Documentation for 3D Ultrasonography usind Telemed or Siemens Devices

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We thank Aurélie Sarcher (University of Nantes) and Francesco Cenni (University of Jyväskylä) for their help during the process.

Note that this documentation heavily builds upon a previous version by Aurélie Sarcher (https://github.com/AurelieSar/3Dultrasound) and contains many elements of it. Nonetheless, we tried to build upon it and extend it.

1 Documentation

1.1 Programs

Install the following applications. The versions that we have used are specified for Windows 10 or Windows 11. If other versions are being used, there is no guarantee that the programs will work together.

1.1.1 Programs for Windows 10:

3D Slicer (Version 5.6.0):

Slicer is an open-source software platform for medical image informatics and visualization. It supports the analysis of data from various medical imaging modalities, including ultrasound, CT, and MRI. Developed by the Surgical Planning Laboratory, it enables users to visualize, analyze, and interact with 3D reconstructions of anatomical structures, aiding tasks like surgical planning and image-guided interventions.

Link: https://download.slicer.org/

Extensions: SlicerOpenIGTLink, SlicerIGT, SlicerIGSIO

These can be downloaded directly in the Slicer program. Open the "Slicer Extension Manager" and then search for the mentioned extensions. Press "Install" to install the extensions. Finally, you need to restart Slicer for them to be displayed correctly. We need these extensions to connect with the Plus Server, which we set up, to link the ultrasound device and the Optitrack cameras.

Figure 1:
Screenshot of the Slicer extensions

Plus Toolkit (PlusApp-2.8 Telemed-Win32);

Plus Toolkit is an open-source software for navigated image-guided interventions, initially designed for ultrasound-guided procedures. It encompasses essential functions for implementing tracked ultrasound systems but is now utilized across various interventions, both with and without ultrasound imaging. The software combines different data streams from various devices to integrate them into other programs.

Link: https://plustoolkit.github.io/download

Ecowave Telemed (Version 4.1.1 x64); **-> ONLY IF TELEMED DEVICE IS USED**

EchoWave II, Telemed beamformer scanning software, features an intuitive interface, customizable settings, user-programmable presets, and versatile functions like measurements, calculations, and error identification. It supports telemedicine with remote control, offers constant updates, and is equipped with unique features for research programs. It is used for the visualization of the ultrasound image from the Telemed devices.

Link: https://www.pcultrasound.com/support/software/

OBS for Siemens Juniper Ultrasound System (Version 30.1): **-> ONLY IF NOT TELEMED**

Open Broadcast Software is a software for video recording and live streaming. We use it to check, if the video stream from the Siemens ultrasound device arrives correctly at the computer.

Link: https://obsproject.com/

Motive (Version 3.1.0 Beta 2);

OptiTrack's Motive is a motion capture software application that enables precise tracking and analysis of movements. Used in various industries, including entertainment, sports, and research, Motive provides robust tools for capturing, processing, and interpreting motion data. With user-friendly features and real-time feedback, it facilitates high-quality motion capture for applications such as animation, biomechanics, virtual reality, and more.

Link: https://optitrack.com/support/downloads/motive.html

1.1.2 Windows 11 adaptations:

Plus Toolkit (PlusApp-2.9 Telemed-Win64);

Plus Toolkit is an open-source software for navigated image-guided interventions, initially designed for ultrasound-guided procedures. It encompasses essential functions for implementing tracked ultrasound systems but is now utilized across various interventions, both with and without ultrasound imaging. The software combines different data streams from various devices to integrate them into other programs.

Link: https://plustoolkit.github.io/download

1.2 File Setup

1.2.1 XML-Files

In order to perform a 3D-ultrasound with the programs from the chapter 3.1 we need a code to connect them. The code includes the data stream from one program and transfers it into another, for example from Motive into Slicer. This process can be achieved by using the free software Plusserver, which is designed to perform this task.

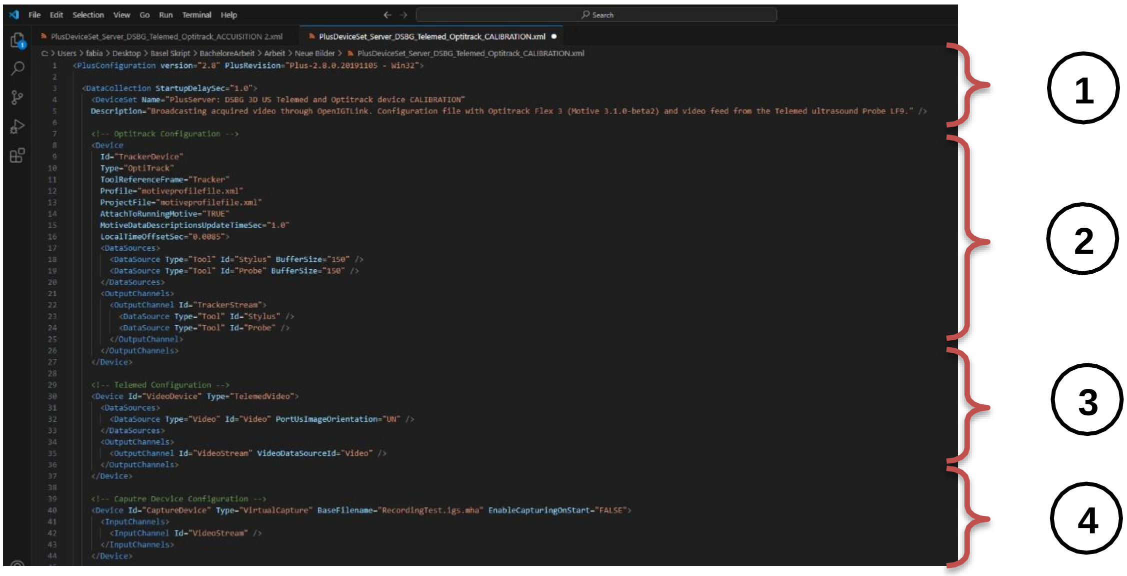
There are many different components to create a 3D scan, such as different types of tracking-cameras or ultrasound devices. These components can result in a huge amount of variations in the code. You can find specific datasets on the Plusserver website to create your own code (Plus applications user manual, 2024a).

The base of our xml files is a combination of the “Telemed Ultrasound System” (Plus applications user manual, 2024d), “Optitrack” (Plus applications user manual, 2024b) and “Virtual Mixer” (Plus applications user manual, 2024e). However, to seamlessly integrate it into our our system, modifications are necessary, to align with our specific requirements and functionalities, which will be explained in chapter “3.2.2 Calibartion XML”. Some of these separate integrations can also be found in Andy’s Brain Book (Andy’s Brain Book, 2023).

The XML- Code we used to create to connect the Telemed ultrasound and the Optitrack cameras is explained in the following. This helps to give you a better understanding of the different parts that are integrated in the code. In the end save both XML- Codes, the calibration and acquisition XML file, in the PlusApp “config” folder.

1.2.2 Calibartion XML

Figure 2:
Part 1 of our calibration XML file



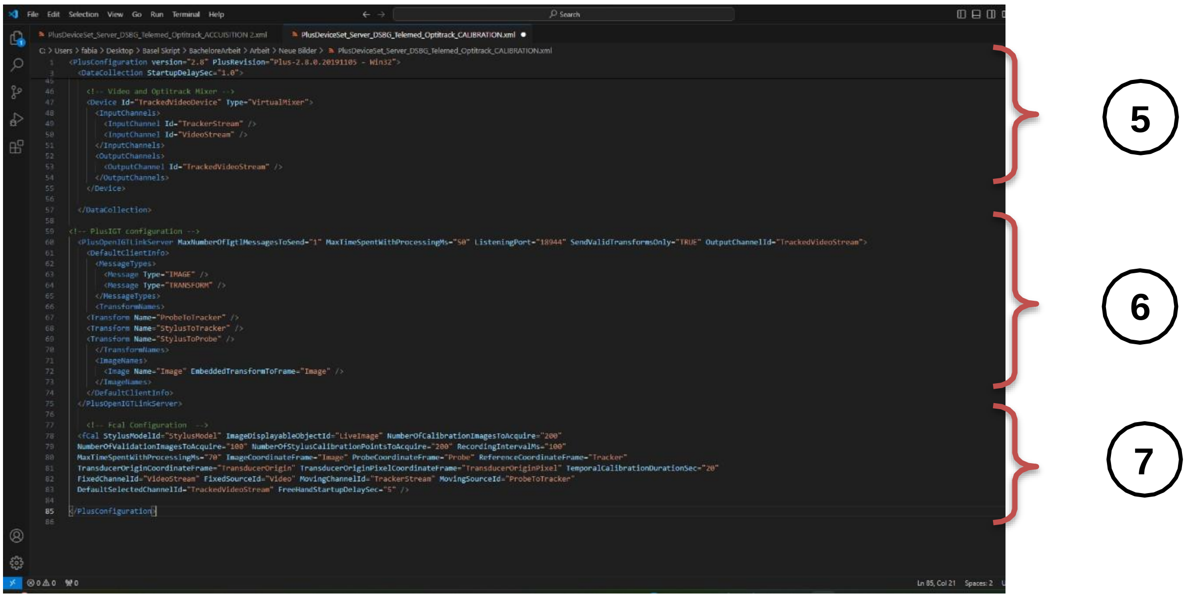
1) This section defines the name of the file and gives insights into the versions of each program and what type of devices are being used.

2) This is the Optitrack section. We need to define which file it should consider for the motive data stream. This is done with the **Profile="motiveprofilefile.xml"** line. To locate this file we need to add the **ProjectFile="motiveprofilefile.xml"**. The "AttachToRunningMotive" is set to TRUE for live broadcasting. The **"LocalTimeOffsetSec"** value is obtained after the temporal calibration. This value should fix any time offset caused by live streaming the Motive data to Slicer. The "DataSources" section includes the probe and stylus model. These tools are created in Motive and used as transforms later on. The "BufferSize" can vary for other systems. It provides an efficient data flow. A lager buffer size typically allows the handling of larger amounts of data at once. Too large of a size can also consume more memory resources and leads to potential inefficiencies. The "OutputChannels" defines an output channel named "TrackerStream" which aggregates data from two data sources, the "Stylus" and the "Probe".

3) This is the Telemed configuration section. It is copied from the Plusserver website database (Plus applications user manual, 2024d). It imports the video stream from the Telemed device. You can flip the Image by 180° if you change the "PortUsImageOrientation" from UN to UF.

4) This section sets up a virtual capture device that receives the video stream from the Telemed system. We named it "VideoStream".

Figure 3:
Part 2 of our calibration XML file



5) In this part the Telemed “VideoStream” data and the “TrackerStream” data from the Optitrack are being combined into one output called “TrackedVideoStream”

6) The next section is a combination of the Optitrack and Telemed dataset from Plusserver and a small part from the code in Andy’s Brain Book (Andy’s Brain Book, 2023). The first line sets up a local server port for the Plusserver to stream over into the Slicer program. The plugin PlusIGTLink in Slicer can access this data stream. We need to change the **“OutputChannelId”** to the **“TrackedVideoStream”** which we set up in step five. With the “MessageType” we can control which information can be transferred. In our case we want image and transform values. To perform the pivot and probe calibration we need three different transforms. The **“ProbeToTracker”** transform defines the position and orientation of the probe in corelation to the trackers’ coordinate system. The same goes for the **“StylusToTracker”.** The third transform represents the spatial relationship between the stylus and the probe. The ”EmbeddedTransformToFrame” is originally set to “Reference” but we changed it to “Image” because in line three of the section six we set the “Message Type“ to Image.

7) The last section is about the Fcal program configuration, which is used for the temporal calibration. This part is also copied from the Plusserver library “Virtual Mixer” (Plus applications user manual, 2024e). We deleted the first three lines because we don’t need the volume information in Fcal. The “ReferenceCoordinateFrame” has been changed from “Reference” to “Tracker” due to previous renaming of this attribute. In the last step we set the duration from “10” to “20” seconds to get more accurate results.

1.2.3 Acquisition XML

The acquisition file is meant for the final 3D ultrasound scan. If the previous steps in chapter 3.2.2 are set up correctly, the acquisition XML can be edited.

The calibration XML can be copied and renamed to “acquisition”.

Because we only need the „Probe“ function for the acquisition, several parts from the code such as the „Stylus“ data source can be deleted.

Figure 4:
Data source part from our acquisition XML file

```xml
<!-- Optitrack Configuration -->
<Device Id="TrackerDevice"
Type="OptiTrack"
ToolReferenceFrame="Tracker"
Profile="motiveprofilefile.xml"
ProjectFile="motiveprofilefile.xml"
AttachToRunningMotive="TRUE"
MotiveDataDescriptionsUpdateTimeSec="1.0"
LocalTimeOffsetSec="0.0085">
  <DataSources>
    <DataSource Type="Tool" Id="Probe" BufferSize="150" />
  </DataSources>
  <OutputChannels>
    <OutputChannel Id="TrackerStream">
      <DataSource Type="Tool" Id="Probe" />
    </OutputChannel>
  </OutputChannels>
</Device>
```

Because we only need the “ProbeToTracker” transform, all the other transforms can be deleted.

Figure 5:
Transform part from our acquisition XML file

```xml
<!-- PlusIGT configuration -->
  <PlusOpenIGTLinkServer MaxNumberOfIgtlMessagesToSend="1" MaxTim
    <DefaultClientInfo>
      <MessageTypes>
        <Message Type="IMAGE" />
        <Message Type="TRANSFORM" />
      </MessageTypes>
      <TransformNames>
        <Transform Name="ProbeToTracker" />
      </TransformNames>
      <ImageNames>
        <Image Name="Image" EmbeddedTransformToFrame="Image" />
      </ImageNames>
    </DefaultClientInfo>
  </PlusOpenIGTLinkServer>
```

The remaining parts stay the same as defined in the calibration XML.

1.2.4 STL-Files and 3D Prints

To track the movement of the probe and to calibrate it, we need two models that can hold the ultrasound head and the markers at the same time. The markers we used to stick onto the models are the M3 base 9 mm x 5 mm (OptiTrack, 2024c).

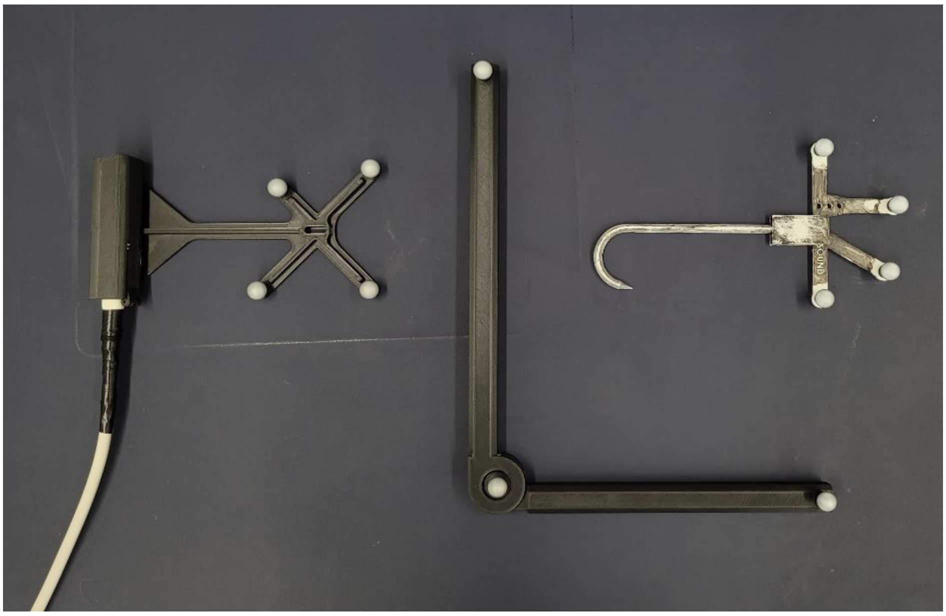
Sarcher (2023) provides a stylus model in her paper, which is used to calibrate the location and rotation of the probe.

The probe holder was designed by Simon Schless at Alyn Hospital Jerusalem and can be downloaded under the following Link: Probe Model

We printed our own calibration square to "set the ground plane" in Motive.

All these models are required to set up the 3D ultrasound system. The STL-Files are on my Github page and can be used for personal projects (Stüben, 2024).

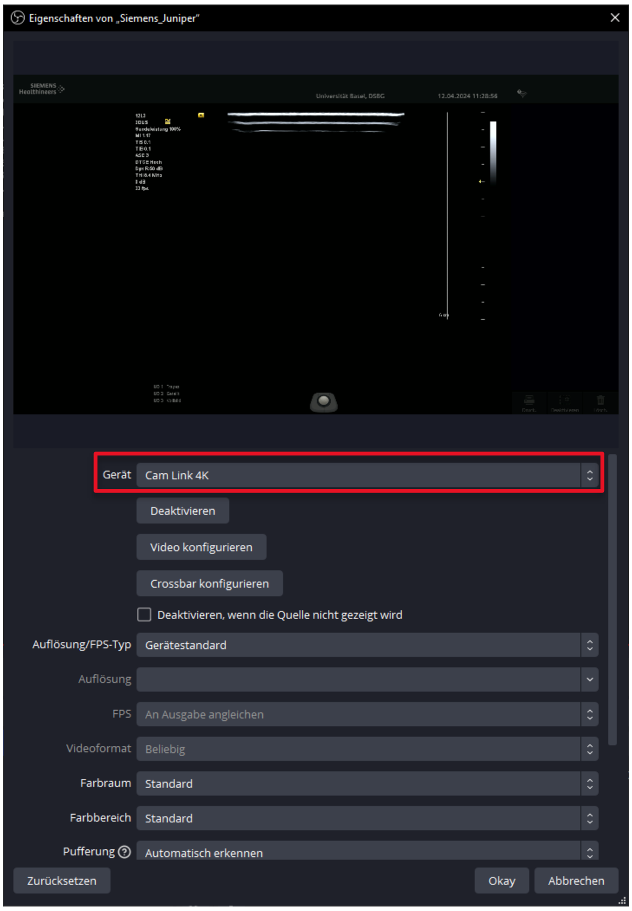
Figure 6:
Probe, calibration square and stylus model



The provided models are STL-files, which means they can be opened in a software for 3D printing. The exact process of printing such models are not explained in this documentation.

1.3 OBS Set Up (ONLY IF NOT TELEMED IS USED)

Once OBS is installed, open it up and create a new Source. Specifically, a **Video Capture Device**. After this the properties menu will open automatically. Ensure that under **Device**, the Capture Card is selected. The rest can be left as standard.



1.4 Siemens Setup (ONLY IF NOT TELEMED IS USED)

Instead of utilizing the Telemed system, one can use the Juniper Ultrasound system from Siemens.

- Connect one end of the HDMI cable to the Siemens machine.
- Attach the other end of the HDMI cable to the capture card. We recommend using one from Elgato.
- Link the capture card to the computer via USB, where 3D Slicer is installed.
- Initiate OBS to verify if the video feed from the ultrasound machine is reaching the computer. This step ensures everything is properly set up. If OBS fails to display the screen from the Siemens machine, you can try the following:
    - First, plug the capture card into the computer, then connect one end to it and the other to the Siemens machine. Then, launch OBS.
    - Alternatively, plug the HDMI end (connected to the Siemens machine) into another computer and start OBS again. If the video appears, close OBS and reconnect the HDMI cable to the Siemens machine.
- Once the video feed is confirmed, indicating that everything is functioning correctly, close OBS. This is necessary as OBS captures the video feed, preventing Plus Server from accessing it.

