Kernel Flow2 - Optode Coordinate Extraction Guide

Kernel Flow2 Optode Coordinate Extraction Guide
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Overview

This guide details the steps to extract optode locations for the Kernel Flow2 wearable TD-fNIRS headset using SolidWorks, SolidWorks API, and photogrammetric reconstruction. The guide will cover creating a usable surface in SolidWorks, creating an assembly with the surface file, importing the headset plate subassemblies with their plates, covers, and respective modules. Additionally, it will cover using Reality Capture to create a photogrammetric reconstruction of a user wearing the headset, and importing that into SolidWorks. Finally, the guide will cover using the SolidWorks API and an included Python script to programmatically extract the coordinates of the optode locations where they intersect the user-created scalp surface. A moderate level of SolidWorks knowledge and experience is required.

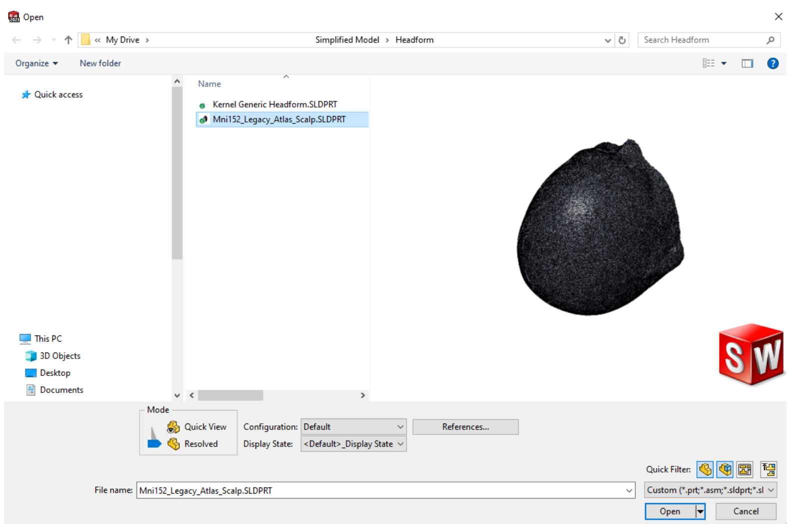
NOTE: This guide covers creation of a SolidWorks assembly from scratch in Steps 1-3. If using the Kernel-provided assembly, skip to Step 4.

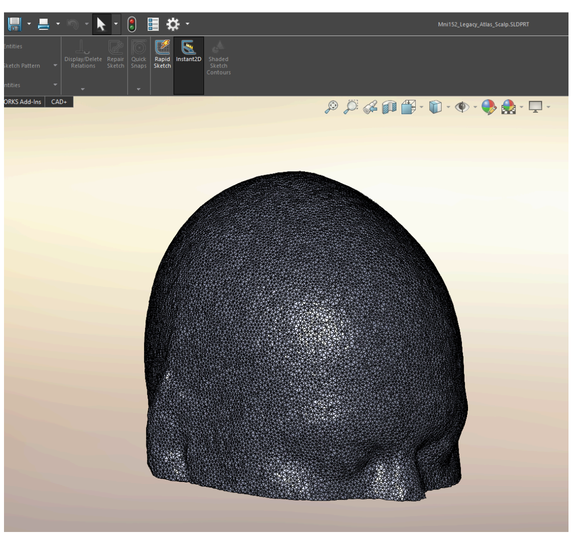
Step 1: SolidWorks - Creating a Reference Surface

For the most accurate optode localization, it is ideal to have a high-resolution file representing the participant's head shape—such as an MRI scan, point cloud, OBJ, or STL file. However, in cases where this is unavailable, an atlas scalp (e.g., mni152_legacy_atlas_scalp) or a generic headform surface may be used to approximate locations.

SolidWorks requires a native, continuous surface for many operations. STL files consist of many discrete polygonal facets, which can create issues. This step outlines how to convert an imported headform into a continuous surface loft in SolidWorks.

1. Load the Headform File in SolidWorks and save the file as a SolidWorks part file - .SLDPRT (if loading from a non-SolidWorks file).



