Manual for Open-Source Neuronavigation System

*Please reference our paper if you use our platform or this manual.

Frank Preiswerk, Spencer T. Brinker, Nathan J. McDannold, and Timothy Y. Mariano

Table of Contents

Manual for Open-Source Neuronavigation System

I. Manual Overview

All procedures mentioned in this overview are explained step-by-step detail within the manual and can be found through the Table of Contents. The initial startup of the neuronavigation system starts by creating a general 3D Slicer scene for a specific transducer from the boilerplate scene provided in the opensource neuronavigation files. The boilerplate scene contains components in the virtual space of 3D Slicer: generic brain MRI, virtual transducer, transducer spatial peak intensity dot, pointer pen stylus dot, and a calibration positioner dot. Each of the virtual components are linked in real space to tracking devices placed within the view of the camera: head tracker, transducer tracker, transducer tracker, pointer pen, and positioner tracker, respectively. The manual incudes a Custom Equipment Registration section so the open-source neuronavigation system can be modified for other applications and includes directions on how construct custom tracking devices.

A transducer template pattern must be drawn or etched into the transducer (or custom transducer tracker has to be rigidly attached to the transducer) in order for the transducer to be registered into the neuronavigation system. First, the spatial peak intensity of the transducer must be identified to spatially calibrate the transducer dot and virtual transducer to the transducer tracker. A positioner tracker can be used to track the measuring device tip during calibration. The transducer-specific scene created will then be used to make patient-specific 3D Slicer scenes.

Immediately after the patient receives their MRI scans (with MRI fiducials on their head) to be used in the Neuronavigation system, the patient must be placed in view of the navigation camera with the fiducials still in place to conduct MRI-to-Anatomical fiducial landmark registration. This event can take place outside the MRI suite. The MRI fiducials must not be moved before this procedure or else the navigation registration will not work properly. Patient MRI scanning files are uploaded into the 3D Slicer scene, which will replace the generic brain MRI scan in the scene. A head tracker is then tightly strapped to the patient's head and then the MRI fiducial locations are measured using the pointer pen. Next the anatomical landmarks locations (inion, nasion, right and left ear preauricular) are measured with the pen and the procedure is then finished. The navigation system is designed so the patient only needs receive one MRI scan for all future neuronavigation-guided transducer usage events.

At the beginning of each transducer usage event, the patient is to be fitted with the head tracker and the patient's scene opened in 3D Slicer. The anatomical landmarks are then measured with the pointer pen so 3D Slicer can track the transducer movement relative to the patient head movement. The MRI coronal, sagittal and axial slice orientations remain static in the 3Dslicer scene regardless patient head movement.

The transducer spatial peak intensity dot position will always be projected in real-time within the MRI images. Camera movement will not affect any of the navigation tracking as long as all of the tracking devices are in the camera field of view and not visually obstructed.

A few practical practices to avoid mistakes when using the system are as follows. Always save the 3D Slicer scene after each modification increment conducted incase an intermediate mistake is made to avoid having to start all over again with the general boiler page scene. After activating the camera in a new session, place the pen on a hard surface and swivel the pen while the tip is still to be sure the pen is swiveling around its tip appropriately. This is recommended to be done before registering new references points. The pivot calibration can be performed if the pens is not swiveling around its tip properly. A common mistake when registering new references points into 3D Slicer is accidently standing in the view of the camera while pointing the pen to a particular positions and clicking the mouse to record the point. It is recommended to wiggle the pen tip and visually verifying the camera is tracking the pen before placing the pen in the final position to record the reference point. The slice follower will need to be toggled on/off during various operations of this system. It is important that the hot-spot MRI slice follower is not active during manipulation of the 3D Slicer scene.

II. System Instillation and Startup

2.1 Software Pre-requisites

1. Windows 64 bit.
2. PLUS Toolkit
3. 3D Slicer with Sequences and SlicerIGT extensions
4. NDI drivers
5. 6D Architect

2.2 Loading software to computer

1. Download NDI_ToolBoxv5-001—017_for_Windows(64-bit).exe driver folder to computer directory. Make sure IGT Open
2. Plug in the NDI camera power cord and verify the camera is turned and then plug the camera USB into the computer.