1.5 Optitrack Setup

We need to calibrate the camera system so that the orientation is correct and the rigid bodies, like the probe and the stylus, are tracked properly. This step has to be done every time the cameras have been moved from their original position. We recommend doing it every time before a measurement.

If the cameras have been calibrated, the correspondent file can be loaded into Motive and you can continue with the step “3.2.2 Acquisition without recalibration”.

1.5.1 Calibration

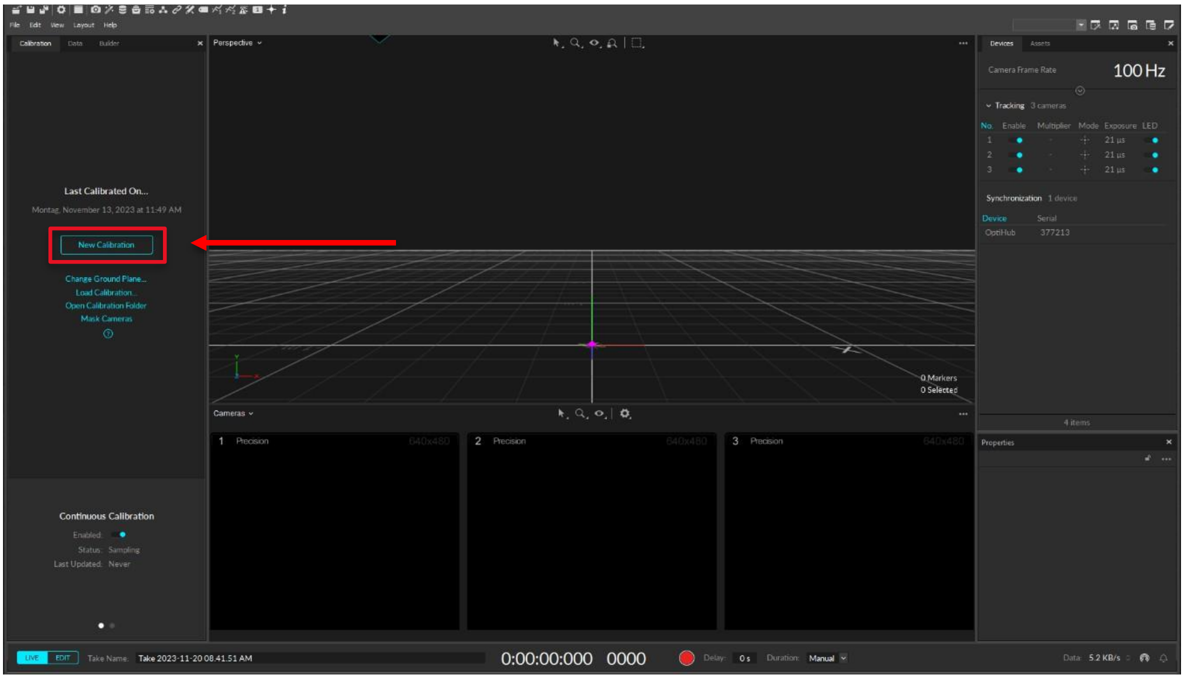
Place the cameras around the main calibration area. Make sure that this area is covered from many angels by placing the cameras in a circle around it. To get better results, the cameras should not be placed too far away from the main calibration area, otherwise the markers will appear too small. To make a precise measurement, it is better if the markers on the stylus and probe appear bigger, so it is easier for the program to recognise complex movements.

Figure 7:

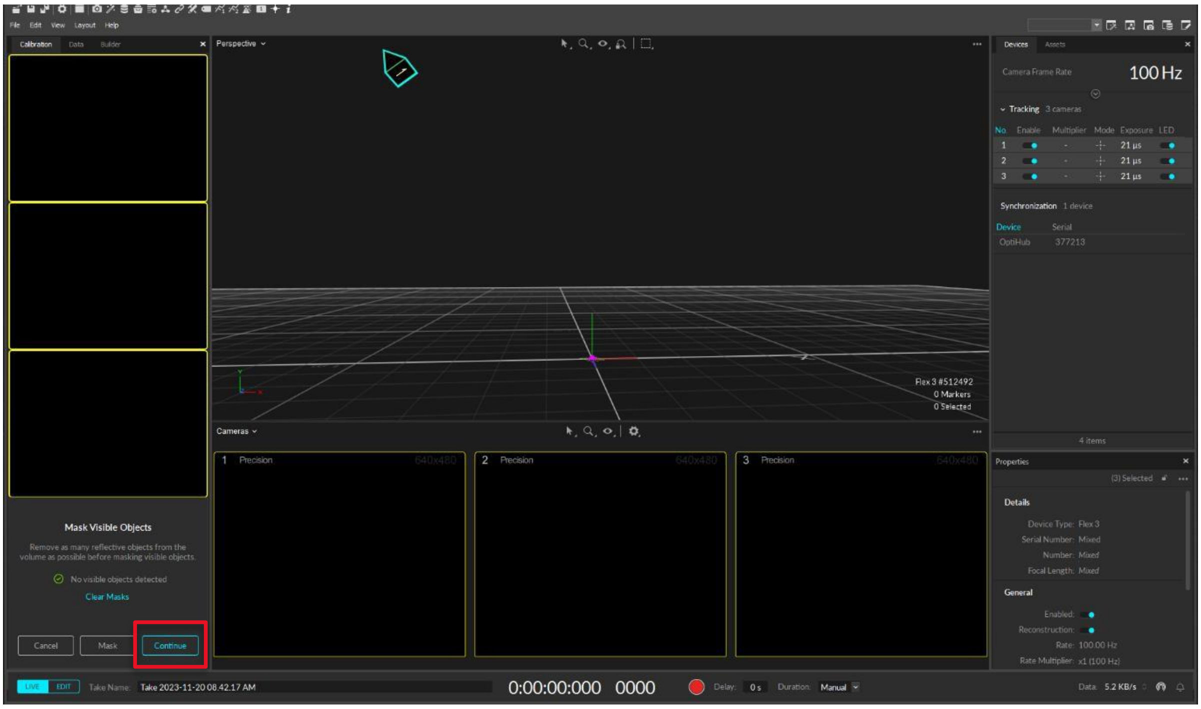
The setup of our camera system around our calibration area

Open **Motive** as administrator and make sure that the access USB is connected to the laptop, otherwise the license will not be effective.

- The first thing inside Motive will be to click on **“New Calibration”.**



- **Select each camera** by clicking on the black viewports while holding the shift key. This makes sure that every camera will be affected by the calibration. The corner should appear yellow.

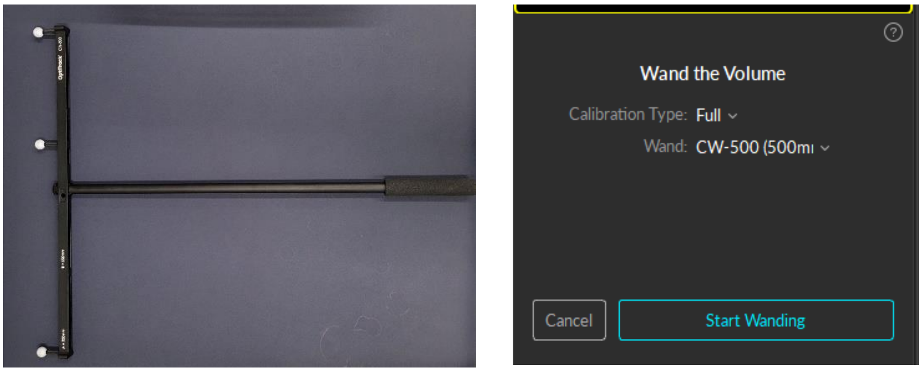


- If some reflective objects are already in the camera sight, hit the **“Mask”** button to create a mask layer to hide these. The best case would be that each camera has a black viewport.

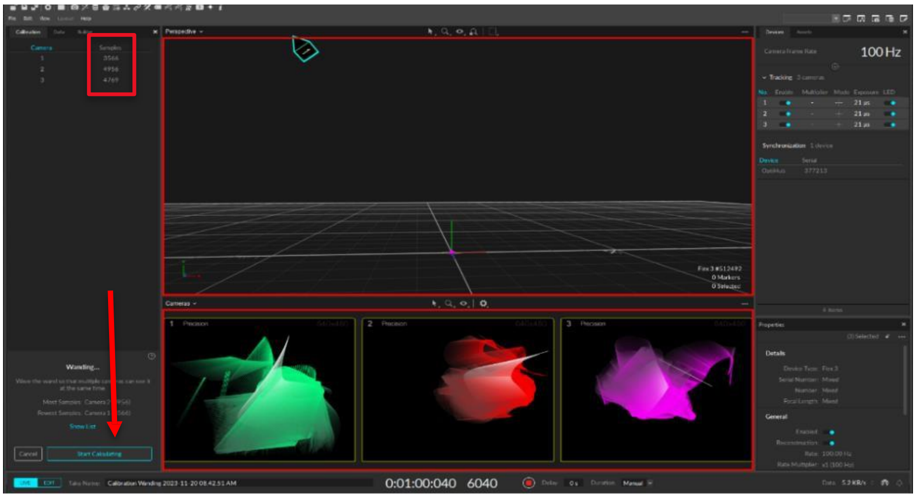
- Press **Continue”**.
- Click the **“Start Wanding”** button, which enables the collection of data from your wands movements.

Figure 8:

The calibration Wand CW-500 (OptiTrack, 2024a)

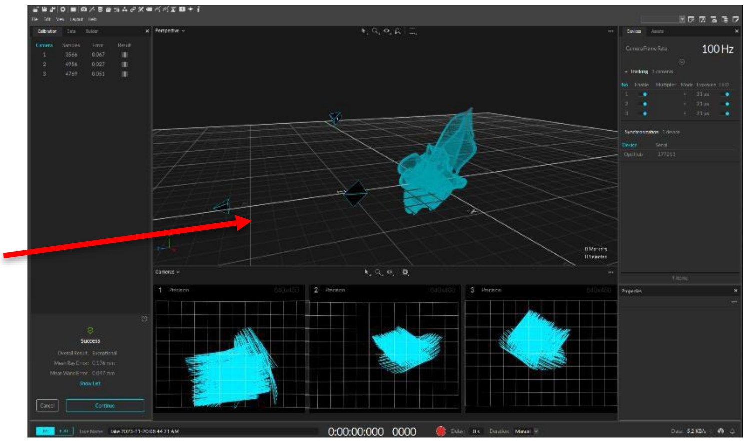


- **Circle the wand** in front of the cameras. Make sure it is done in the location where the performance of the 3D ultrasound will take place later on.



- Each camera should have at least **3000 samples** for an accurate and precise calculation.
- If the number of samples is correct, click on the **“Start Calculating”** button.

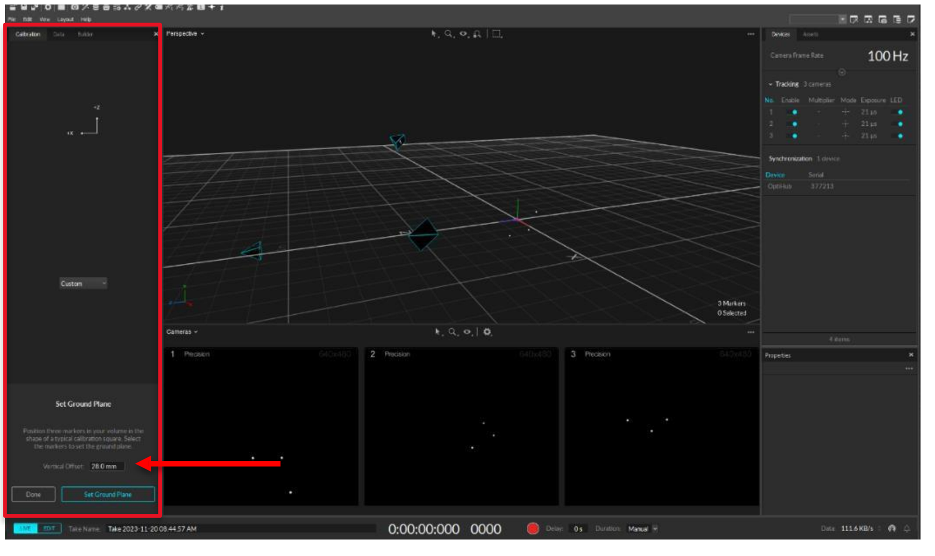
After the calibration a similar result as the one shown in the image should appear.



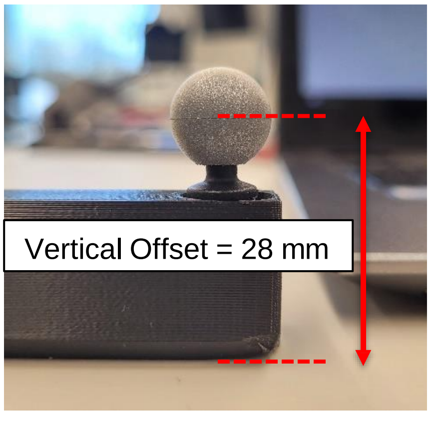
- To get the correct location of the cameras in 3D space, place the **calibration triangle** on the floor.

Figure 9:
Our calibration square as mentioned earlier in capter 3.2.4

- Press **“Continue”** and a new window should appear on the left side.

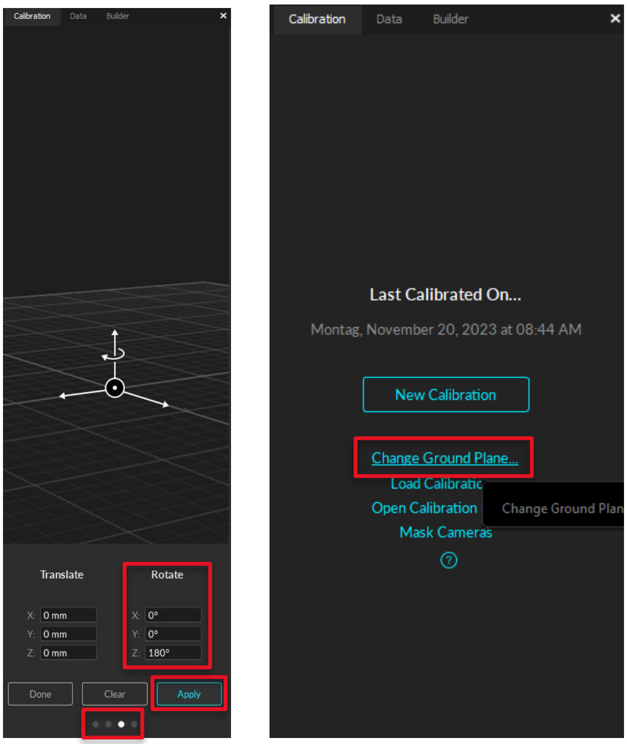


- Enter the **vertical offset** value in the designated slot, indicating the height from the base of the calibration triangle to the centre of the reflective ball.

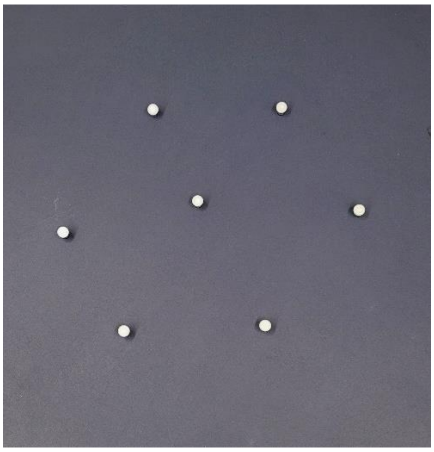


- **Set the ground plane** so the cameras are oriented correctly.

- For **additional adjustments**, such as rotating cameras in the event of inversion or refining the accuracy of the ground plane, select the **"Change Ground Plane"** button.



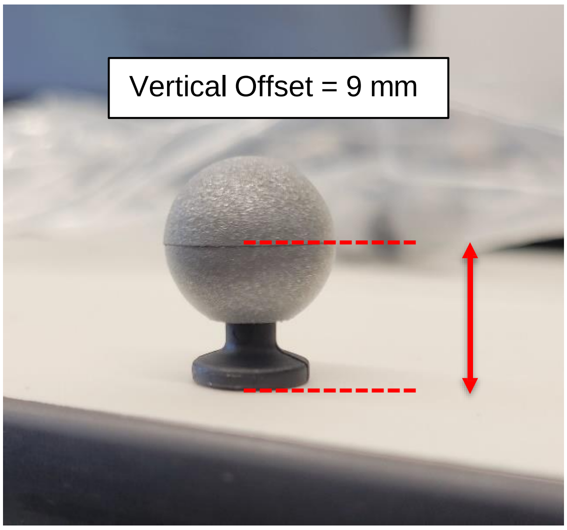
- To modify the rotation, navigate to the third slide by selecting the third circle at the bottom.
- In the event of inverted cameras, as in our case, input a 180° correction in the Z-Axis. This adjustment is only necessary if the cameras are not correctly oriented.
- To refine the ground plane for more accuracy, lay **7-9 markers** on the ground.



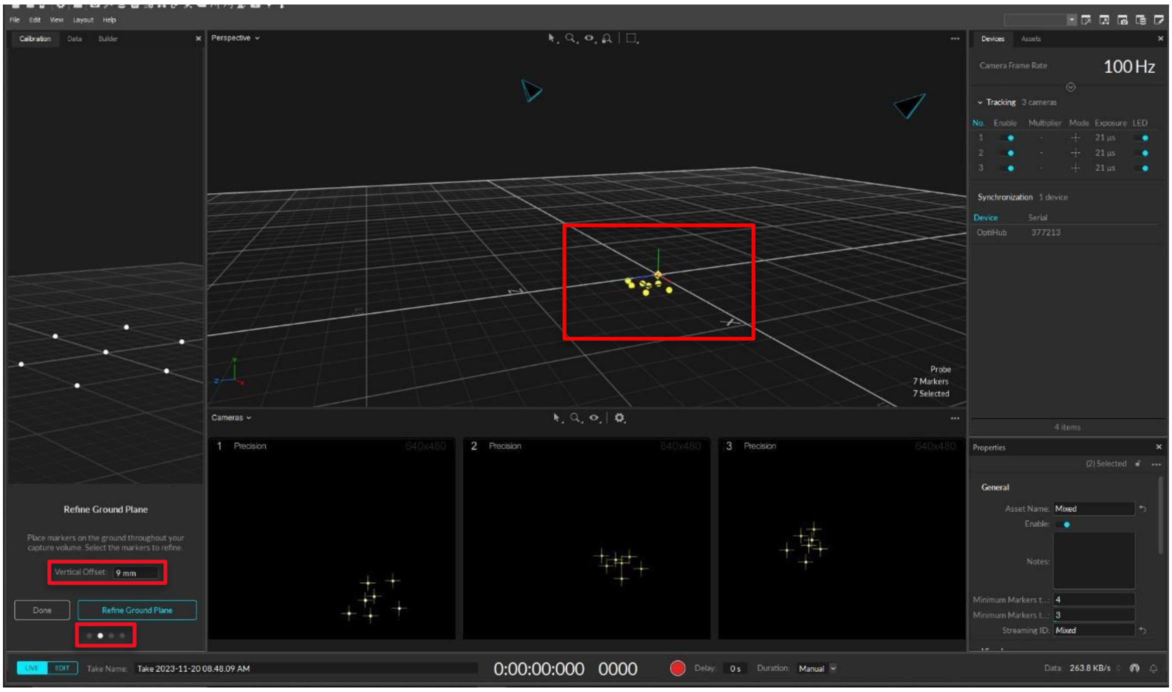
- On the second slide, there is another vertical offset input, that specifically represents the distance from the marker side to the centre of the marker.