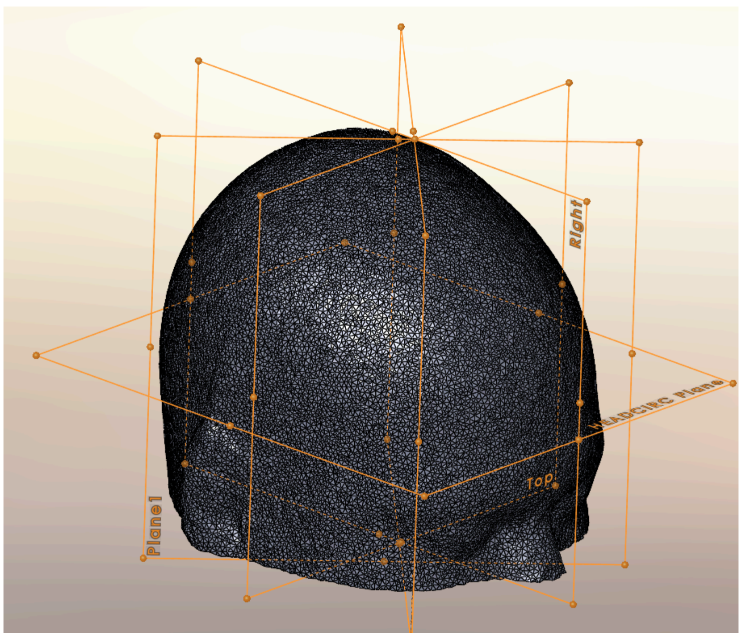


2. Create a set of reference planes to define the geometry of the surface loft.

    a. Ensure the coordinate system includes useful anatomical planes (e.g., bitragion–crown, nasion–inion–crown). The exact setup of these planes is beyond the scope of this guide.

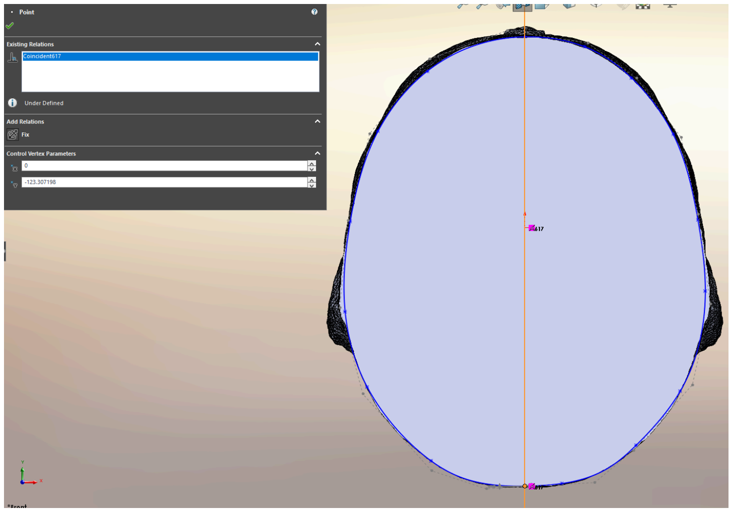
    b. Create a head circumference plane that approximately intersects the widest part of the headform. This will serve as the guide sketch for the loft.

    c. Create 4 or more additional planes that revolve around a user-defined axis (formed from the intersection of the Top and Right planes). These planes will act as sketch planes for the surface loft and improve control of the surface shape.



3. Create guide and section sketches.

    a. Draw a continuous spline that approximates the intersection of the imported headform and the head circumference plane. Do not use a direct intersection curve—this will create segmented lines, not a smooth spline. Be sure to add points on this spline which are coincident with each of the 4 (or more) intersecting planes created above. Add at least two points per section plane to the spline (i.e., one for each side of the plane's intersection), for a total of 8. For each of these points, apply a 'coincident' constraint with its respective section plane. Add extra unconstrained points as needed to better follow the headform shape.