3. Install NDI_ToolBoxv5-001—017_for_Windows(64-bit).exe driver. When the dialog box asks you to Select Destination Directory, click Browse. Then create a new folder in Documents and call the folder NDI. Click on the new folder and then click Select. Then copy and paste the directory path shown in the text box for use in a later step.
4. Plug in the NDI camera power cord and verify the camera is turned and then plug the camera USB into the computer.
5. Open Control Panel, search for Device Manager in the search box and then click on it when it shows up in the results list.
6. In Other Devices, expand the list to see NDI Host USB Converter. Double click on it and select Update Driver, select Browse my computer for driver software.
7. Paste the directory path from the early step into the text box and then click Next. Then click Install. Once Driver Software is successfully installed click Close.
8. To validate the camera is properly linked to the computer, expand Ports (COM & LPT) to see NDI Host USB Converter Port (COM3) is there. In some cases, you must close and reopen device manager to see this validation.
9. Next install PlusApp-2.6.-.20171113-Win64.exe.
10. It is important during the rest of these instructions to use the correct directory path or else the system will not work. All the Neuronavigation folders should not contain spaces in the title or directory path.
11. Open Plus Server Launcher and under Device set configuration directory: Open the directory path to the ending in the Config folder.
12. Under Device set: choose Neuronavigation real skull.
13. Then push the pencil & paper icon left of the Device set scroll down menu. A Notepad script window will appear. Within this script, there are four separate lines containing directory path text. They each include RomFile="…\Rom\. The boilerplate script included in this research article has for example: RomFile="C:\Users\Spencer\Documents\Navigationbackup5-22-2018\Rom\sentinel_reference_2.rom". Here the directory path must match where you have store the neuronavigation main folder containing the Rom and Cong files.
14. The COM number listed in the Device Manager must also be implemented in the Notepad script. The Boilerplate script contains a line text as SerialPort="3". The number in this line must match

the COM number in the NDI Host USB Converter Port (COM3) in the Device Manager list. It may change depending on which USB port is used during instillation of the NDI driver software.

15. When all changes are made to the Notepad script, select File and push Save. Then exit Notepad.
16. With the camera power plugged in and the USB converter properly linked to computer as described above in Device Manager, press Launch Server in Plus Server Launcher.
17. The Plus Server Launcher should read Connection successful! If the camera is correctly linked to the computer.
18. In 3D Slicer you must download the correct extensions as follows.
19. While in 3D Slicer, click on **View** drop down list in the top left corner and then select **Extension Manager**.
20. Then click the **Install Extensions** tab and in the Search box in the top right type **Sequences**.
21. Next click on **Install** under the Sequences modules. Click **Yes.** Once the module is up loaded, click **Restart** button shown in the lower left region of the screen. Then click **Ok.**
22. Repeat this process to install the **SlicerIGT** module to 3D Slicer.

2.3 Startup camera in 3D Slicer

1. Start PLUS Server Launcher
    a. Device set configuration directory: *H:/Neuronavigation/Config*
    b. Device set: *Neuronavigation real skull*
    c. *Launch server*. Indicator light on the bottom right of the window should turn green.
2. Start 3D Slicer, or better the *Slicer preset scene*
3. In the top menu, click the magnifying glass (search), type *OpenIGTLinkIF*
4. Connectors: If there is no node below Scene, click the *+ button.* In any case, select that ***IGTLConnector*** underneath Scene
5. Properties:
    a. Make sure Type is *Client*, Hostname is *localhost*, Post is *18944*
    b. Click *Status:* ***Active***