Figure 10:

Shows how the vertical offset is measured on the M3 base markers 9 mm x 5 mm (OptiTrack, 2024c)



- After positioning all markers on the ground, left-click in the main window and drag a rectangle to cover all visible markers. This action will cause the markers to appear in yellow color.

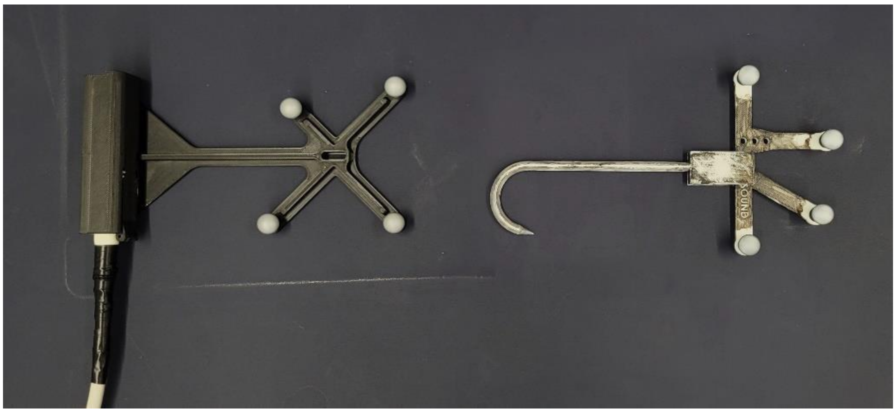


- Now select the **"Refine Ground Plane"** button.

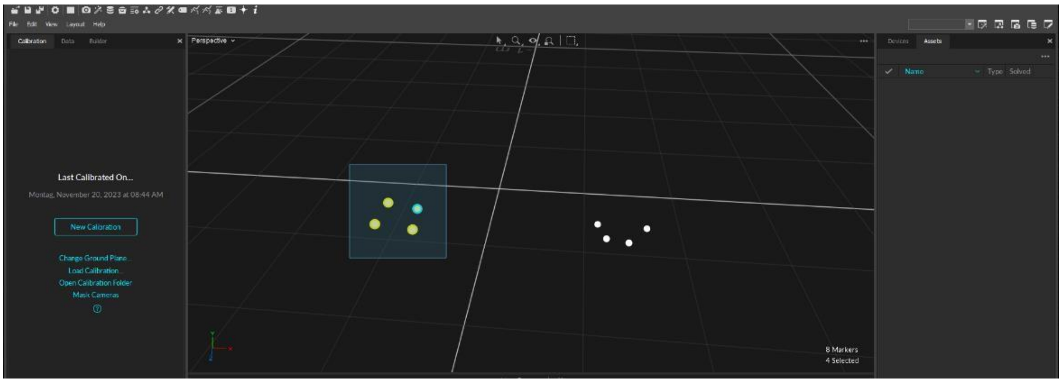
1.5.2 Acquisition without recalibration

- Place the probe and the stylus in the scene to make them visible for the cameras.

Figure 11:
Stylus and probe 3D prints as mentioned in capter 3.2.4

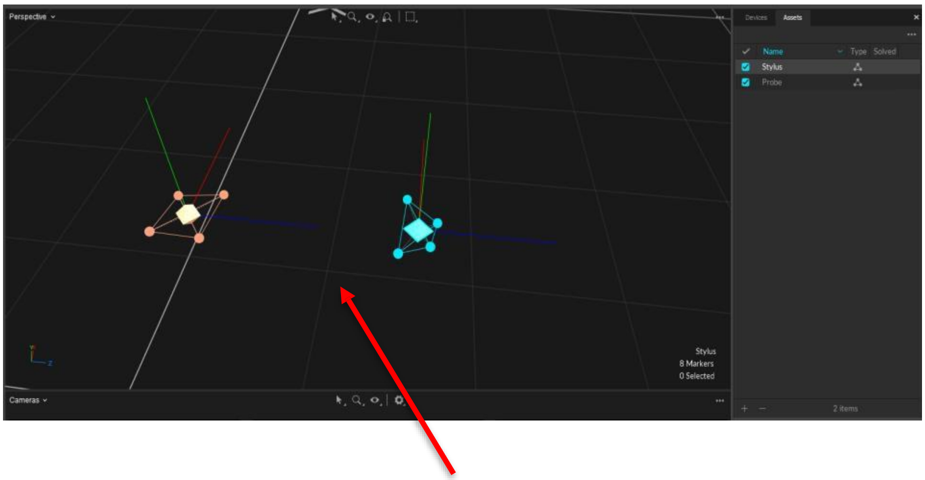


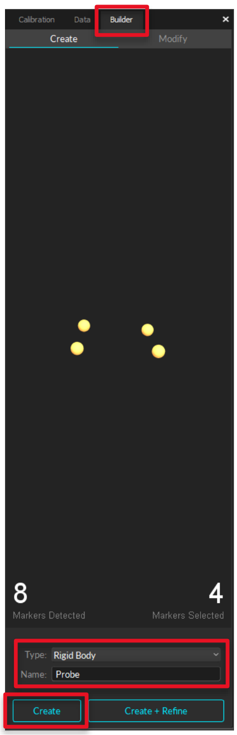
- Select the group of points that represent the probe, so they appear yellow.



- Select the **“Assets”** tab on the right side of the screen.
- Hit the plus sign at the bottom and choose **“New Rigid Body”.** This creates a new rigid body point group for the probe.

- On the left side under **“Builder”** change the name to **“Probe”** and select **“Create”.**
- **Repeat** the previous steps to create a second rigid body for the **stylus**.

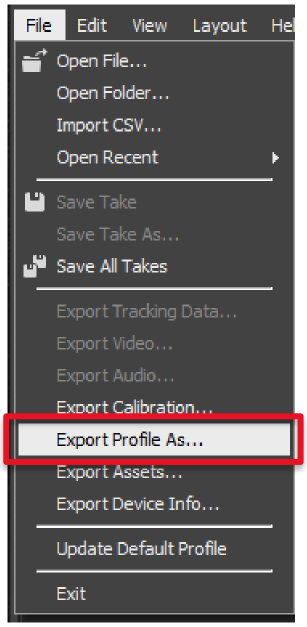


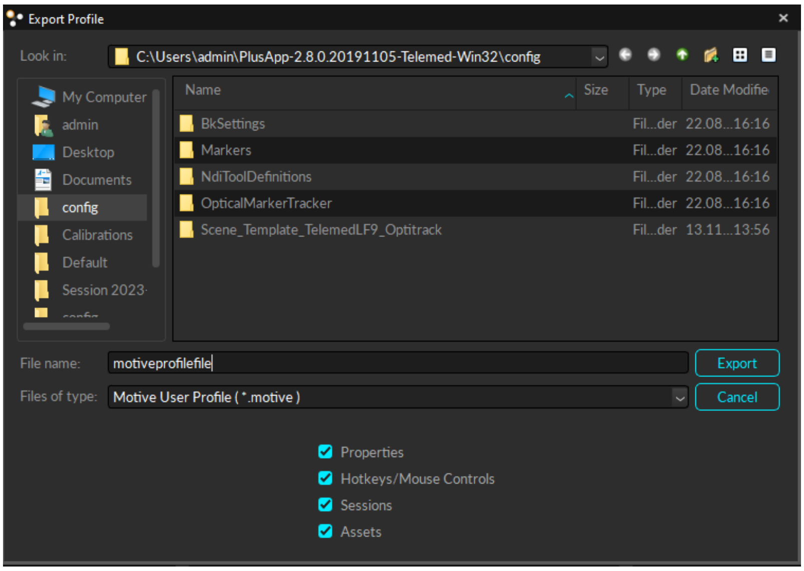


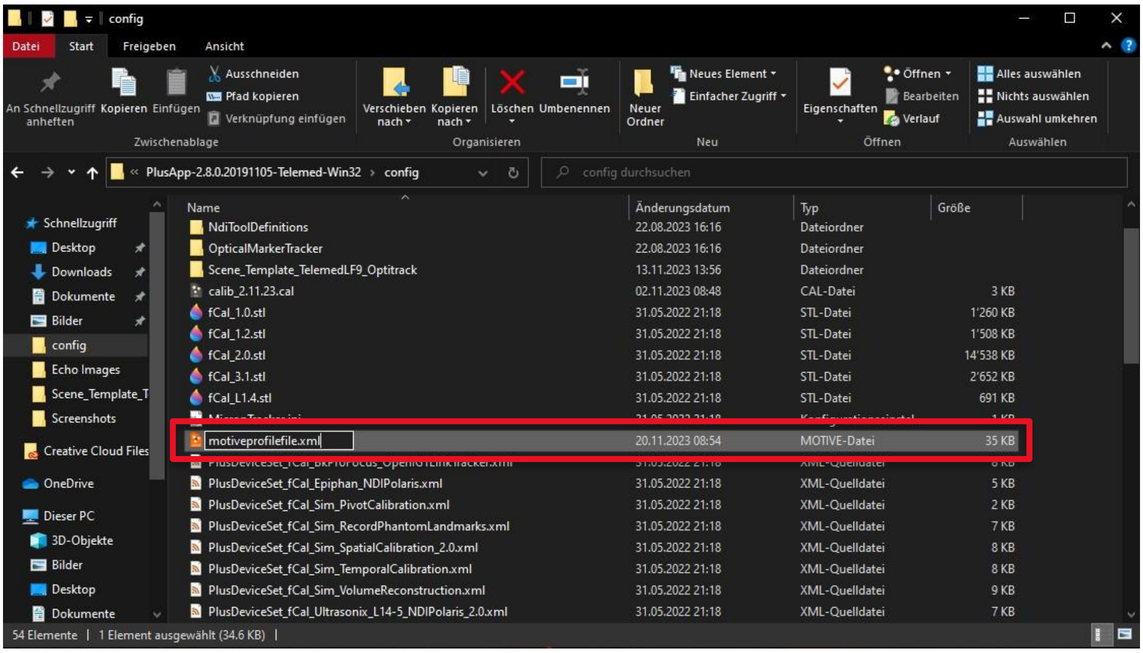
(The probe and the stylus should now appear like that in the viewport.)

1.5.3 Save Motive Profile

- Go to “File” and select **“Export Profile As…”** to save this calibration.
- Find the PlusApp folder and select the **“config”** folder.
- Save the file and name it **“motiveprofilefile”**. It is important that the name is correct because later steps are dependent on it.







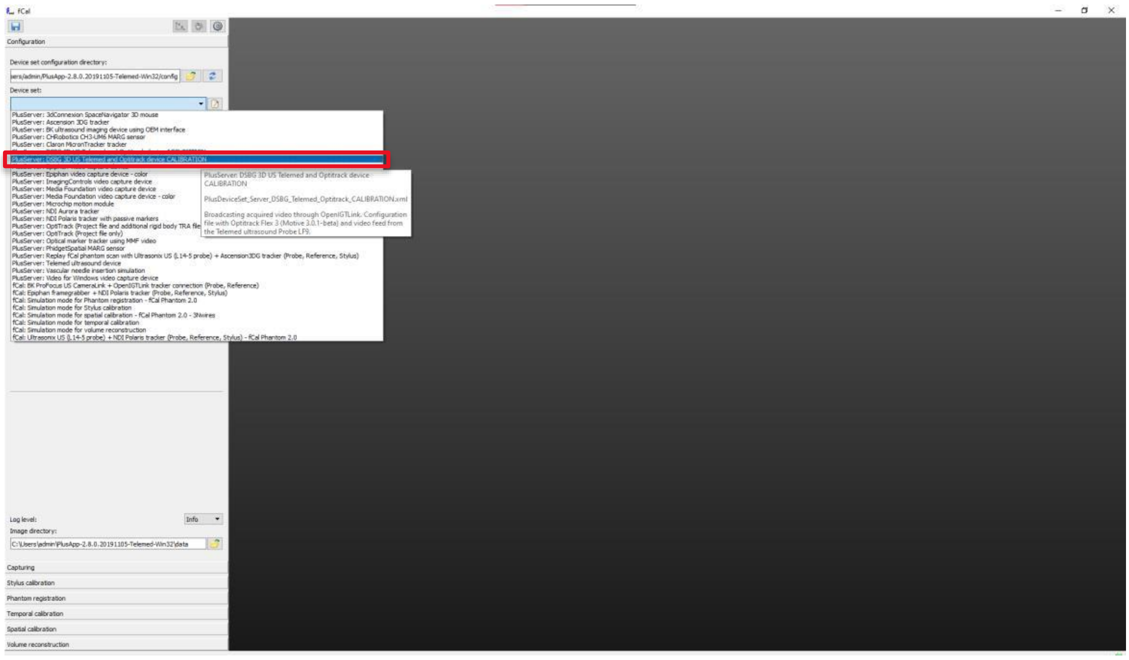
- Open the config folder, where the “motivepfofilefile” is saved.
- Right click and **rename** the file from “.motive” to **“.xml”**.
- **Do not close Motive!**

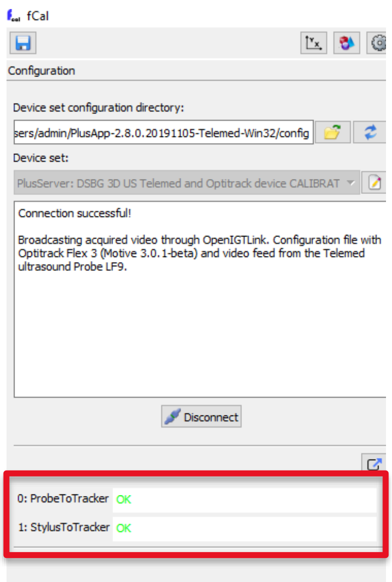
1.6 Temporal Calibration

This calibration is an important step to calculate the temporal offset between the tracking from the Optitrack-Cameras and the video stream of the ultrasound.

We recommend doing it, if a different motion tracking system, new cameras, or ultrasound device is used.

- Open the **“Fcal”** Software. It should already be on the device if the PlusApp is downloaded and installed correctly.
- Search up the “config” folder from the Plusserver and select the “Calibration” XML File that was created in “3.2.2 Calibartion XML”.



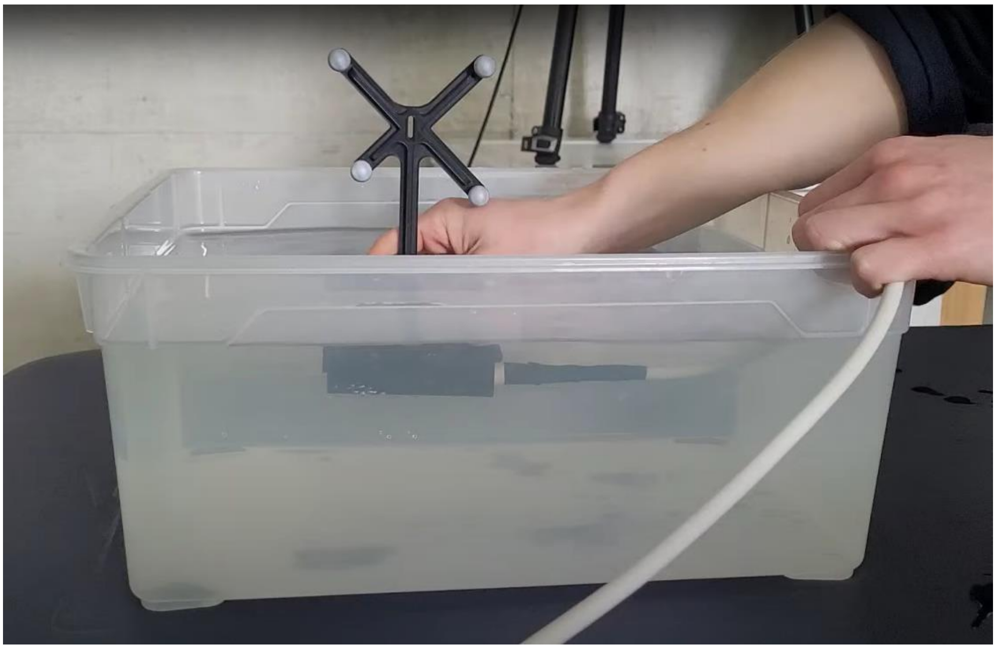


- Click **“connect”.**
- Both, the **“ProbeToTracker”** and **“StylusToTracker”,** need the status **“OK”.** This means they are visible for the cameras.
- Now go to the **”Temporal Calibration”** tab.

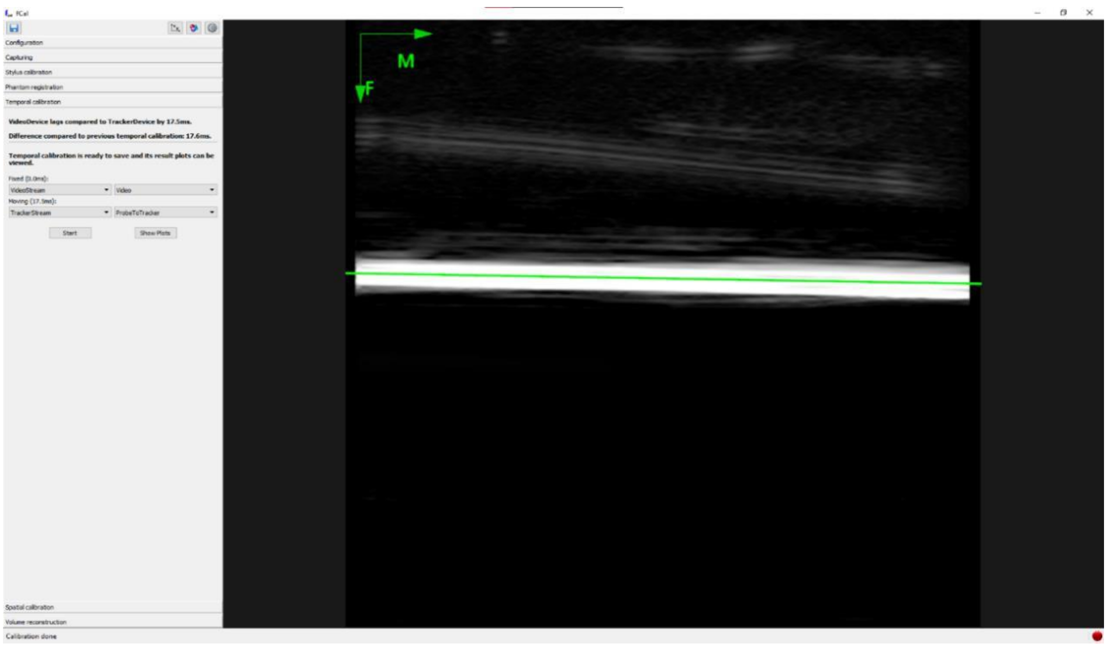
- Bring a basin of water into the centre of the camera volume. Wait until the water stabilizes.

