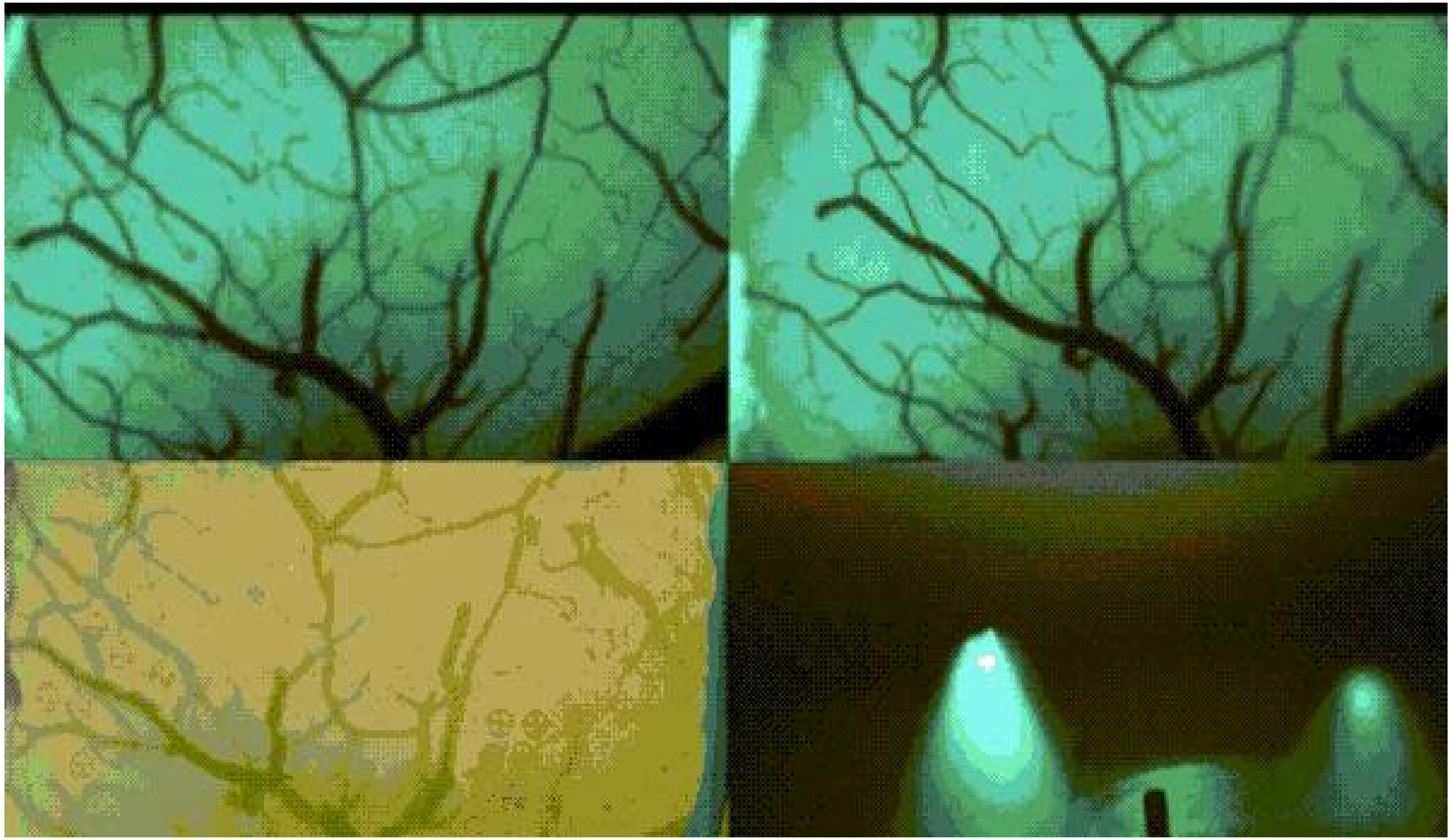
Storage Device & Memory:
- computer-readable **storage** media
e.g., RAM, ROM, EEPROM, hard drives, CD-ROMs, optical storage devices, flash, etc.
- computer-readble **signal** media
propagated signal (electromagnatic/optical)- with computer-readable program code

Video: Implanting Thread Process



Source: https://zhuanlan.zhihu.com/p/574574159

Video: Implanting Thread Process



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