III. Transducer Spatial Calibration

3.1: Setting transducer with template to transducer tracker

1. *Fiducial Registration Wizard*
2. ***From fiducials***: select ***ApplicatorModelFiducials*** from dropdown list (pts clicked on model)
3. ***To fiducials***: select ***ApplicatorFiducials*** from dropdown list (pts gathered from 3d camera)
4. Place fiducials using transform (click triangle if menu is collapsed): select ***StylusTipToStylus Applicator*** in **second** dropdown box
5. Registration result (From->To) transform: select ***ApplicatorModelToApplicator***
6. Result transform type: ***Rigid*** *(or similarity)*
7. Delete all points in "***To fiducials***" if any.
8. Select all landmarks using the pointer tool one by one by clicking ***Place 'To'***. The template pattern contains 4 points around a 54 mm dimeter circle at 3, 6, 9, and 12 o'clock. This template pattern must be etched into the physical transducer being registered to the navigation system. The points must be selected on the transducer with the pointer tool in same order as the points appear in the Boilerplate scene 3D model transducer.
9. Check the order of the four points on the transducer geometry listed in the ***ApplicatorModelFiducials***. It may take some troubleshooting to make sure the **ApplicatorFocus** appears on the correct side of the virtual transducer. The notch points may need to be flipped to change the direction of the virtual transducer to match the physical transducer orientation.
10. Click ***Update*** button to compute and store the transform and to complete the transducer and transducer tracker registration.

3.2: Selecting positioner focus (hydrophone tip example for focused ultrasound transducer application)

1. *Fiducial Registration Wizard*
2. ***From fiducials***: select ***Positioner focus*** from dropdown list
3. ***To fiducials***: select ***ApplicatorFocus_temp*** from dropdown list
4. Place fiducials using transform: (click triangle if menu is collapsed): select ***StylusTipToStylus Applicator*** in the ***first*** and ***second*** dropdown box.

5. Delete all points in "***To fiducials***" if any
6. Select the hydrophone tip landmark position using the pointer tool by clicking ***Place 'To'***.
7. Drag the ***Positioner focus*** point from the ***From fiducials*** box to overlay on the new ***ApplicatorFocus_temp*** just created in the MRI window representing the hydrophone tip location.
8. Then verify the ***Positioner focus*** point is locked.
9. It is very important to register the transducer to the transducer tracker before setting Selecting the ApplicatorFocus with the hydrophone tip. This step must be done because 3D Slicer needs to know the location of the transducer via the transducer tracker before marking the ApplicatorFocus location. To register the transducer to the transducer tracker, the navigation pen must be used, which cannot be done while the transducer in underwater before or after a hydrophone scan.

3.3: Setting the transducer crosshairs

1. This section is to be done once the location of the spatial peak intensity of the FUS focus in identified with the hydrophone. Or in the TMS case by using a custom template to identify the hot spot desired to projected in the MRI virtual space.
2. *Fiducial Registration Wizard*
3. ***To fiducials***: select ***ApplicatorFocus*** from dropdown list (pts clicked on model)
4. Drag the ***ApplicatorFocus*** point from the ***To fiducials*** box to overlay on the location of the ***Positioner focus*** point in the MRI window representing the hydrophone tip location. Make sure the ***Positioner focus*** point remains locked during this operation and then lock the ***ApplicatorFocus*** point once dragged over the position of the ***Positioner focus*** point.
5. Then save the 3D Slicer scene once completed.
6. All landmark points can be made invisible or visible from ***Data*** in the ***Subject hierarchy tab***. Locking the landmark points can only be done from ***Fiducial Registration***

IV. Patient Registration Procedures

4.1: Creating new patient scene from boilerplate scene

1. Create new folder and name it with something to identify the patient number. This will be the folder to access the navigation scene for the patient throughout all future procedures.
2. Download the patient MRI to the computer.
3. Open Boilerplate scene. Select File and click Save. In the top-left tab containing File Name, click the check mark box. All the boxes in the File Name column should be checked. Then click Change directory for selected files. Choose directory path to the folder created specifically for the patient scene in the previous step. Then click Choose.
4. Then click DICOM icon in the top-left corner. Select all files already upload and delete them by right clicking on the files and clicking Delete.
5. Click Import then select the MRI folder containing and then click Import. Then press Okay click okay once the next dialog box appears showing how many images where imported. Then select the MRI scan in the lower row of DICOM Browser and then click Load.
6. Go to the Data module. In the Subject hierarchy tab, expand the second row called No study description by clicking the + icon to the left of the text. -The imported patient MRI scan should then be listed on the 3rd row down.
7. Click and hold the mouse button to drag the patient MRI title down to No study description (20180516). While still holding the mouse button down, drag the selected item and hold it towards the bottom of the window of the Subject hierarchy window to get the scroll bar to move down. Place the patient MRI title over the No study description (20180516) and then unclick. The patient MRI title should be located under 9: SAG T1 as an equivalent tabular branch arm.
8. Next click on the Transform hierarchy tab. Scroll down to then drag the patient image title below 9: SAG T1. Then right click on 9: SAG T1 and click Delete.
9. Place head band on patient while MRI fiducials are still on the patient's head.
10. Activate the camera in Plus ToolKit and 3D Slicer.