Figure 12:

A picture from our video on how to perform the Temporal Calibration

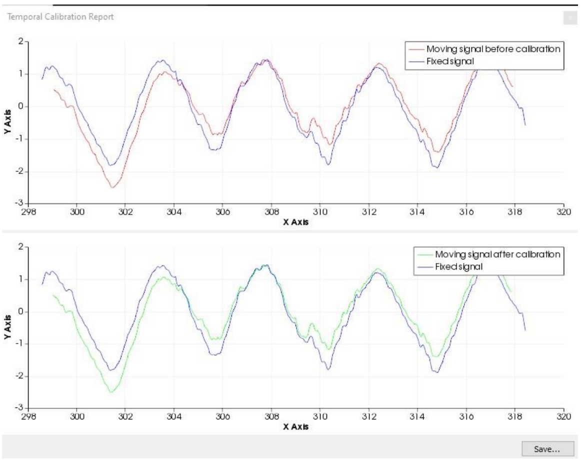


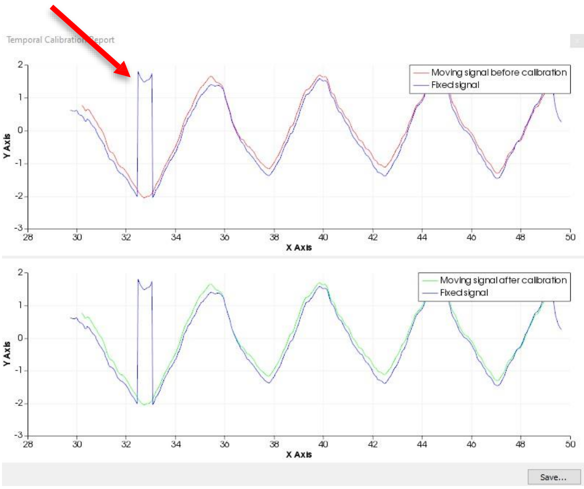
If the ultrasound probe with the tracking attachment is placed into the basin of water, the floor should appear as a white line on the screen. On this white line there should be a smaller green line, created by the program that follows the movement.



- Now press **"Start".**
- Do a periodic movement with the probe in a vertical position from top to bottom.

- After the calibration select **“Show Plot”**. The images show some **bad examples**. Make sure the movement is done slow and steady. If a second white line appears and the green line jumps, as shown in the second image, repeat the calibration.



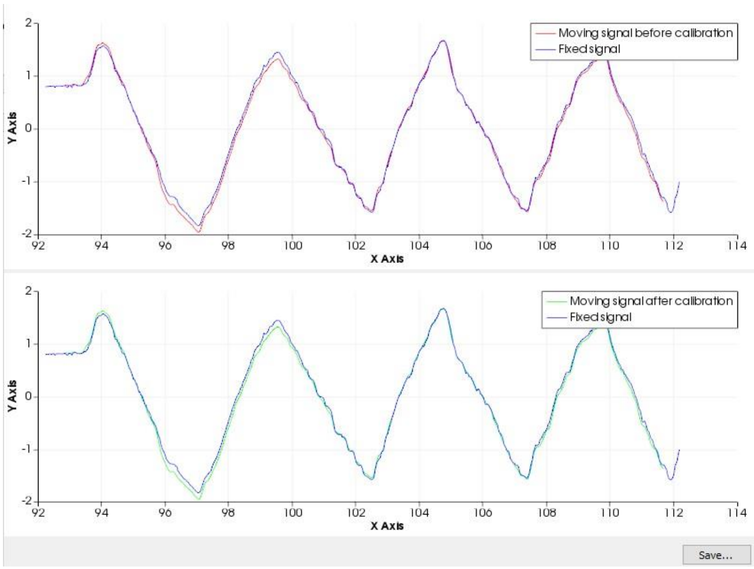


In the end the two signals should be on top of each other, which means that the initial offset between the signals is cancelled out. If the calibration is done successfully, check how many milliseconds the difference between the “VideoDevice” and the “TrackerDevice” is. In our case it's 16.7 milliseconds.

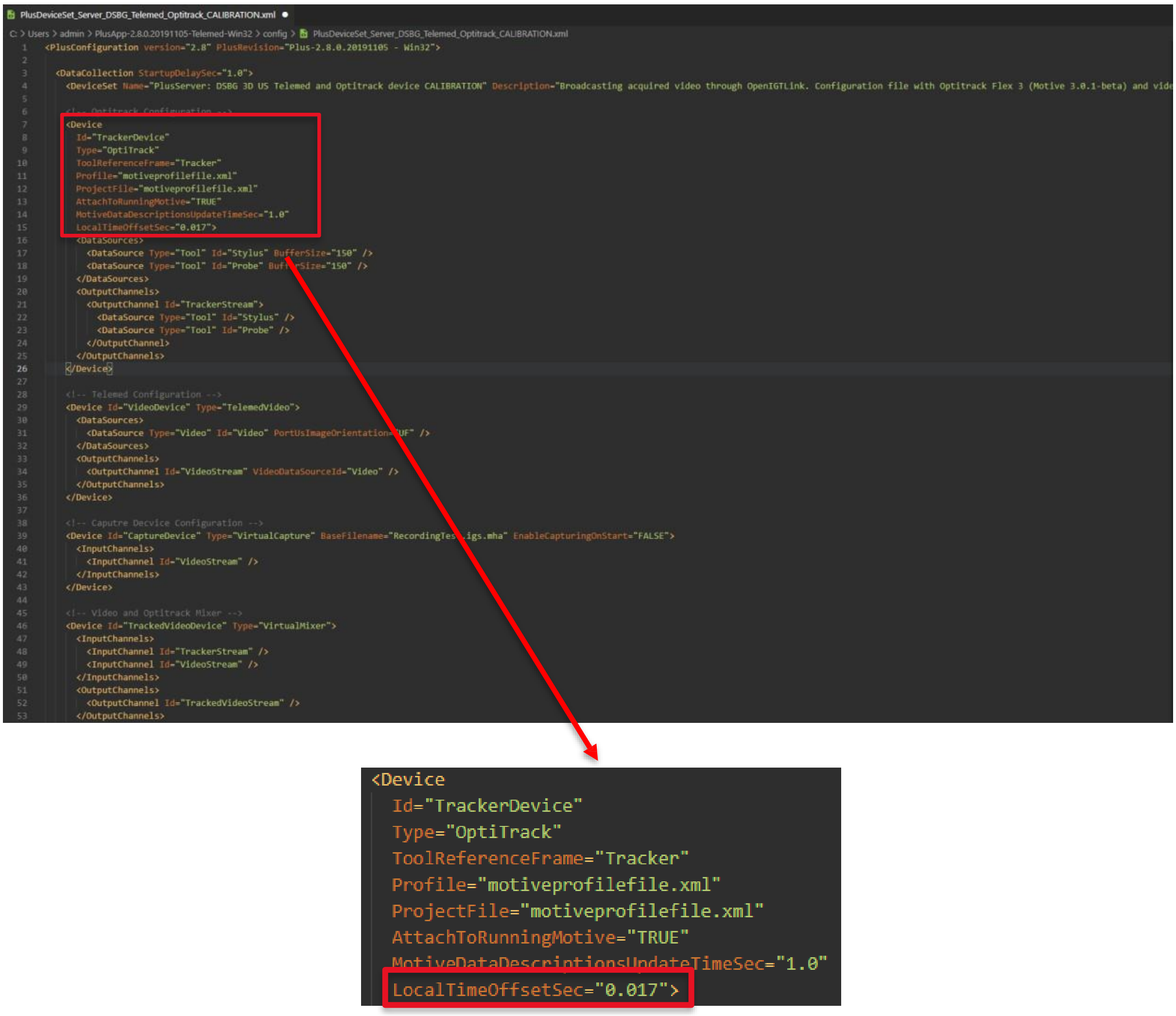
VideoDevice lags compared to TrackerDevice by 16.7ms.

Difference compared to previous temporal calibration: 5.4ms.

Best case scenario would be, if for each temporal calibration the difference from the previous temporal calibration is as small as possible. This ensures that the systems are well coordinated and no artifacts have been introduced.



- The value obtained in this calibration needs to be copied to our “Calibration” and “Acquisition” XML code.
- Therefore open both XML files from your PlusApp “config” folder and search for the line: **“LocalTimeOffsetSec"** and change the values to the ones received. We changed it to “0.017” because it is given in seconds.



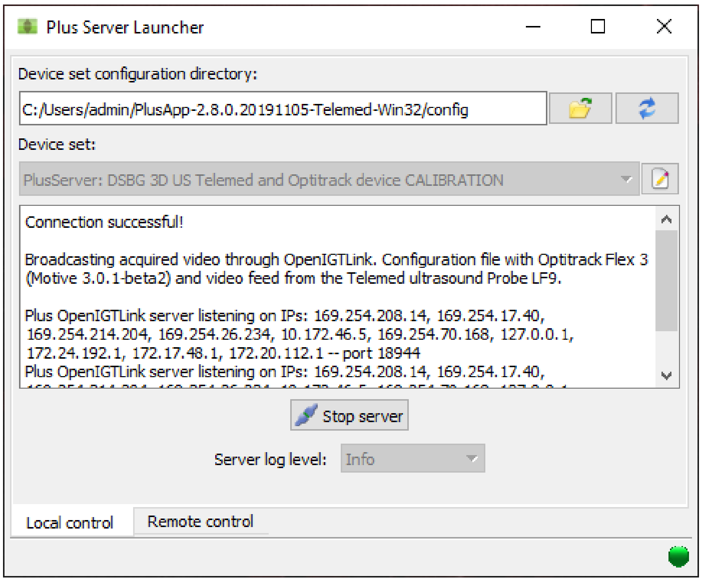
- **Make sure both codes are changed!**
- **Quit “NotePad”** and **“Fcal”**.

1.7 Pivot Calibration

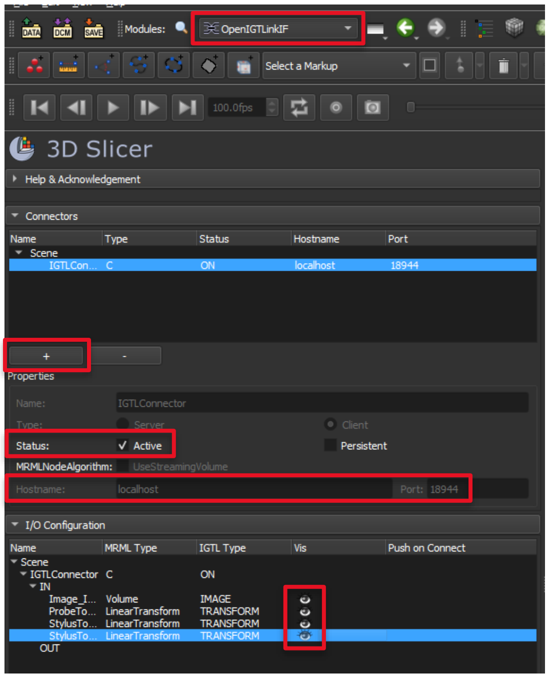
The pivot calibration calculates the transform matrix between the referential of the stylus (markers on the stylus) and the stylus tip.

Do this calibration if a new stylus is being used. After this calibration has been performed once and the same stylus is used, there is no need to repeat the pivot calibration.

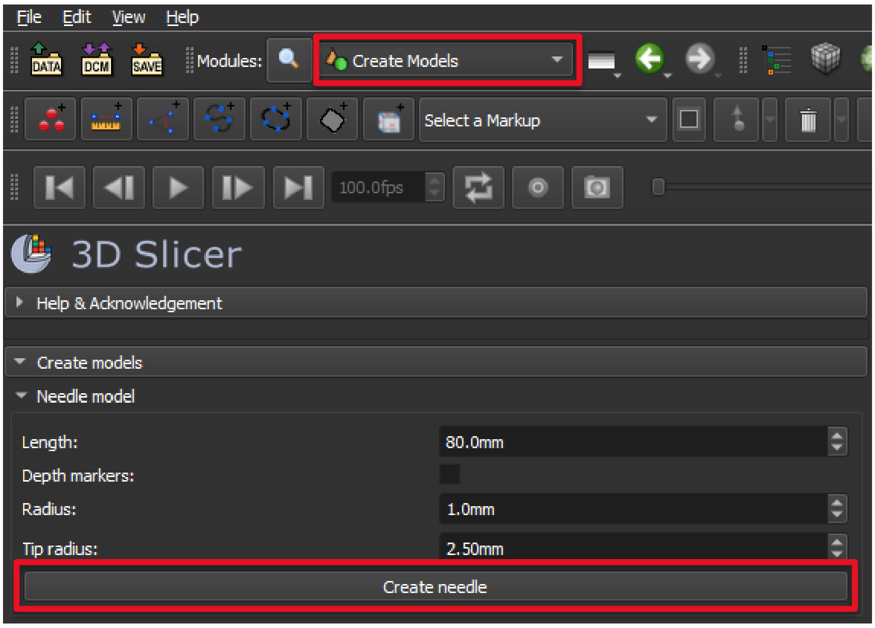
- Open the **PlusServer** and launch the **"Calibration"** file.



- In "Slicer" open the **"OpenIGTLinkIF"** menu under the "IGT" module**.**
- Add a connector by clicking on the **+ button**.
- Check the **"active"** setting under "status".
- The hostname is **"localhost"** and the port should be **"18944".**
- The **status** indicator must be **"ON"**, so that Slicer is correctly connected to the Plusserver.
- Open the dropdown menu **"IGTLConnector"** and make sure that under **"IN"** the different connectors have their **eyes opened**. This ensures that they are visible in the viewports.

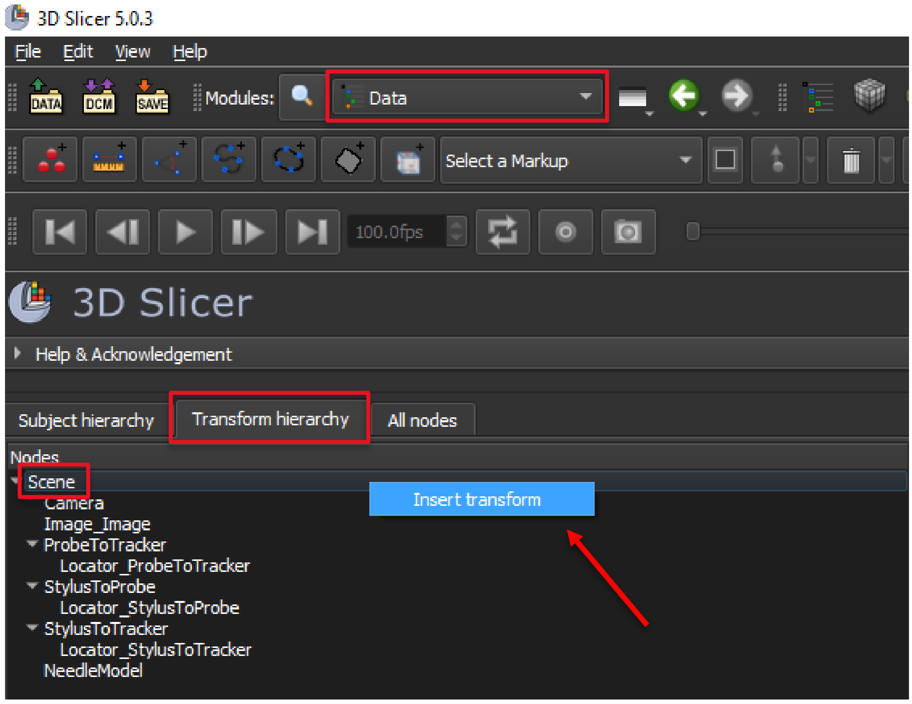


- Now make sure that both the Stylus and the Probe are in the scene. The probe should lay on the ground and will be used by Slicer as a reference point.
- Go to the module **"Create Models".**

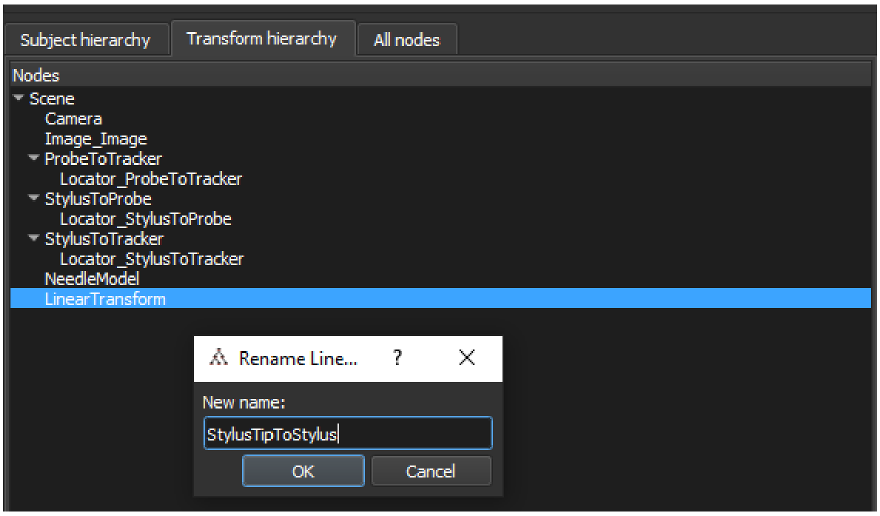


- Without changing any settings select **"Create needle".** This adds a new blue needle Model in the 3D Viewport.
- To connect our Stylus with the new needle model we need to go to the **"Data"** module.

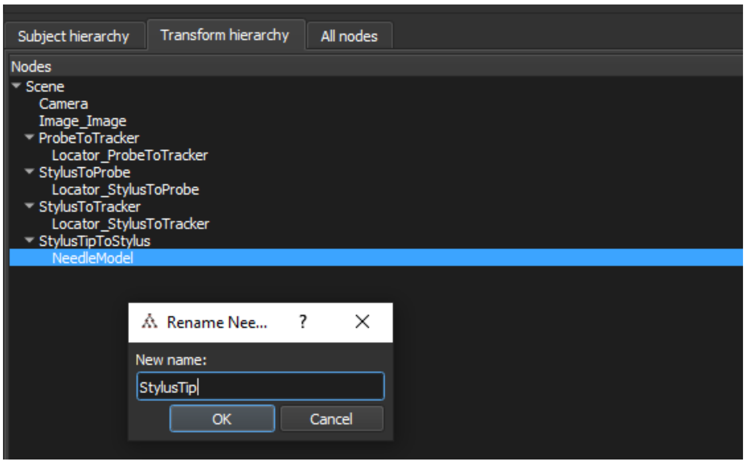
- Select the **“Transform hierarchy”** tab and click right on the “Scene”. Choose the **“Insert transform”** option.