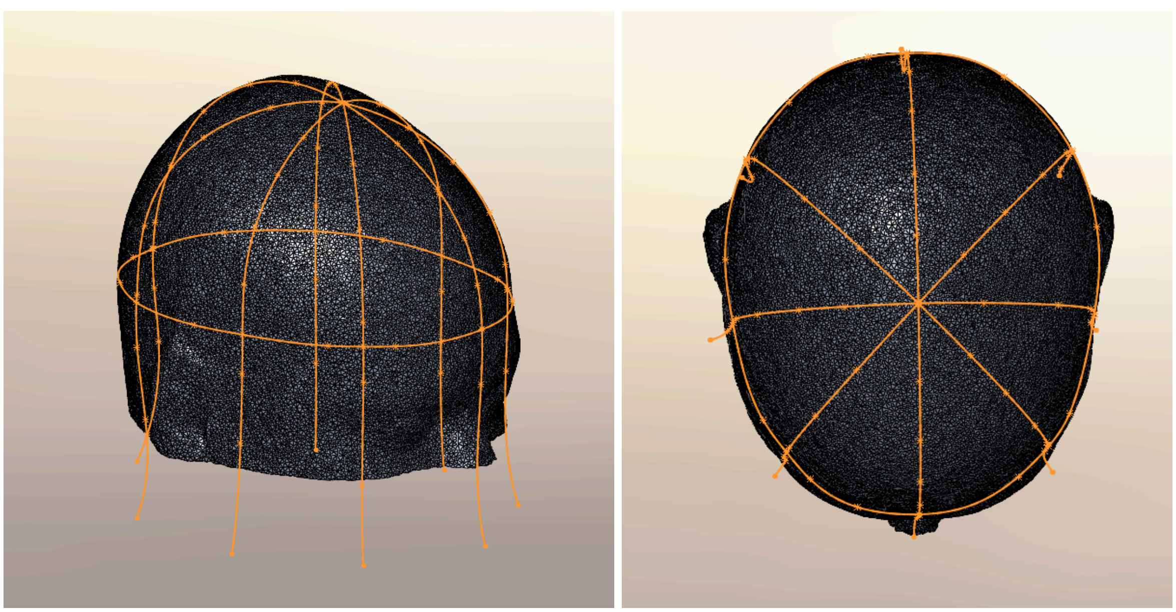


b. Using a similar methodology as in step (a), For each of the 4+ reference planes:

   i. Create a sketch that intersects the headform.

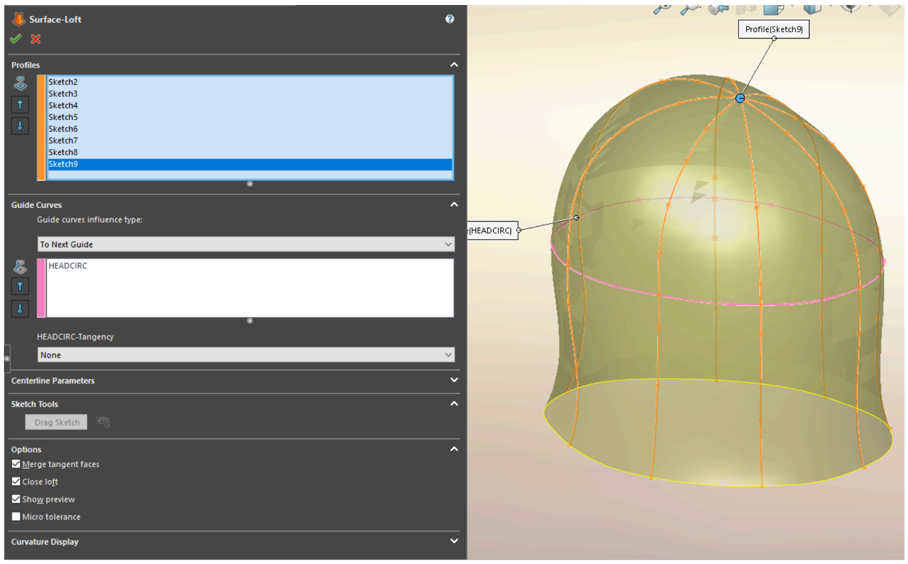
   ii. Create a spline that includes 1) a point that is coincident with the corresponding point from the guide sketch and 2) a shared point near the crown of the head that is coincident with all planes (i.e., the center of the loft).

   The result should resemble a vertical “slice” of the head that smoothly connects to the guide sketch and crown point.