4.2: MRI Fiducial placement on patient

1. It is recommended placing at least four MRI donut fiducials on the subject for the MRI Navigation scan.

2. **Registering anatomical references with MRI fiducials after patient MRI scans to be used as neuronavigation images in 3D Slicer**

4.3: Anatomical reference registration to 3D Slicer post-MRI scanning

1. It is recommended to have the patient wear safety glasses if using a sharply pointed pointer pen during these registration procedures to avoid eye injury.
2. First, make sure the **ReferenceToRas** transform is set to identity:
    a. Transforms
    b. Active Transform: **ReferenceToRas**
    c. Click Identity button
3. **Fiducial Registration Wizard**
4. **From fiducials**: select **ReferenceFiducials** from dropdown list
5. Delete all landmarks in **From fiducials** box
6. **To fiducials**: select **RasFiducials** from dropdown list
7. Delete all landmarks in **To fiducials** box
8. Place fiducials using transform (click triangle if menu is collapsed): select **StylusTipToStylus** in **first** box
9. Registration result (From->To) transform: select **ReferenceToRas**
10. Result transform type: **Rigid** (or similarity)
11. In **From fiducials**, select each MRI fiducial landmark on patient:
    a. Point at MRI fiducial landmark on patient with pointer tool
    b. While holding pointer tool steady on landmark, click **Place 'From'**
12. In **To fiducials**, select and then click each MRI fiducial landmark in the image in the same order as above
    a. When done, click again to make sure no additional landmarks accidentally get clicked
13. Click **Update** button to compute and store the transform.
14. Confirm with the tracking pen that the patient head is properly aligned with the MRI fiducial landmarks.
15. From fiducials: select **AnatomicalReferences** from dropdown list
16. It is important that the head tracker is not moved from here on out.
17. Delete all the landmarks in the **From fiducials** box.

18. In **From fiducials**, select each anatomical landmark on patient:
    a. This includes the Inion, Nasion, Right Preauricular (ear), and Left Preauricular (ear).
    b. It is recommended to take a photo of each of these locations for every individual patient for when the patient is reregistered to the camera and head tracker with their anatomical landmarks over a series of procedures. Then save the photos with the 3D Slicer scene folder.
    c. Point at each anatomical landmark on patient with pointer tool
    d. While holding pointer tool steady on landmark, click **Place 'From'**
19. It is recommended to rename the fiducial in the landmarks in 3D Slicer as the Inion, Nasion, Right Preauricular (ear), and Left Preauricular (ear).
20. Then save the scene as previously described.
21. Finally the head tracker and MRI fiducials can be removed.
22. When it is time to reregister the patient to the camera and head tracker with their anatomical landmarks for a procedure, open the patient's scene and activate the camera.
23. Place the head tracker on the patient.
24. As before, make sure the **ReferenceToRas** transform is set to identity:
    a. 🔍 Transforms
    b. Active Transform: **ReferenceToRas**
    c. Click Identity button
25. 🔍 **Fiducial Registration Wizard**
26. **From fiducials**: select **ReferenceFiducials** from dropdown list
27. Delete all landmarks in **From fiducials** box
28. **To fiducials**: select **RasFiducials** from dropdown list
29. Delete all landmarks in **To fiducials** box
30. Place fiducials using transform (click triangle if menu is collapsed): select **StylusTipToStylus** in **first** box
31. Registration result (From->To) transform: select **ReferenceToRas**
32. Result transform type: **Rigid** (or similarity)
33. In **From fiducials**, select each Anatomical landmark on patient:
    a. Point at Anatomical landmark on patient with pointer tool
    b. While holding pointer tool steady on landmark, click **Place 'From'**

34. In **To fiducials**, select and then click each Anatomical landmark in the image in the same order as above
    a. When done, click again to make sure no additional landmarks accidentally get clicked
35. Click **Update** button to compute and store the transform.
36. Confirm with the tracking pen that the patient head is properly aligned with the Anatomical landmarks.