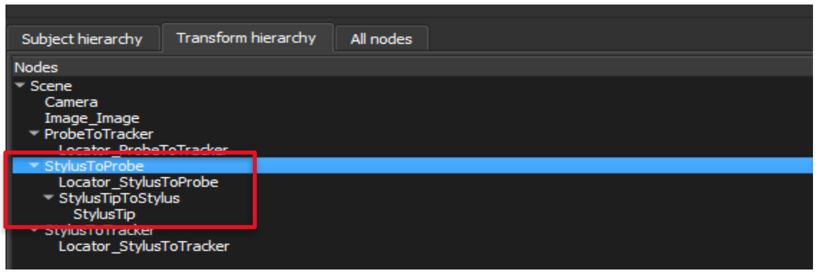
- Click right on the newly created “LinearTransform” and rename it to **“StylusTipToStylus”.**



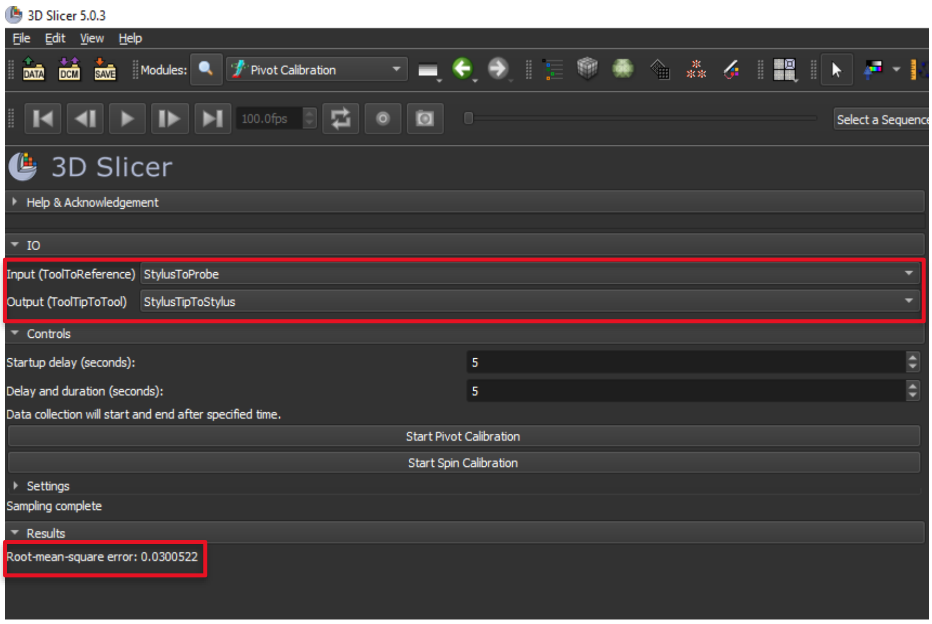
- Move the “NeedleModel” with drag and drop under the created “StylusTipToStylus” transform and rename the “NeedleModel” to **“StylusTip”.**



- Move the “StylusTipToStylus” transform with the “StylusTip” in it **into the “StylusToProbe”** transform.



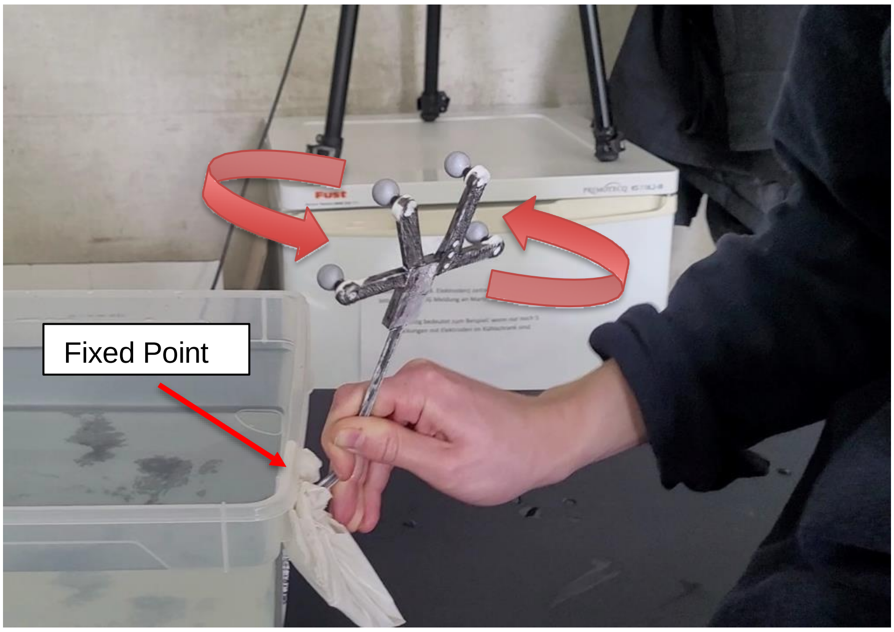
- Now choose the module **“Pivot Calibration”.**
- Change the input to **“StylusToProbe”** and the output to **“StylusTipToStylus”.**



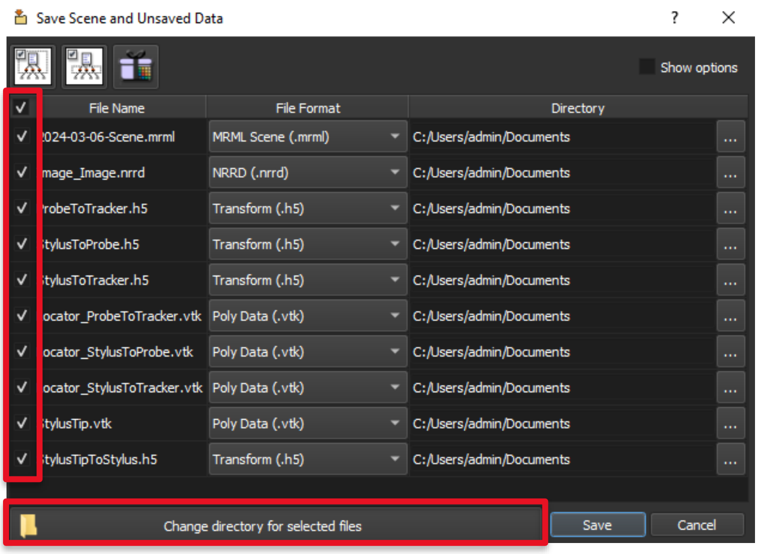
- Now place the stylus so that the tip has a fixed position.

- Click on **“Start Pivot Calibration”**.
- Start rotating the stylus around its tip until the timer stops.

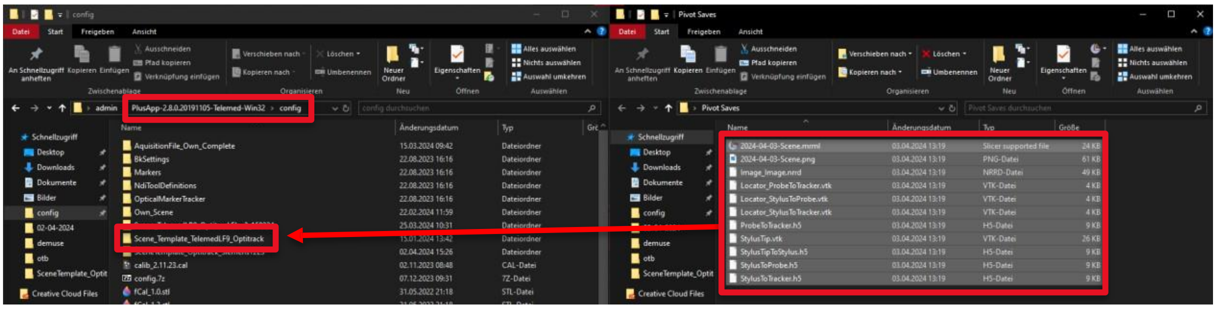
Figure 13:
A picture from our video on how to perform the [Pivot Calibration]



- If the calibration was calculated correctly, there should be a number next to **“Root-mean-square error”.** This number indicates how precise it can measure the position of the stylus tip and its corresponding markers. Make sure it is as close to 0 as possible.
- If a non-vertical stylus like ours is used, the **“spin calibration”** must be performed**.** Click on start and rotate the stylus around its tip again, as in the previous step.
- Save the file in a separate folder called, for example, “PivotSaves” by clicking on “Change directory for selected files” and check all boxes.



- Create a **new folder** inside the config folder of the Plusserver. Name it “Scene_Template_*Ultrasoundmodel_CameraSystem*”. (In our case it is called **“Scene_Template_TelemedLF9_Optitrack”**)
- Copy all the files from the “PivotSaves” folder and paste it into that folder that was just created.



- **Do not quit** Slicer and PlusServer and continue working in the same scene.

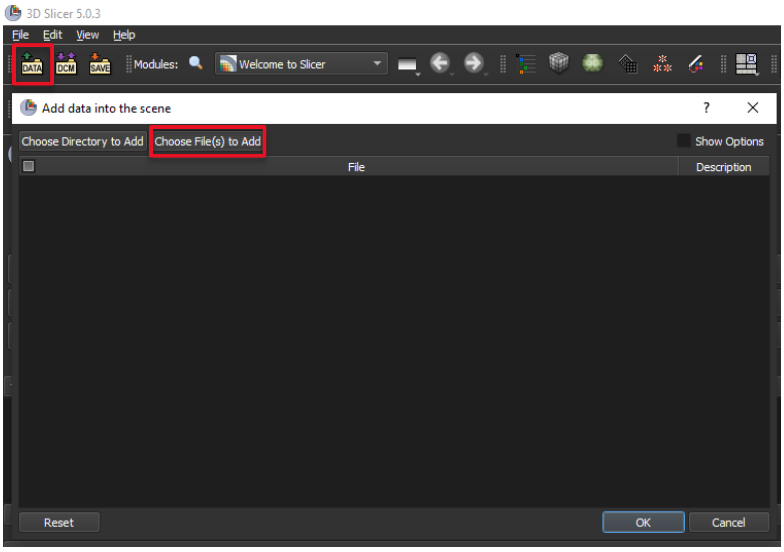
1.8 Probe Calibration

This time the transform matrix is calculated between the probe markers and the ultrasound image.

We suggest doing this every time a new motive calibration is created or if the settings of the ultrasound device have changed, especially the depth. Do not change the settings of the Telemed ultrasound in the Ecowave program after running the probe calibration, otherwise the tracking data will be negatively affected.

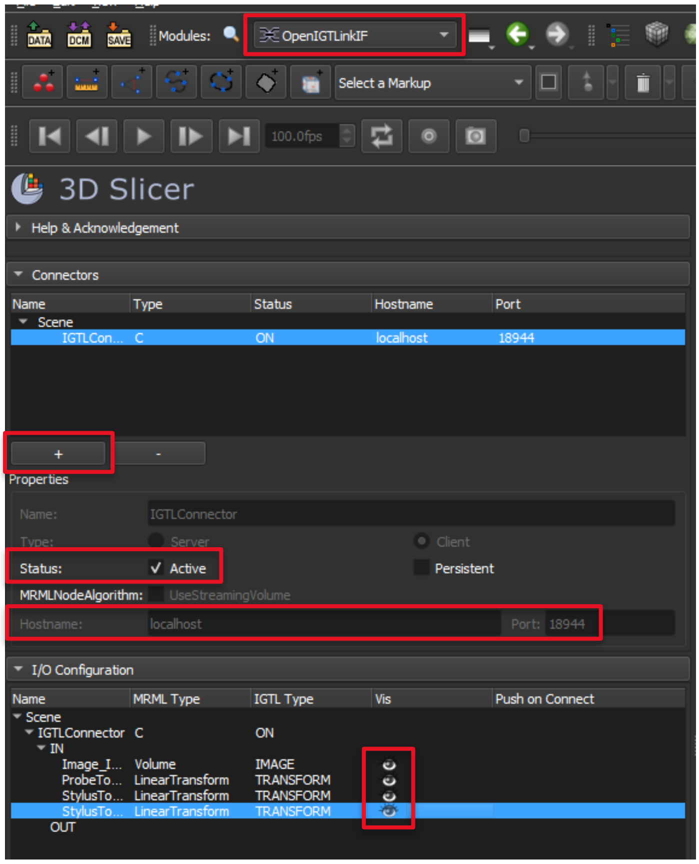
1.8.1 Bug fixes

- If, for any reason, the program crashed or you wanted to continue at a later point in time, start the PlusServer again and launch the **"Calibration"** file. If that is not the case continue with chapter "3.6.2 Spatial calibration sequence".
- Open up "Slicer" and click on **"Add Data".**
- Select **"Choose File(s) to Add".**

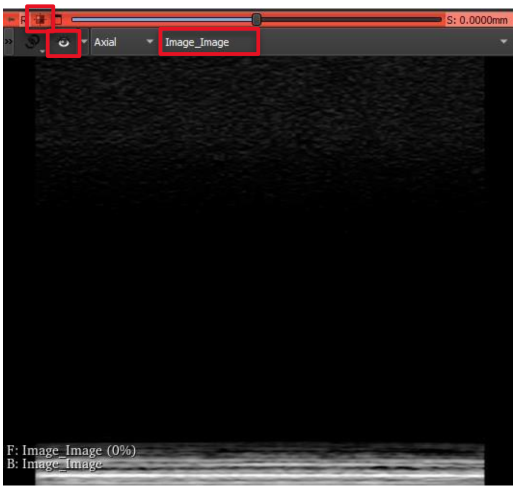


- Load in the **".mrml"** file from the saves folder of your pivot calibration created in chapter "3.5 Pivot calibration".
- Select the module **"OpenIGTLinkIF"** under "IGT".
- If a connector already exists, use it. Otherwise, click on the "+" button to create a new one.
- The hostname is **"localhost"** and the port should be **"18944".**
- Check the **"active"** setting under "status".

- The status indicator must be **“ON”**, so that Slicer is correctly connected to the PlusServer.
- Open the dropdown menu **“IGTLConnector”** and make sure that under “IN” the different connectors have their eyes opened. This ensures that they are visible in the viewports.

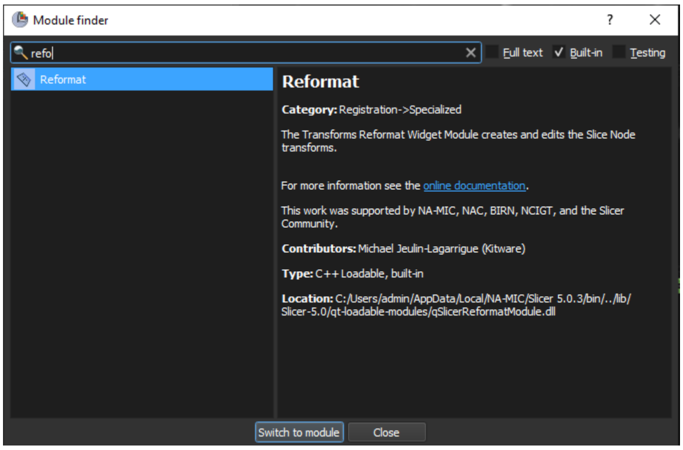


- The live ultrasound image should now show up in the red viewport. To center it, select the third symbol on the red line with the gray nuances.
- If it does not appear, select the “pin symbol” to open more settings. Make sure the “eye symbol” is on and the **“Image_Image”** port is selected.

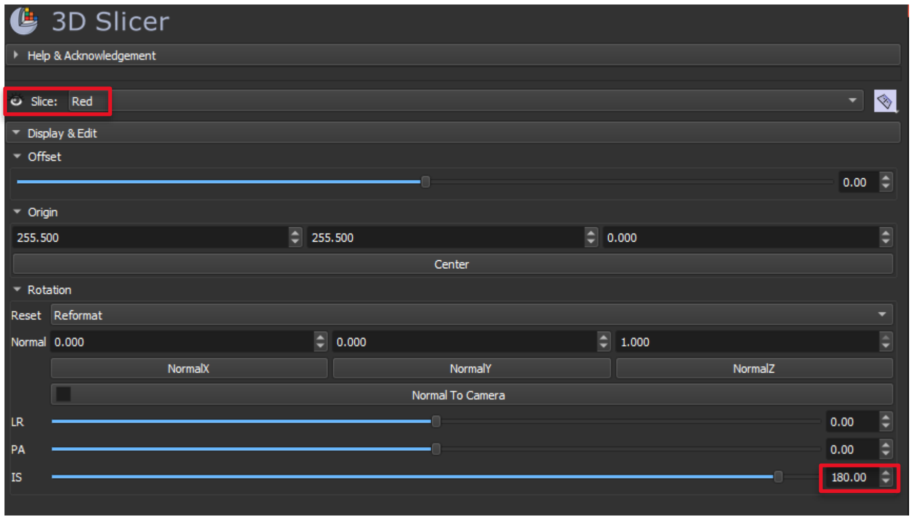


If the ultrasound image is upside down or out of alignment use the “Reformat” module.

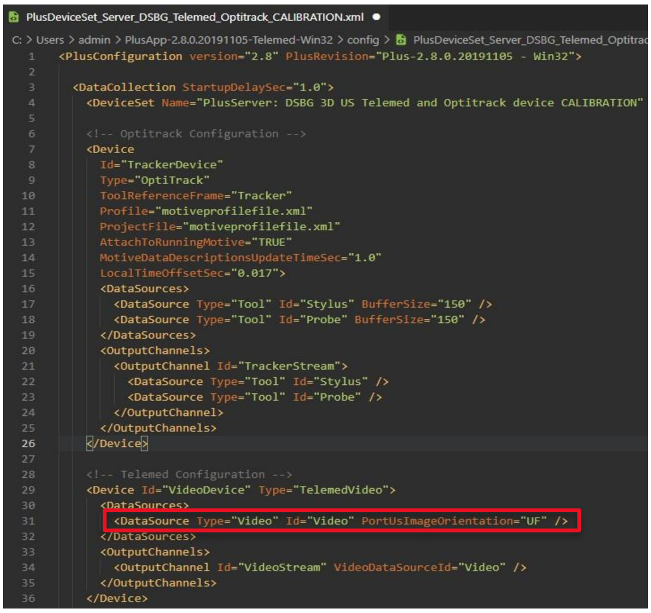
- Search for the **“Reformat”** module and select it.



- Choose in the “Slice” dropdown menu the viewport you want to change. In our case it is the red one.
- To **flip the viewport 180°,** type the number into the “IS” slider at the bottom. This should fix the orientation problem.