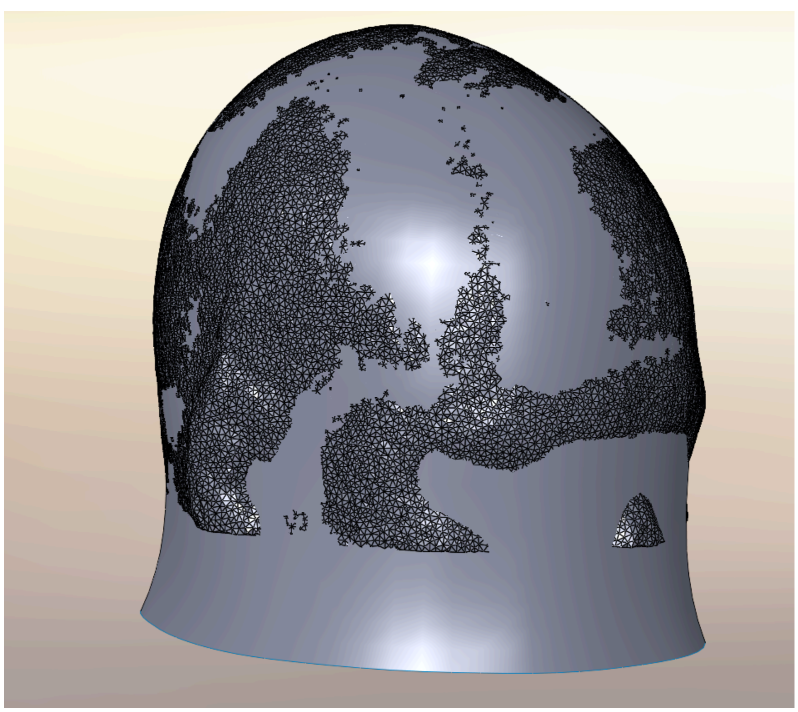


4. Generate the **Surface Loft:**

    a. To create a successful loft, use the head circumference sketch as the **Guide Sketch** and select the other sketches sequentially. If a loft error occurs, check the following: ensure that the points in each sketch have coincidence constraints with the head circumference sketch, and confirm that all sketches converge at the shared crown point.



    b. Verify that the loft closely follows the imported headform model and adjust the splines as necessary. Once satisfied, save this file for use in Step 2.

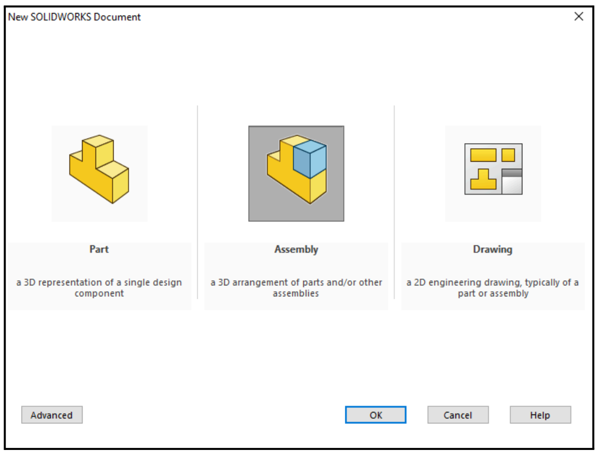


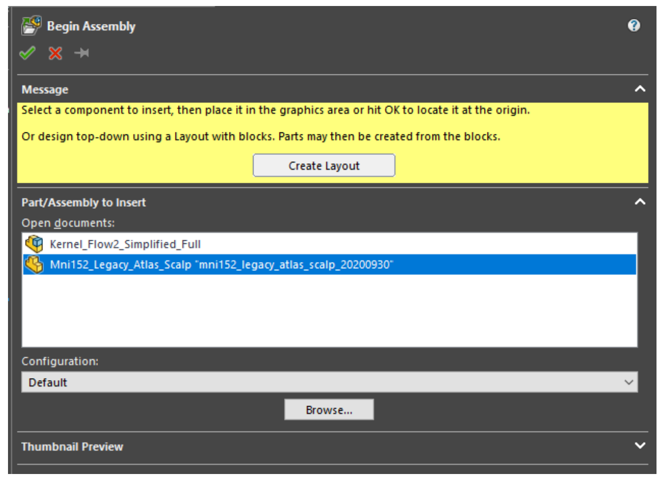
Step 2: SolidWorks Assembly & CAD Module + Plate Insertion

This step covers the creation of a new SolidWorks assembly and the import of headset plate subassemblies. These steps are critical for aligning the Flow2 components to the reference head surface and maintaining a consistent coordinate system.

1. SolidWorks Assembly
    a. Start by creating a new SolidWorks assembly and inserting the headform surface created in Step 1. Open SolidWorks and create a New Assembly. Insert the reference surface part (.SLDPRT) created in Step 1.

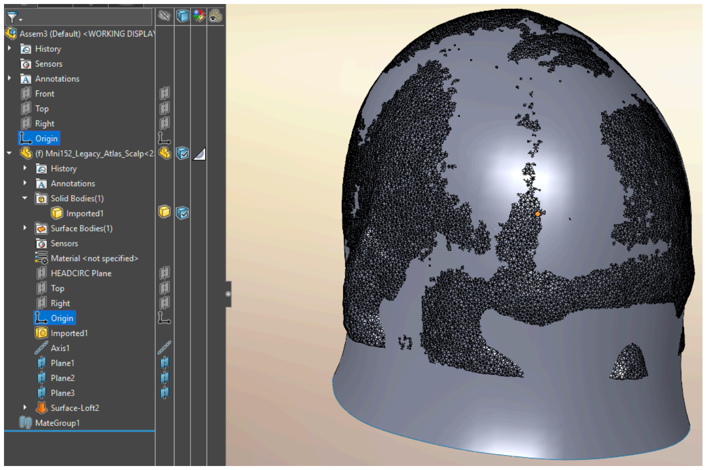
    ⚠️ **Important:** Using the correct coordinate system here avoids the need for post-processing affine transformations during coordinate extraction.