4.4: Head tracker registration pre-treatment

1. First, make sure the ***ReferenceToRas*** transform is set to identity:
    a. *Transforms*
    b. Active Transform: ***ReferenceToRas***
    c. Click *Identity* button
2. *Fiducial Registration Wizard*
3. ***From fiducials***: select ***ReferenceFiducials*** from dropdown list
4. ***To fiducials***: select ***RasFiducials*** from dropdown list
5. Place fiducials using transform (click triangle if menu is collapsed): select ***StylusTipToStylus*** in **first** box
6. Registration result (From->To) transform: select ***ReferenceToRas***
7. Result transform type: *Rigid (or similarity)*
8. In *From fiducials*, select each reference landmark on patient:
    a. Point at reference landmark on patient with pointer tool
    b. While holding pointer tool steady on landmark, click *Place 'From'*
9. In *To fiducials, select* and then click each landmark in the image in the same order as above
    a. *When done, click* again to make sure no additional landmarks accidentally get clicked
10. Click *Update* button to compute and store the transform.

4.5: How to assign target references in MRI pre-procedure

1. Open **Fiducial Registration Wizard**.
2. In the **From fiducials** drop down list select **Targets**.
3. The "place a markup point" button can be used to place target points within the MRI images in the scene.

4. The visibly and position lock can be toggled on and off in this list.

4.6: Setting up hot-spot MRI slice follower

1. In **Data** under the **Transform Hierarchy** tab expand **ApplicatorModelToApplicator.**
2. Right click on ***ApplicatorFocus*** and click Edit properties. Then write down the three coordinates of the ***ApplicatorFocus*** in the L or R, P or A, and I or S directions.
3. Next return to the **Data** under the **Transform Hierarchy** tab and right click on **ApplicatorFocusToApplicatorModel** and click Edit properties.
4. In the **Translation** type in the LR, PA and IS coordinates that were written down from the ***ApplicatorFocus*** coordinates. Do not click the Identity button after this is done. Then save the 3D slicer scene.
5. Next open the **Modules** drop down list and select All Modules.
6. Select **Volume Reslice Driver.**
7. In R, Y, and G change the **Mode** drop down list to Axial, Sagittal, and Coronal in each section respectively.
8. The object in the **Driver** dropdown list of each section is the object the image slices will follow as the object moves in real space. It is important to select **none** in the R, Y, and G and saving the 3D Slicer scene before exiting 3D Slicer. selecting **none** will turn off the slice follower, which will need to be toggled off and on during most operations of this system.
9. To make the image slices follow the location of the ***ApplicatorFocus*** location in each the Axial, Sagittal, and Coronal planes, select **ApplicatorFocusToApplicatorModel** in the **Driver** dropdown list in the R, Y, and G sections.
10. Other objects can be selected in the **Driver** dropdown list, as well for the imaging slices to move along with the respected object in the real space (example: the tracking pen).