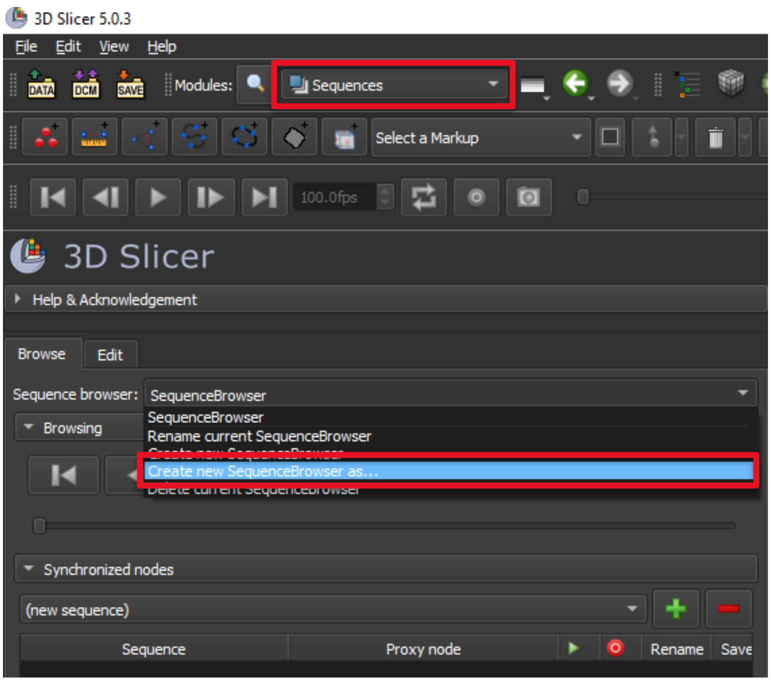


Other than the option with the “Reformat” module, there is a solution to change it in the code of the calibration and acquisition XML files. Search for the “PortUsImageOrientation” and change it from UF to UN or vice versa. This will also flip the image 180 degrees.

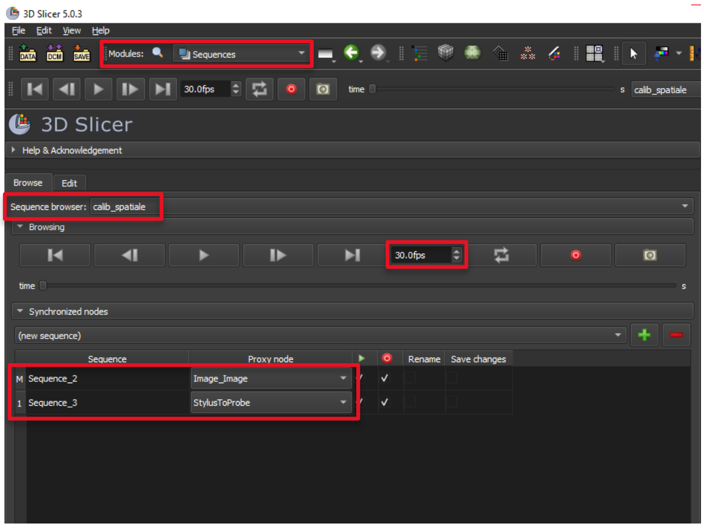


1.8.2 Spatial calibration sequence

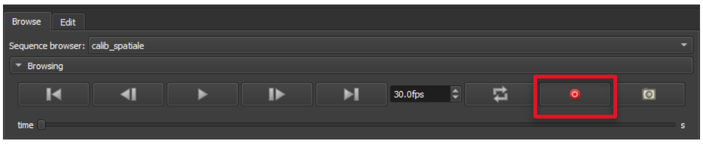
- Choose the module **“Sequence”.**
- Under “Sequence Browser” open the dropdown menu and select **“Create new SequenceBrowser as…”** and name it whatever you like, for example **“calib_spatial”.**



- Click the **“+” button two times** to add two new sequences.
- Change the first proxy node to **“Image_Image”** and the second proxy node to **“StylusToProbe”.**
- To get a better result set the **FPS to 30** or higher.



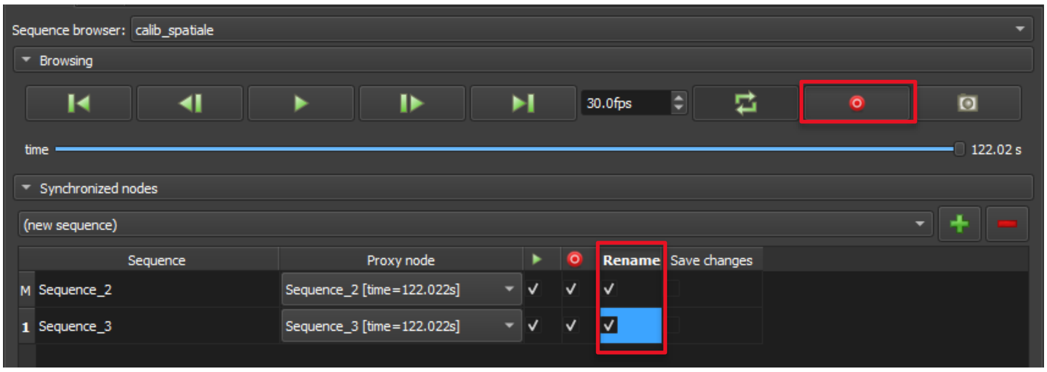
- To start the spatial calibration, press the red record button. A timeline will appear and the seconds will start increasing.



- Place the probe and the stylus in a basin of water. The stylus tip needs to appear in the viewport of the ultrasound image.
- During the calibration place the **tip of the stylus in each corner** of the ultrasound image. Make sure the tip is visible in the viewport as clearly and in as much detail as possible. Hold it in place in each corner for a few seconds to get a better result.
- With the recording still on, rotate the probe and the stylus about 45°-90° and repeat the steps. Make sure the tip is visible again in every corner.

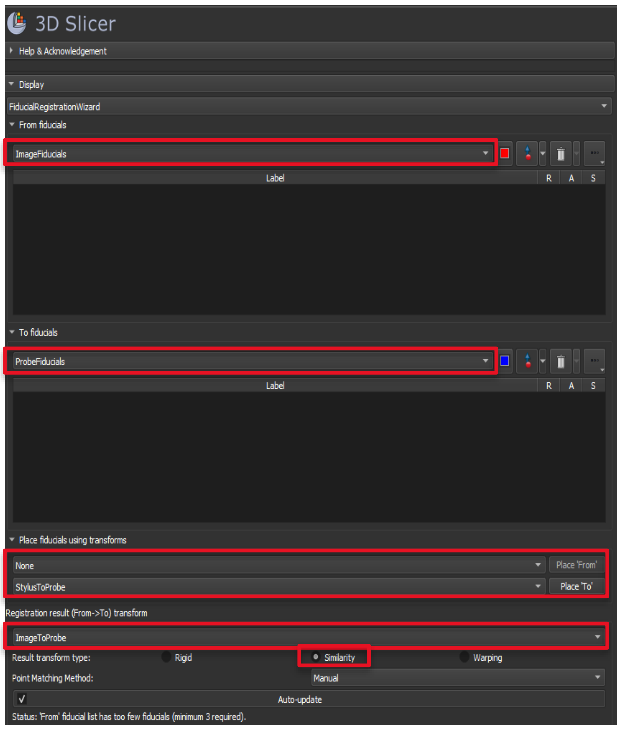
Figure 14:
A picture from our video on how to perform the [Spatial Calibration](#)

- Stop the recording by pressing the red dot.
- To save the calibration, check the column **"rename"** for both sequences.



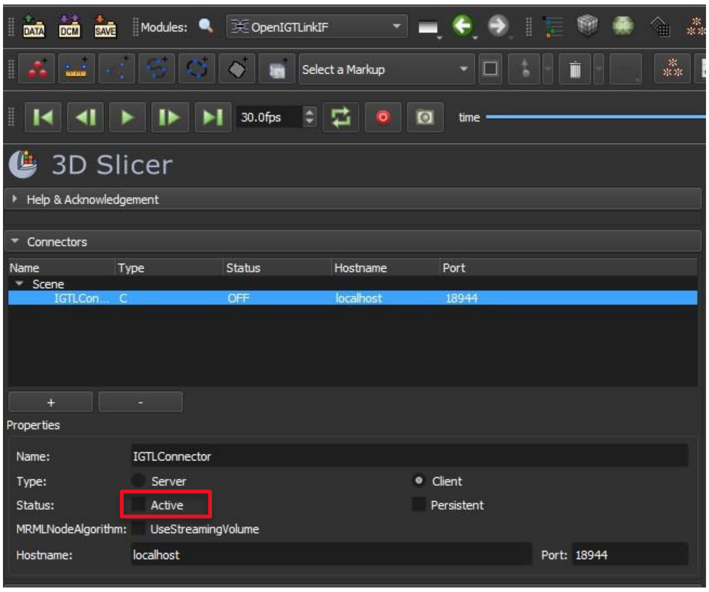
1.8.3 Probe calibration processing

- Open the **“Fiducial Registration Wizard”** to evaluate the recording.

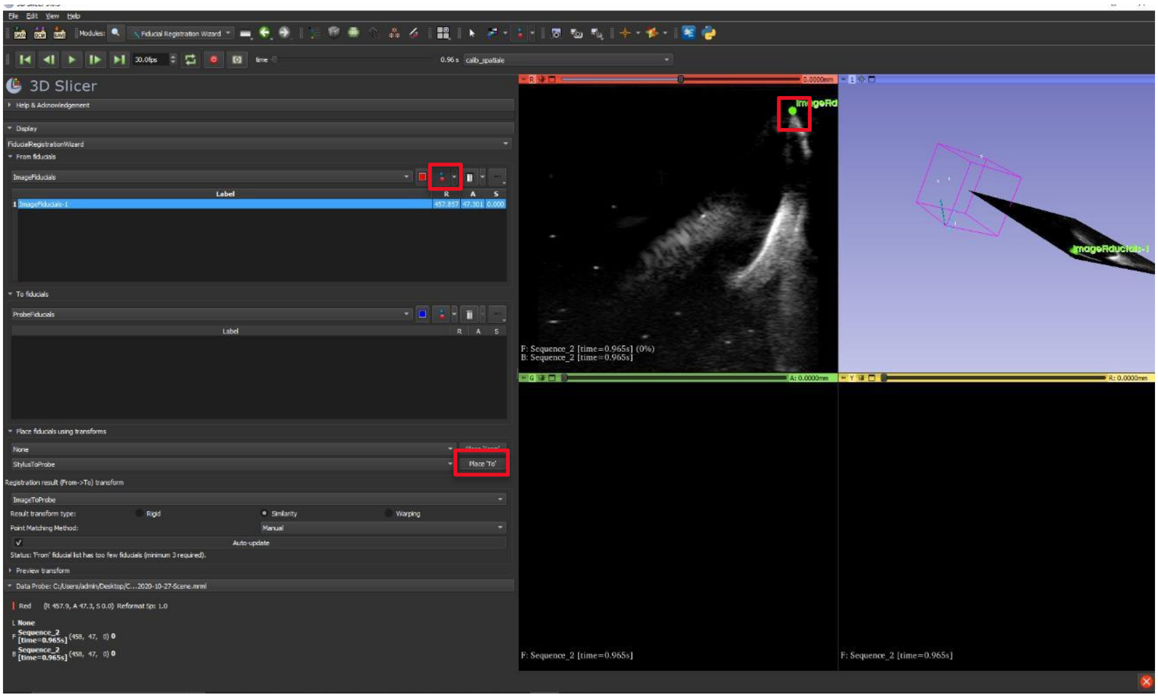


- Go to the first dropdown menu and select **“Create New Point List as…”** and name it **“ImageFiducials”.**
- Do the same for the second dropdown menu and name it **“ProbeFiducials”.**
- Click on the small triangle next to “Place fiducials using transforms” which opens two new options. The first should be set to **“None”** and the second one to **“StylusTipToStylus”.**
- In the dropdown menu from “Registration results” select **“create new transform as…”** and name it **“ImageToProbe”.**
- Set the “transform type” to **“Similarity”.**
- **“Auto update”** should be activated.

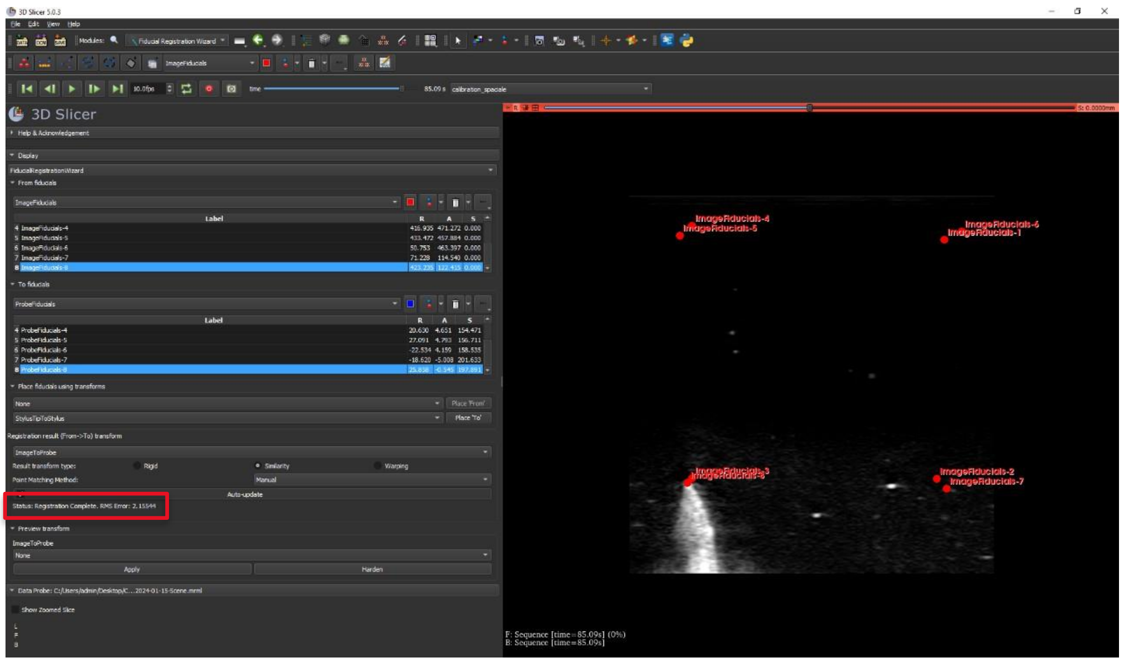
When the recorded sequence is played by pressing the play button above, the viewport flickers because the live broadcast overlaps with it. To fix that problem, select the **“OpenIGTLinkIF”** module and **deselect** the **“Active”** checkbox.



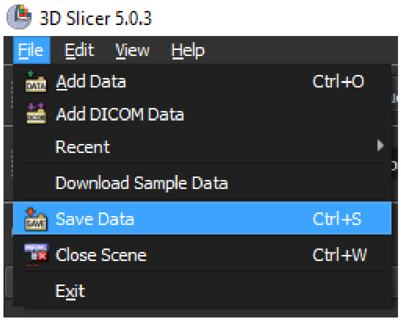
- Back in the **"Fiducial Registration"** module, start to play your sequence.
- As soon as the tip is in a corner and visible, pause the recording.
- Select the **blue arrow pointing up with the red dot**. Hover over the red viewport to select the tip of the stylus. This creates a point.
- To transfer the data to the "ProbeFiducials" click, next to the "StylusToProbe", the **"Place To"** button.

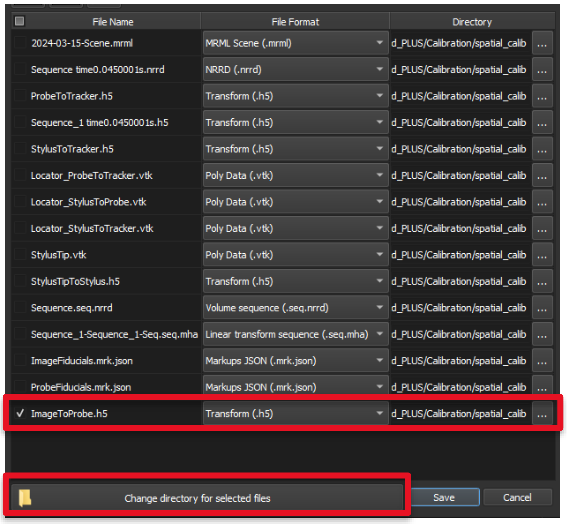


- Scroll through the timeline and **repeat** that action for each corner where the stylus tip is visible. In total you should do it **eight times**.

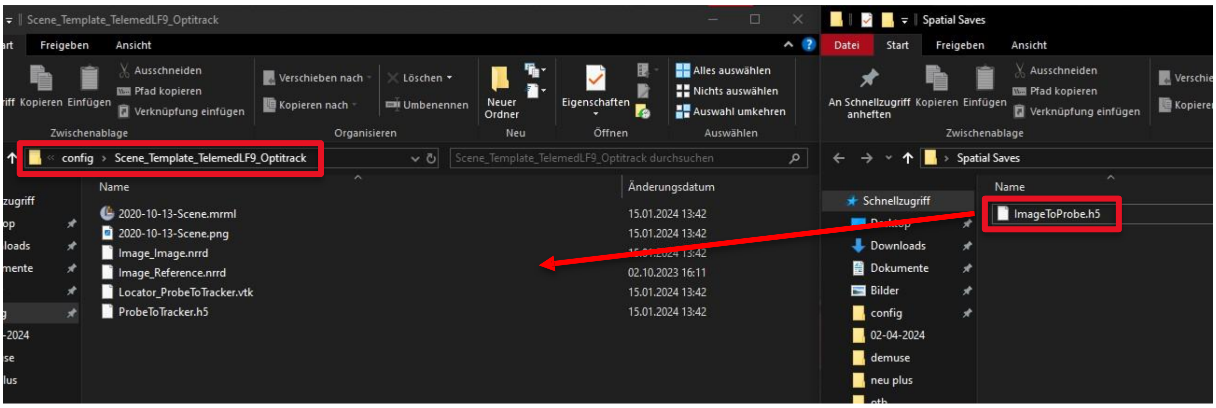


- After three selected points a **“RMS error”** gets displayed**.** This error shows how precise the points are in relation to the motive tracking data. The error should be between 1 and 3.
- Click under files **“Save Data”.**
- Only select the “ImageToProbe.h5” file and save it in a separate folder.





- After saving, open the folder and copy the “ImageToProbe.h5” file to paste it into the **“Scene_Template_TelemedLF9_Optitrack”** folder. All the saves from the pivot calibration and the *ImageToProbe.h5* file from the probe calibration should now be in this folder.



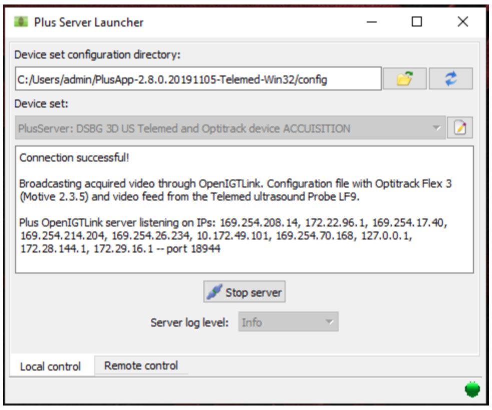
- **Quit** Slicer and PlusServer.

1.9 Acquisition

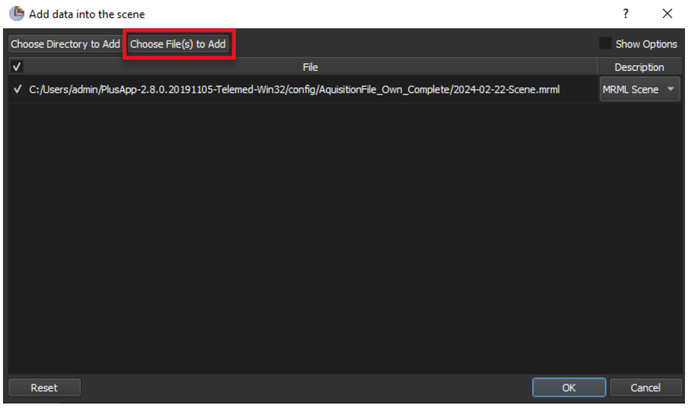
At this point every system and program should be correctly calculated. In the following, we will capture a sequence from which 3D Slicer can extract all the necessary data to create a 3D volume from the scanned muscle or object.