V. Custom Equipment Registration

5.1: Creating new ROM file in NDI 6d Architect

1. Open NDI 6D Architect
2. Make sure Plus Toolkit is not connected to camera.
3. File then click New

4. Select Passive Tool and Collection, and then click System Settings and verify the COM port is the same COM port as the camera USB is plugged into, then click OK. This can be verified in Device Manager. Then click Next
5. Select Port_00: Passive Tool in the Tool Selection scroll down list. Then click Next.
6. Put arbitrary names in Part Number and Manufacturer. In Tool Type select Reference. In Marker Type select NDI002 Passive Marker – sphere. Then click Next.
7. Place device tracker in view of camera on a flat surface with no other reflective sphere in the camera view.
8. Click Start Passive Tool Snapshot. Make sure device is close to middle view of the camera. Also make sure there are the same amount of spheres appearing in the software window as in on the device itself. This can be verified if all the Marker Values spheres in the box to the left are lit up as green.
9. While not moving the device, click Take Snap shot.
10. Choose directory for Rom file to be saved to and name the file then click Next.
11. Then click collect while not moving the device. Do not touch anything until the entire collection is completed, which takes about ten seconds. Once completed, click Next.
12. Click Next
13. Click Next, then click Yes.
14. Click Pre-Generate Normals. Then click Next.
15. Make sure Pivot the tool to locate the tool's tip is unchecked. And make sure Save tool definition file (recommended) is checked, then click Next.
16. Click Next.
17. Click Finish.
18. In Description write in name of Rom file and the click Save. Then reenter name of Rom file in from of the .crm file. Then choose a directory path. Then click save.
19. In Description write in name of .crm file and the click Save. Then reenter name of .crm file in from of the .crm file. Then choose a directory path. Then click save.
20. Place the Rom and .crm files into the Rom folder, which is connected to the directory path in the Plus Server Launcher Notepad script. And also add the name the Rom file in the correct location in the script.
21. Exit NDI 6D Architect before reconnecting with camera through Plus Toolkit.

5.2: Changing ROM files out in Plus Launch Server

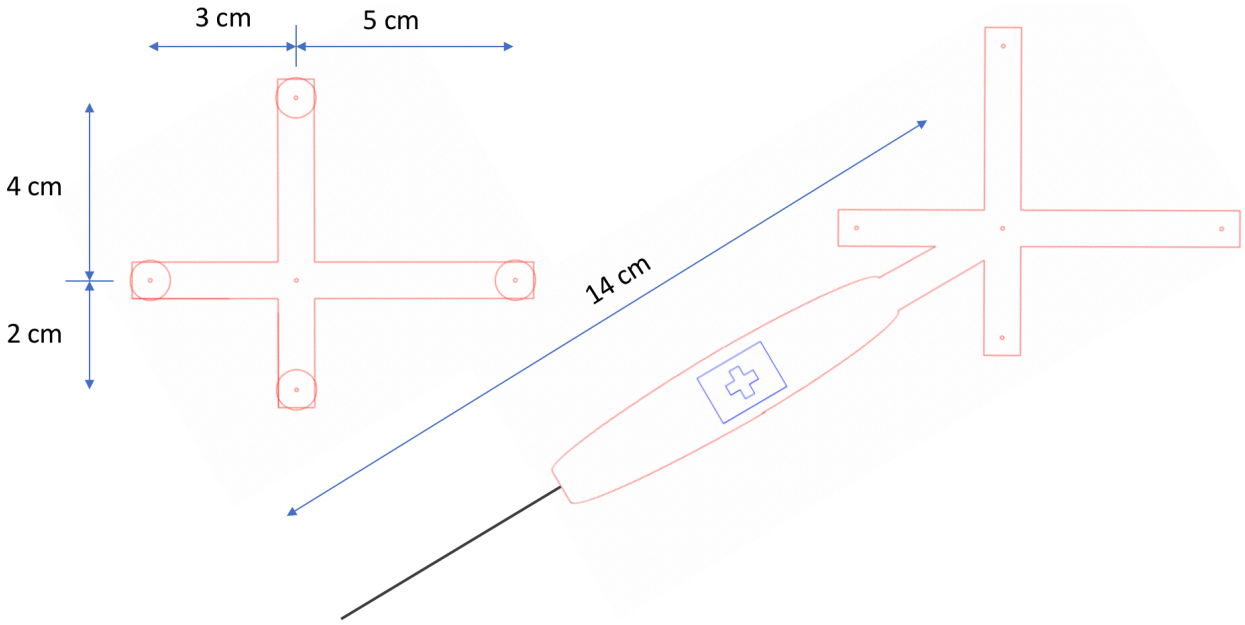
1. Open Plus Server Launcher and be sure to Stop server if not already disconnected.
2. Under Device set: choose Neuronavigation real skull.
3. Push the pencil & paper icon left of the Device set scroll down menu. A Notepad script window will appear. Within this script, there are four separate lines containing directory path text. The Boilerplate Notepad script included in this research article has for example: RomFile="C:\Users\Spencer\Documents\Navigationbackup5-22-2018\Rom\Head_tracker.rom". Here the directory path contains the Rom file head_tracker.rom, which is the head tracker rom file. The script contains the four objects to track being the head_tracker.com, applicator_tracker.com, positioner_tracker.rom, and the pen.rom. These rom files are located in C:\Users\Spencer\Documents\Navigationbackup5-22-2018\Rom\ for the boilerplate script. The boilerplate scene includes only these four tracked devices. However, if a new pen or tracking devices are to be replaced with a new fabricated tracker and NDI 6D Architecture, then Rom file would need to be placed in the Rom folder and the file name of the old Rom file in the Notepad script would need to be replaced with the new in the appropriate directory path line of code.
4. When all changes are made to the Notepad script, select File and push Save. Then exit Notepad. Pointer pen Rom files must include a pivot calibration, which are conducted in 3D Slicer.

5.3: Pivot calibration in 3D slicer

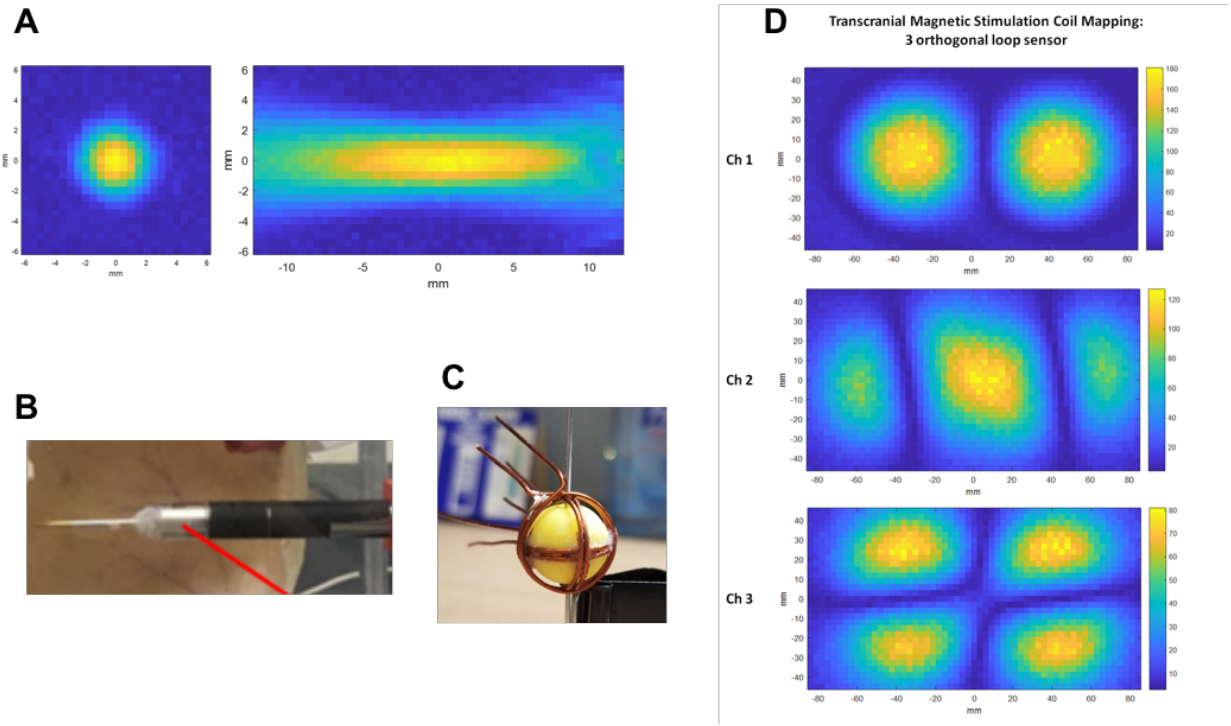
1. Activate a scene like normal with head tracker, transducer tracker, and the new pen that is being pivot calibrated in the view of the camera.
2. Open the **Pivot Calibration** module in 3D Slicer.
3. **Input (TooltoReference):** select **StylusToReference**.
4. **Output (ToolToTipTool)**: select **StylusTipToStylus.**
5. Then place the new pen on a steady placemat so the tip does not move. Whit all the tracking devices in the view of the camera, click Start Pivot Calibration. After 5 second pass, the camera will collect data points of the new tracker pen. During this 5 seconds, pivot the pen forward and backwards and then pivot right to left and repeat this within the 5 seconds with =out the tip slipping and not obstructing the camera view of the reflective spheres on any of the tracking devices. A Root-mean-square error value will appear below the Results text. This number should be under 0.25 and if it is not, repeat the Start Pivot Calibration operation again.