3.1.7 Acquisition Setup

- Start the Plusserver and load in the **“Acquisition”** XML-file.
- **Launch** the server and do **not quit** the program.

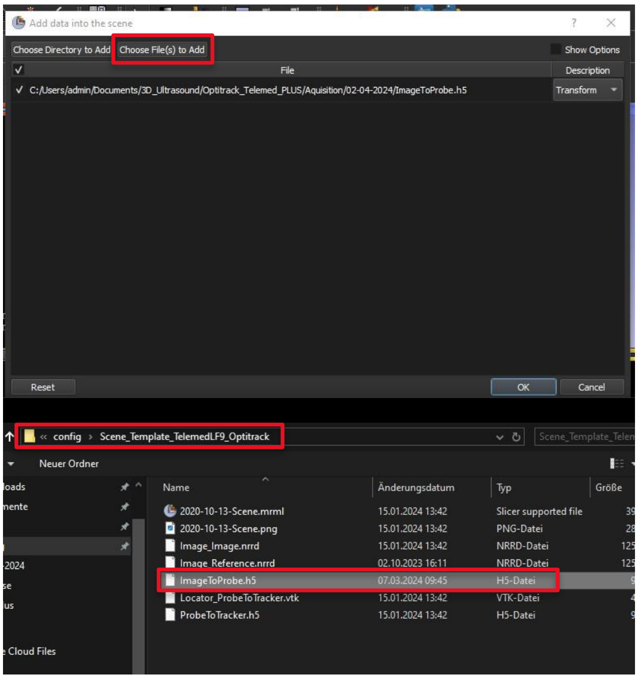


- Open up Slicer and click on **“Data”**.
- Select **“Choose File(s) to Add”.**
- Search the folder called “Scene_Template_*UltrasoundModel_CameraSystem*”, which is in the config folder of the Plusserver.
- Select the scene “.mrml” scene file and open it.

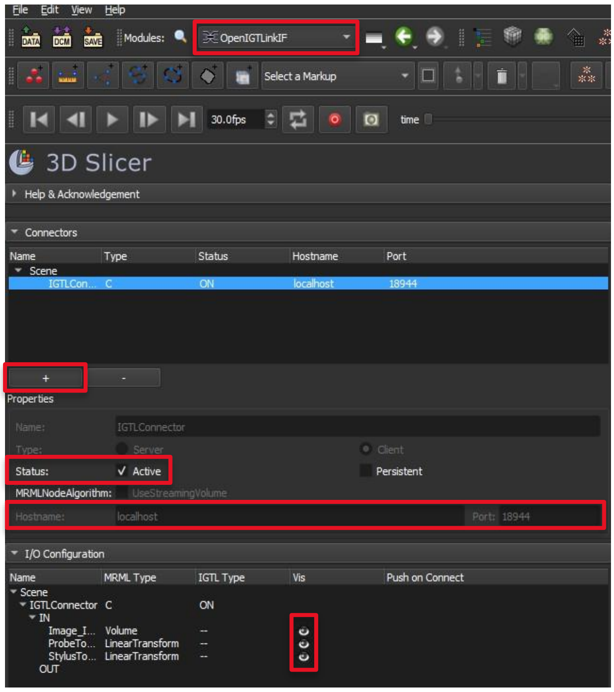


Even though we copied the “ImageToProbe.h5” file into this folder it is not added automatically. We have to import it separately.

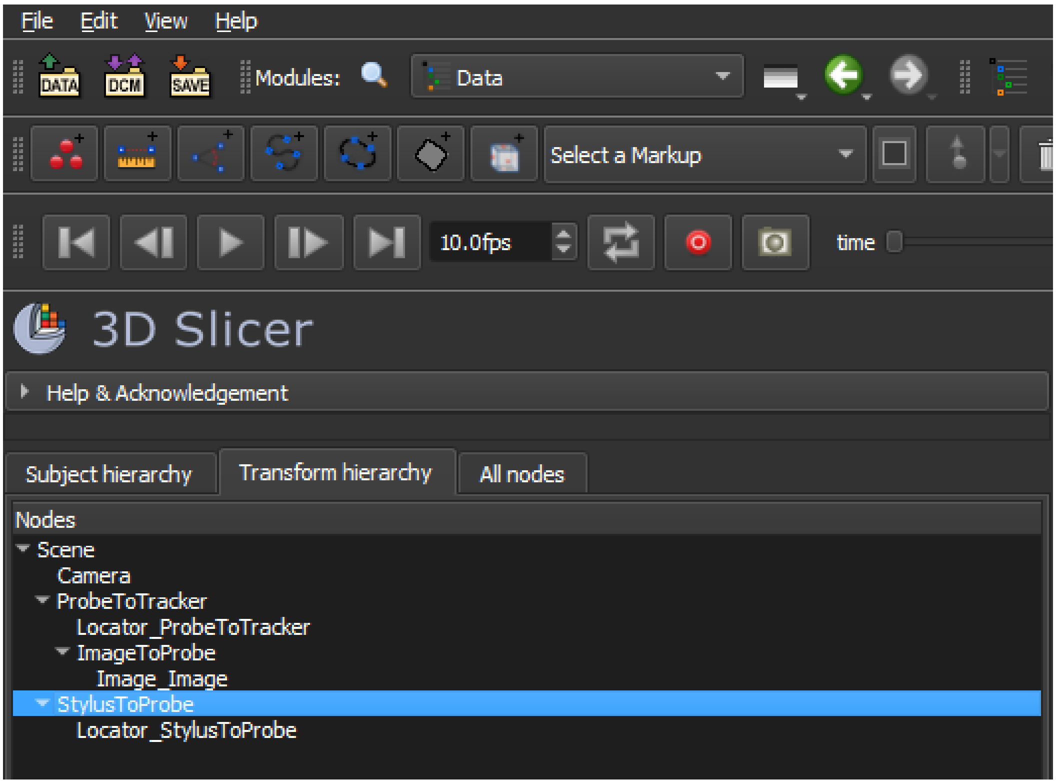
- Again click on **“Data”** and select **“Choose File(s) to Add”.**
- Only select the “ImageToProbe.h5” file and open it.



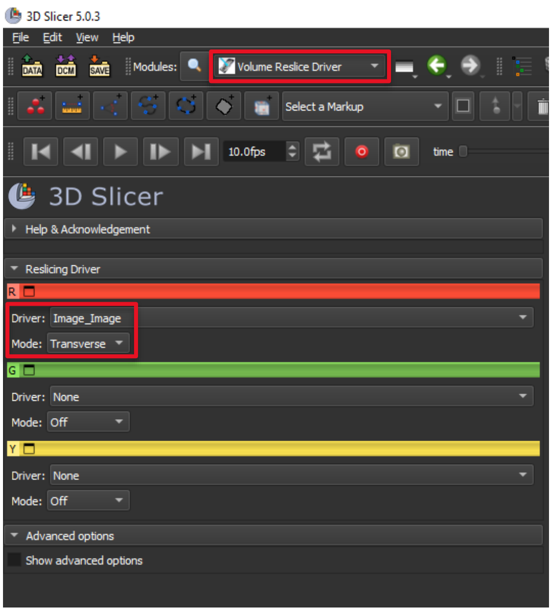
- Select under “IGT” the module **“OpenIGTLinkIF”.**
- If a connector already exists, use it. Otherwise, click on the “+” button to create a new one.
- The hostname is **“localhost”** and the port should be **“18944”.**
- Check the **“active”** setting under “status”.
- The status indicator must be **“ON”**, so that Slicer is correctly connected to the PlusServer.
- Open the dropdown menu **“IGTLConnector”** and make sure that under “IN” the different connectors have their eyes opened. This ensures that they are visible in the viewports.



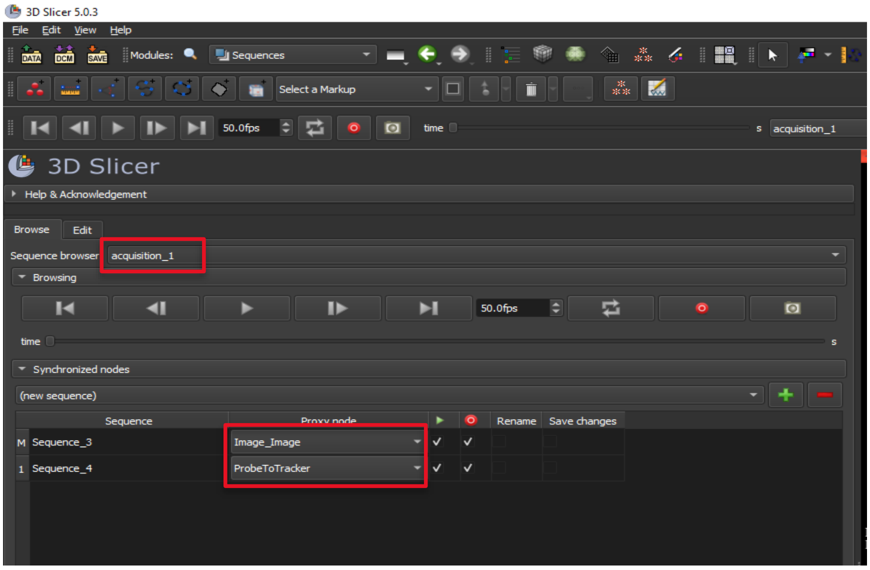
- Search the module **“Data”** and make the same changes under the **“Transform hierarchy”** as you can see in the following picture. If you have more transforms in the scene, you can right click and delete them.



- In the module **“Volume Reslice Driver”** the link between Image_Image and the acquisition mode needs to be made.
- In the red driver choose **“Image_Image”** and change the mode to **“Transverse”.**



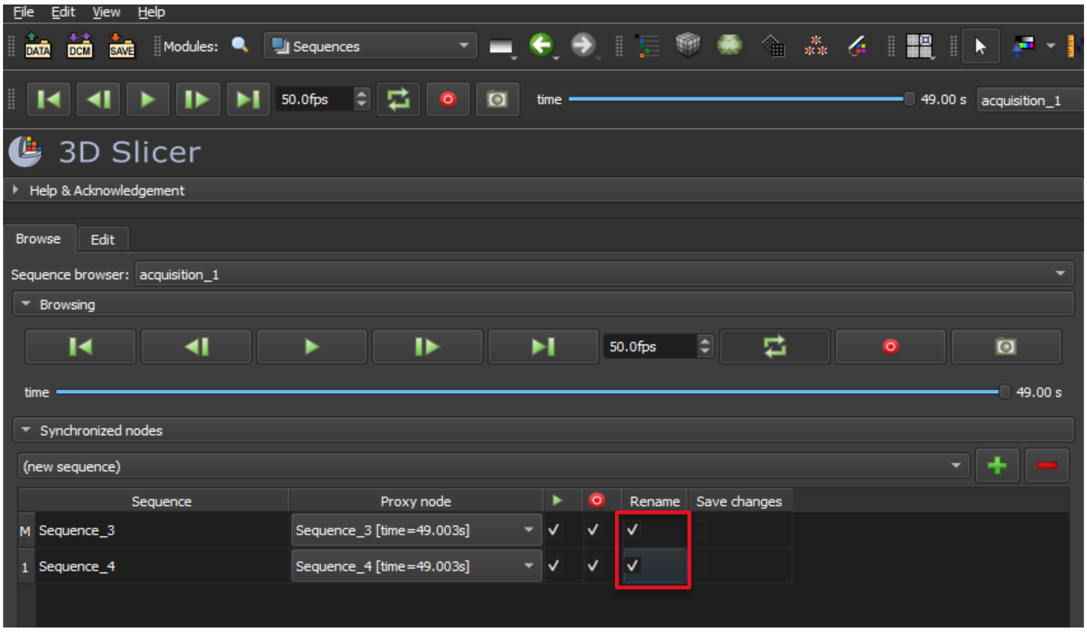
- Select module **“Sequences”**.
- Click on the drop down menu **“SequenceBrowser”** and select “Create new SequenceBrowser as…” and name it **“acquisition_1”.**
- Click the “+” button two times to add two new sequences. Change the first proxy node to **“Image_Image”** and the second one to **“ProbeToTracker”.**
- Set the **fps to 30** to record more images per second and have a better acquisition. Only go higher if your ultrasound model is able to record at a higher fps rate.



At this stage you can save the scene in a separate **“Final_Aquisition”** folder in the config of the Plusserver. If you want to do an acquisition at a later point in time with the same setup, you can load the saved .mrml scene and start the acquisition without having to repeat the previous steps.

3.7.2 Acquisition recording

- Import the .mrml scene from the **“Final_Acquisition”** folder.
- Select the **“aquisition_1”** in the sequence browser.
- Prepare the acquisition and **press the red dot** to start the recording.
- After the recording is finished, **press the red button again** and check the column **“rename”** for both nodes to save the file.

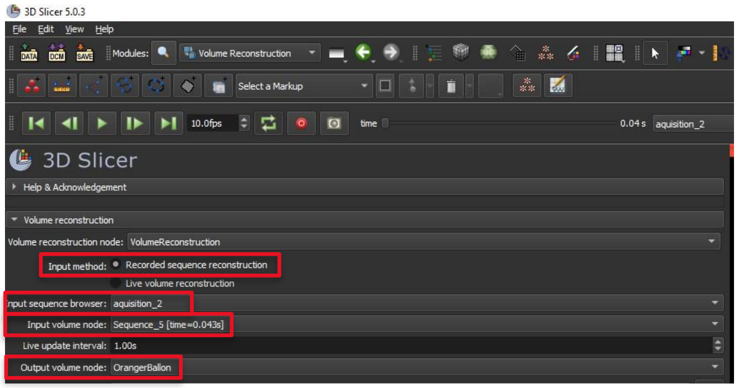


1.10 Volume Reconstruction

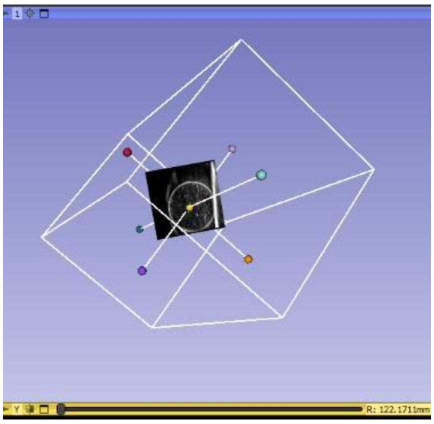
The acquired material can now be processed with some additional filters to create an accurate 3D volume, which will be explained in the following. Perform this either right after the acquisition or save the whole scene and load the “mrml.” file from that date into slicer at a later point in time.

Make sure that under “OpenIGTLinkIF” the “Active” setting is **not checked**. Otherwise, if it is set on “checked”, the live broadcast will overlay with the recording which can result in a bad reconstruction.

- Search the module **“Volume Reconstruction”** and select it.
- Make following changes;
  - *Input method:* “recorded sequence reconstruction”.
  - *Input sequence browser:* choose the recorded sequence.
  - *Input volume node:* “Sequence [time=xx s]”.
  - *Output volume node:* “create new volume as…” → name it whatever suits best, for example the muscle that was scanned.

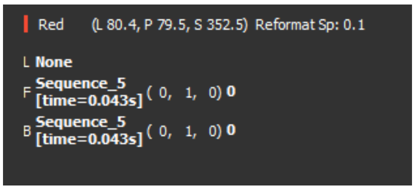


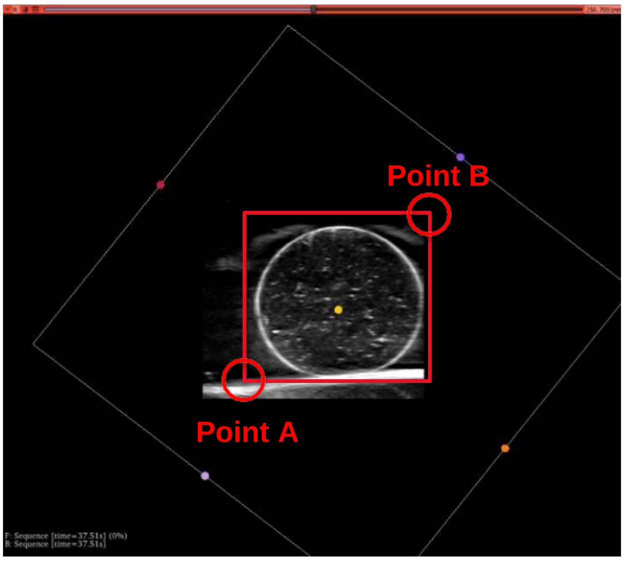
  - *ROI node:* **“create new AnnotationROI”** → A new square appears in the 3D viewport. This is the ROI which can be scaled and moved around. The dimensions of the ROI should contour the volume scanned during the recording.
  - Play the recorded sequence by pressing the green play button and make sure that, during the whole sequence, the image is inside the ROI.



- *Output spacing*: This value represents how much spacing between two recorded images/slices are. The smaller this value is, the better the reconstruction quality, but the longer it takes to calculate. The value goes between 0,1 and 1,0. We recommend taking a lower number, in our case we used **0,3.**
- *Interpolation mode:* “linear”.
- *Compounding mode:* “mean”.
- Check ***“Fill holes”.***

- *Clipping:* The correct coordinates must be set for the real ultrasound image frame. This can be achieved by hovering over the red viewport with the cursor. The coordinates are displayed at the bottom left of your screen.

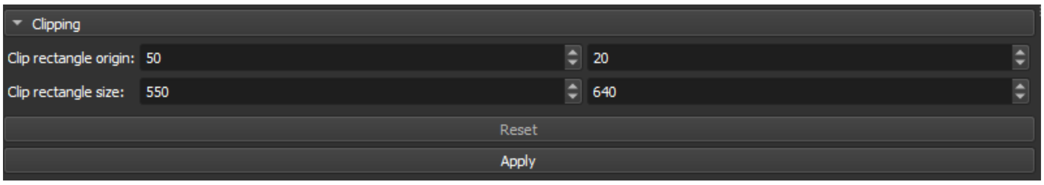




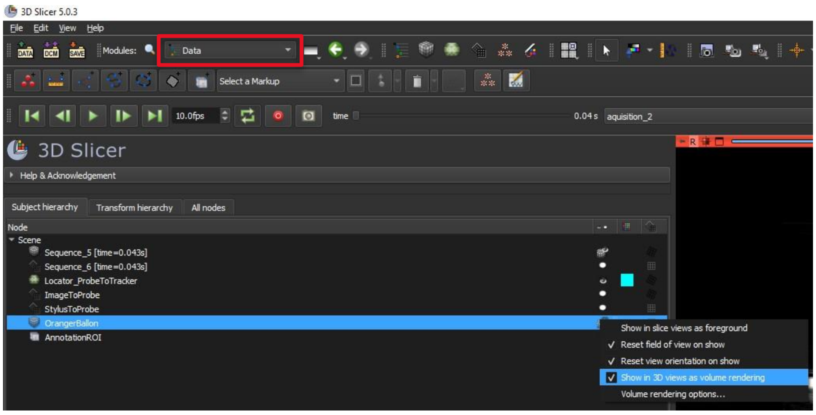
Clip rectangle origin: To find Point A hover over the bottom left corner of the real ultrasound image. Make sure that this point is always outside of the object and never clips through it. Note the first two coordinate values into the “clip rectangle origin”.