5.4: Tracker and pen pointer geometry examples

1. The tracker geometries must be different from each other so the camera can distinguish between the different ROM files.



5.5: Hydrophone and magnetic field sensor for scanning transmitting energy field to establish ApplicatorFocus position



A) Focused ultrasound transducer pressure field mapping with hydrophone to assign crosshairs to the spatial peak pressure in the focal zone. **B)** Hydrophone used to produce **A. C)** Custom 3-axis magnetic field sensor to produce images in **D**. **D)** Transcranial magnetic stimulation coil field maps of the magnetic field produced in the parallel plane approximately 3 mm away from the device coil recorded with the three orthogonal components of the senor in **C.**

1. Example: Mapping Magnetic Field from a Commercial Transcranial Magnetic Stimulation System Using a Custom Sensor and the Open-Source System

2. Sensor Construction
    a. References
        i. http://www.bic.mni.mcgill.ca/~llim/Apparnsetup.html
        ii. http://www.bic.mni.mcgill.ca/~llim/Workinprogress/figure8.html
        iii. https://www.researchgate.net/figure/The-schematic-of-ECoG-electrode-in-the-presence-of-TMS-coil_fig1_233330682
    b. The Sensor was constructed from Belden 22AWG magnet wire wrapped in three orthogonal loops around an acrylic bead 11.7mm diameter at equator, then potted in epoxy (Lord 310A/B) and connected to shielded leads with BNC connectors.

3. TMS System used in example: MagVenture MagVita with MagPro X100 stimulator connected to figure-8 coil MagVenture Cool B65 “butterfly”
    a. Turn on MagVenture MagVita system per manufacturer procedure.
    b. Position Figure-8 coil
        i. Do not position figure-8 coil upside-down as it will not cool properly.
        ii. Use a level to ensure coil handle is horizontal (or vertical)
        iii. Active face of coil (the unmarked flat side that would touch a patient’s head) should be oriented such that its long axis is vertical (or horizontal). Use a level to check this.
    c. Position 3-axis magnetic field sensor
        i. Affix to non-magnetic rod such that sensor can move horizontally and vertically (check with level if necessary).
        ii. Check to ensure that the three wire loops comprising the sensor are correctly aligned (e.g. parallel to or orthogonal to active face of figure-8 coil).
    d. Set start position
        i. For positioning robot, *x*-axis control at its limit switch to prevent sensor from being accidentally advanced into the figure-8 TMS coil’s face
        ii. Measure distance from figure-8 coil case to magnetic field sensor: **___ mm**
    e. MagPro X100 setup for triggered control
        i. Connect trigger cable to D-sub connector on back panel of MagPro
        ii. Connect Trigger In of MagPro X100 to TTL control output of custom mapping system
        iii. Connect Trigger Out of MagPro X100 to trigger input of data acquisition system to instruct it to acquire and save a sample window

f. Set MagPro X100 to “External Trigger” control (falling edge, no delay) and record amplitude setting (<75% recommended to maintain coil temperature): **___ % max stimulator output**
g. Prepare automated mapping and data acquisition system. Note automated scan parameters: **___ x ___ mm area** with **__ mm resolution**
h. Commence mapping and data acquisition