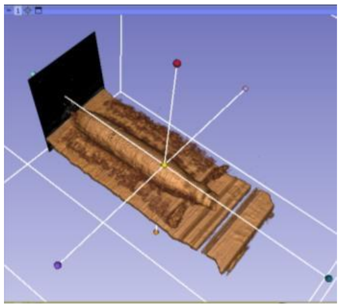
Clip rectangle size: Point B is at the top right corner of the real ultrasound image. The imaginary rectangle, that is created with the two points, should always enclose the object. The values to note into “clip rectangle size” are **Point B - Point A**.

For example: Point A is at 50,20 and Point B is at 600,660 so you need to type in the value 50 & 20 into the origin and 550 & 640 into the size.

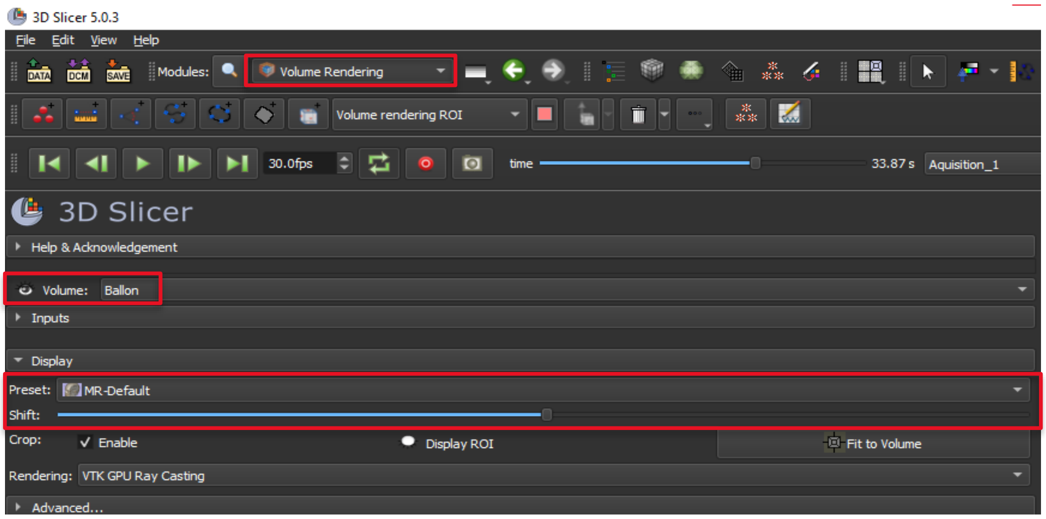


- Click **“Apply”** and wait until the reconstruction is finished.
- Search the module **“Data”** and select **“Subject hierarchy”**
- Display the volume by right clicking on the eye symbol of the volume and selecting **“Show in 3D views as volume rendering”.**





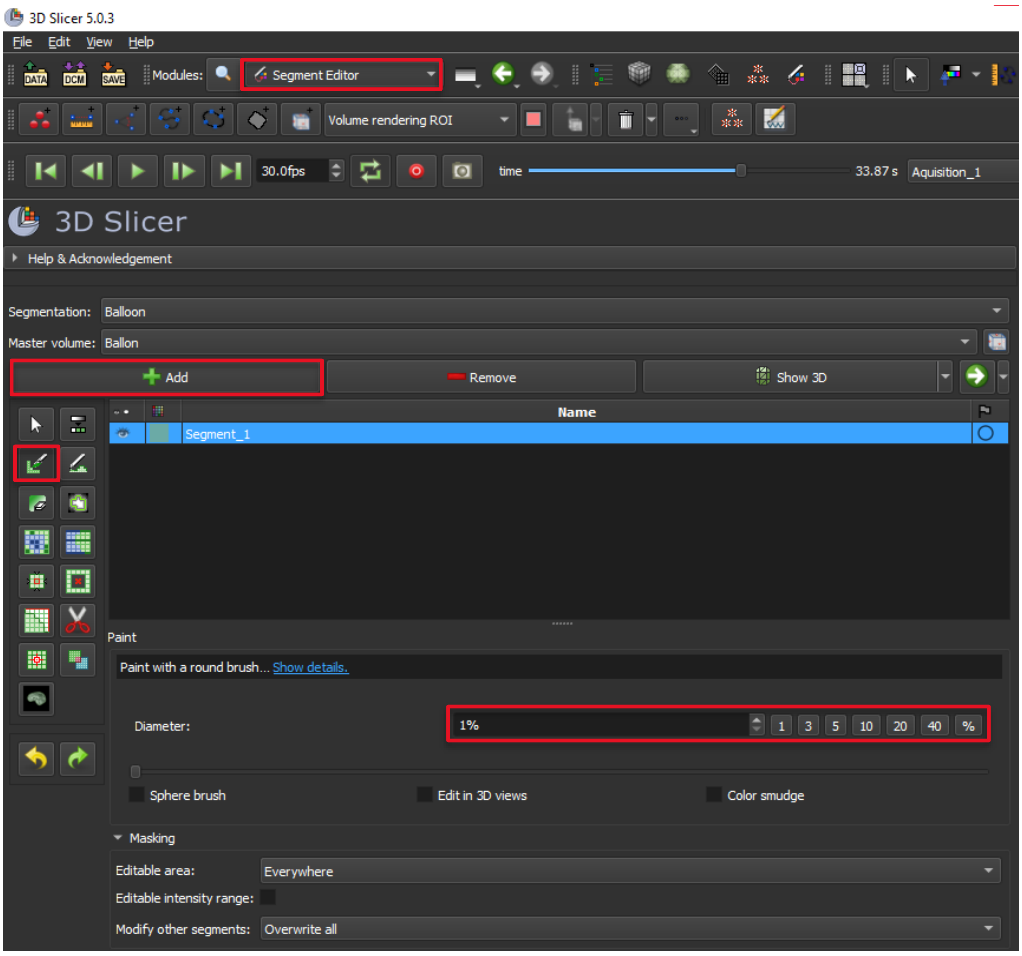
- If the volume appears black in the 3D viewport go to the module **“Volume Rendering”** to change the volume visualization settings.
- Try out different presets but the **“MR-Default”** usually works fine.
- To improve the rendering the **“Shift”** value can be modified.



1.11 Segmentation

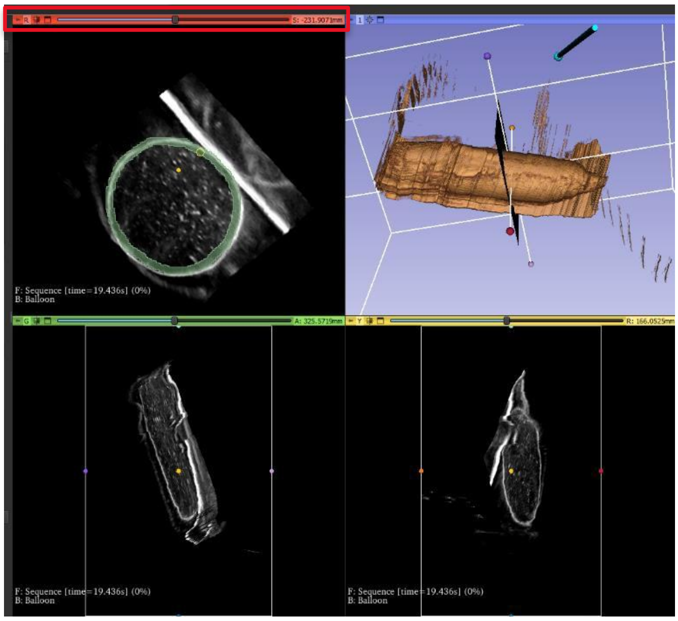
This step will allow us to modify and improve the volume even further. The process could take a while because the slices need to be drawn by hand. The advantage of this is that the volume of your muscle or object can be determined. Make sure you use the exact same Slicer version if you want to do the segmentation on a different computer than before. If you change the Slicer version, the next steps will not work.

- Open the module **“Segment Editor”.**
    - *Segmentation:* “create a new segmentation as…”.
    - *Master volume:* Select the reconstructed volume.
- Click the **“Add”** button to create a new segment.
- Select the effect **“Paint”** to draw the outline of the volume. The diameter of the brush can be modified between 1% and 40%. Zooming the 2D view can help being more precise.

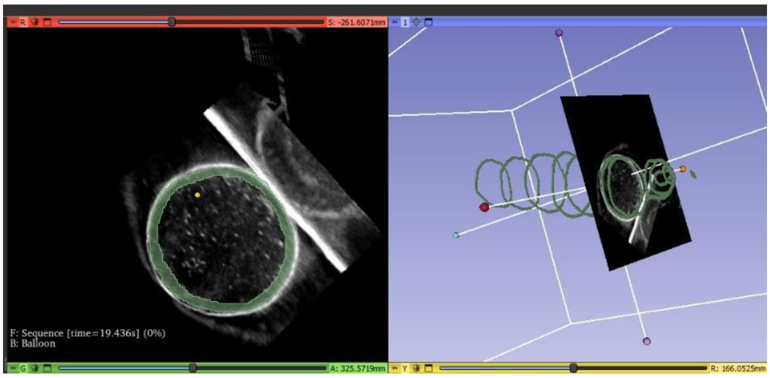


- To draw the volume outline for this slice, **click and drag** the mouse in the red viewport.

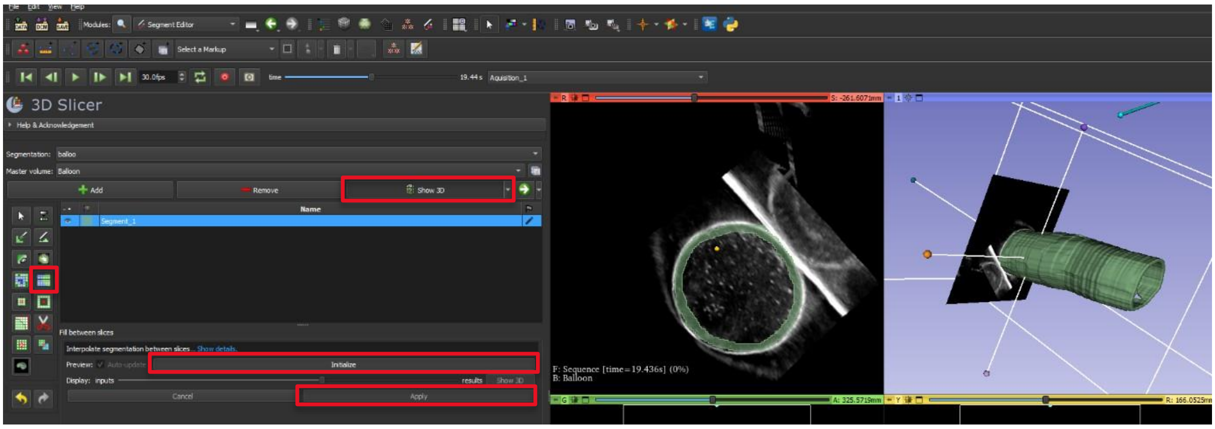
- **Make sure that the segmentation is done in the “Axial”, “Sagittal”, or “Coronal” axis and not in the “Reformat” one!**
- Move the slider just above the red viewport to scroll through the recording. Draw different slices in different time frames from start to finish. The more slices drawn by hand, the preciser the overall reconstruction will be.



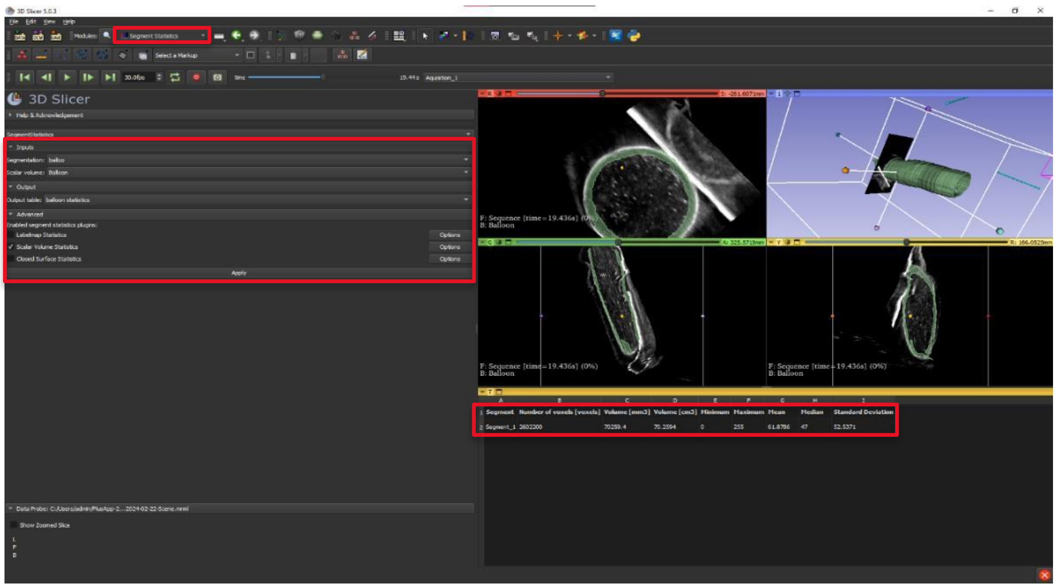
- To see the segmentation in the 3D viewport click on **“Show 3D”**.
- Make sure the old reconstruction volume is disabled by going to the “Data” module and right click on the eye symbol next to the according volume and deselect “Show in 3D views as volume rendering”.



- Once all the outlines are drawn, choose the effect **“Fill between slices”.**
- Click on **“Initialize”** and after it is done loading, select “Show 3D” to get a preview in the 3D viewport.
- **“Apply”** the effect, so the segmentation will be filled between the slices.



- To get information about the segmentation, for example the volume size, open the module **“Segment Statistics”.**
  - *Segmentation:* Select the created segmentation
  - *Scalar Volume:* Select the scanned volume
  - *Output Table:* “Create a new table as…” and give it a name.
  - *Advanced:*
    - Deselect the “Labelmap Statistics” and “Closed Surface Statistics”
    - Click on “Options” of “Scalar Volume Statistics” to choose the parameters needed.
    - Select “Apply” to get the volume statistics.
    - The table is displayed under the four viewports.



This is the final result of the 3D-freehandultrasound with the Optitrack cameras and the Telemed ultrasound. If the setup stays the same, you can repeat the steps from chapter “3.7.2 acquisition recording” until the end, to create a new 3D ultrasound scan.

1.12 Phantom construction

Before starting the measurements on the muscles, it is important to try the acquisition on a phantom with a known volume. A possibility is to fill a plastic balloon with gelatine and let it harden.

Material:

- 30g Instant white gelatine. (Ingredients: Maltodextrine and edible gelatine 40% from pork)
- Syringe
- Balloons or condoms (these have a similar shape as the leg muscles and they are transparent, which means it is easier to see the air bubbles and remove them)
- Glass beaker
- Hot plate magnetic stirrer

Procedure:

1. Take a packet of **agar** and mix it with **400mL** water, less than written in the instructions (500mL). The gelatine will be harder and will not shatter after a few uses.
2. Using the hot plate, **heat up** the solution until all the gelatine is dissolved while constantly stirring.

Syringe option:

1. Let it cool down a few minutes and then use a **syringe** to measure the wanted volume, pour it in a balloon and do a knot.

2. Check that there are no bubbles of air or the volume inside of the balloon will change and the comparison with the measurements will not be reliable anymore.

By using the syringe some liquid losses could happen, to avoid them determine the density of the solution.

Density option

1. Measure the weight of the empty beaker $m_{beaker,\ empty}$.
2. Measure the weight of the beaker filled with the total amount of the water and agar solution $m_{beaker,\ full}$. The difference between the two is the mass of the solution m_{sol}.
3. Using the scale on the beaker note the volume of the solution v_{sol}.
4. The density of the solution will be given by $d = m_{sol} / v_{sol}$.
5. Fill up the condom with a random amount of solution and make a not. Measure the weight m_{cond}.
6. Neglecting the small weight of the condom calculate the desiderated volume $v_{cond} = m_{cond} / d$.

5. Literaturverzeichnis

3D Slicer. (2024, Mai 27). *3D Slicer image computing platform*. https://slicer.org/

Andy’s Brain Book. (2023). *Slicer Tutorial #2: PLUS and the Configuration file*. https://andysbrainbook.readthedocs.io/en/latest/Slicer/Slicer_Short_Course/Slicer_02_PLUS_Config.html

OptiTrack. (2024a). *Calibration Tools*. http://optitrack.com/accessories/calibration-tools/index.html

OptiTrack. (2024b). *Flex 3*. http://optitrack.com/cameras/flex-3/index.html

OptiTrack. (2024c). *Markers*. http://optitrack.com/accessories/markers/index.html

OptiTrack. (2024d). *Motion Capture Cameras*. http://optitrack.com/cameras/index.html

OptiTrack. (2024e). *Motive*. http://optitrack.com/software/motive/index.html

OptiTrack. (2024f). *OptiTrack Documentation*. https://docs.optitrack.com/

Plus applications user manual. (2024a). *Device set configuration*. http://perk-software.cs.queensu.ca/plus/doc/nightly/user/Configuration.html

Plus applications user manual. (2024b). *OptiTrack*. http://perk-software.cs.queensu.ca/plus/doc/nightly/user/DeviceOptiTrack.html

Plus applications user manual. (2024c). *PlusServer application*. http://perk-software.cs.queensu.ca/plus/doc/nightly/user/ApplicationPlusServer.html

Plus applications user manual. (2024d). *Telemed USB ultrasound systems*. http://perk-software.cs.queensu.ca/plus/doc/nightly/user/DeviceTelemed.html

Plus applications user manual. (2024e). *Virtual Mixer*. http://perk-software.cs.queensu.ca/plus/doc/nightly/user/DeviceVirtualMixer.html

Sarcher, A. (2023, August 14). *3Dultrasound*. https://github.com/AurelieSar/3Dultrasound (Original work published 2022)

Science in the Break (Regisseur). (2021). *3D Freehand Ultrasonography: A video tutorial*. https://www.youtube.com/watch?app=desktop&v=lMJnpthHP2k

Stüben, F. (2024). *3D_Ultrasound_Telemed_Optitrack*. https://github.com/FabianStueben/3D_Ultrasound_Telemed_Optitrack

Supersonic Imagine. (2024, Mai 3). *Transducers*. https://www.supersonicimagine.com/Aixplorer-MACH2/TRANSDUCERS

Telemed. (2023). *MicrUs Pocket-Size Ultrasound*. https://www.telemedultrasound.com/en/micrus-scanner/

Telemed. (2024a). *ArtUs Ultrasound scanner*. https://www.pcultrasound.com/products/products_artus/index.html

Telemed. (2024b). *Ecowave Software*. https://www.pcultrasound.com/support/software/