    b. Verify that the imported surface is fixed which indicates it is fully constrained (denoted by the (f) next to the part name in the assembly tree structure. If you do not see the (f) in the tree structure, right-click the part in the tree structure and click Fix in the pop-up menu.

    c. Additionally, verify that the assembly origin and part origin are aligned by selecting both from the feature tree and confirming that they overlap visually. Once this is done, save the assembly with a descriptive name.



2. Importing Headset Plate Subassemblies
    a. Next, import the Flow2 plate subassemblies into the assembly. Each subassembly includes the plate, plate cover, and modules. The shared CAD files are already in SLDASM file format. The CAD files can be found in the Kernel docs at docs.kernel.com/docs/determining-3d-positions. The following subassemblies should be imported::

        i. **Front Plate:** Kernel_Flow2_Simplified_FrontPlate_wModules.SLDASM

        ii. **Top Plate:** Kernel_Flow2_Simplified_TopPlate_wModules.SLDASM

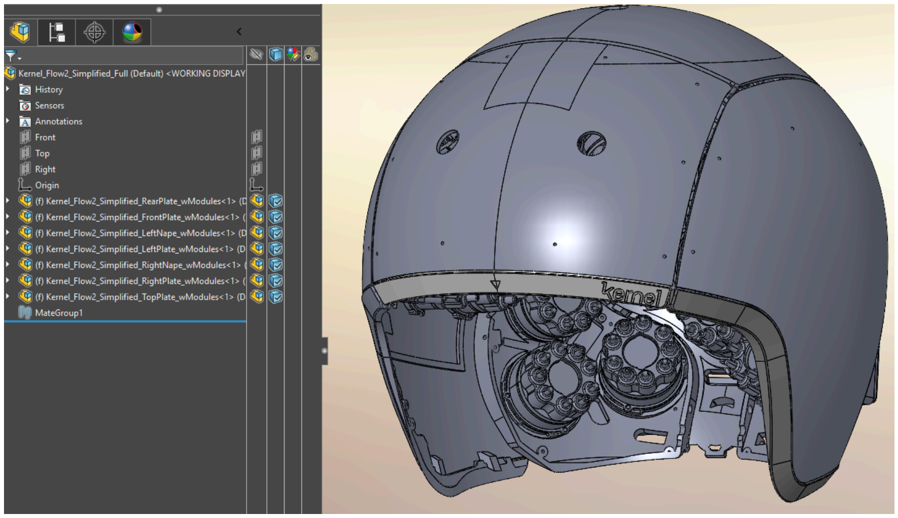
        iii. **Left Plate:** Kernel_Flow2_Simplified_LeftPlate_wModules.SLDASM

        iv. **Right Plate:** Kernel_Flow2_Simplified_RightPlate_wModules.SLDASM

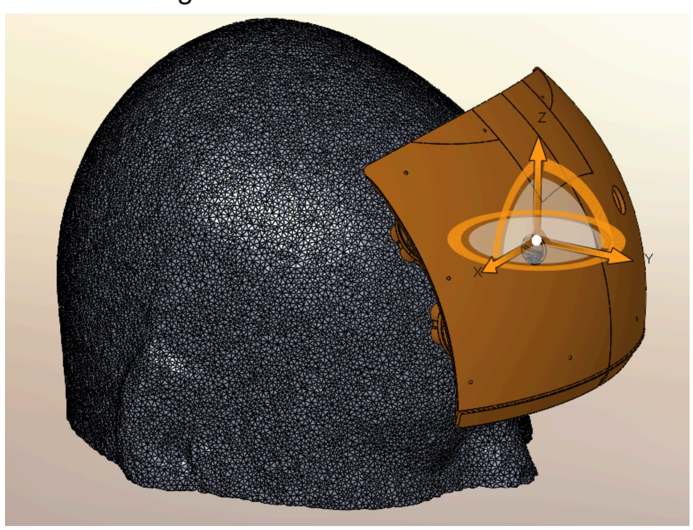
        v. **Left Nape:** Kernel_Flow2_Simplified_LeftNape_wModules.SLDASM

        vi. **Right Nape:** Kernel_Flow2_Simplified_RightNape_wModules.SLDASM

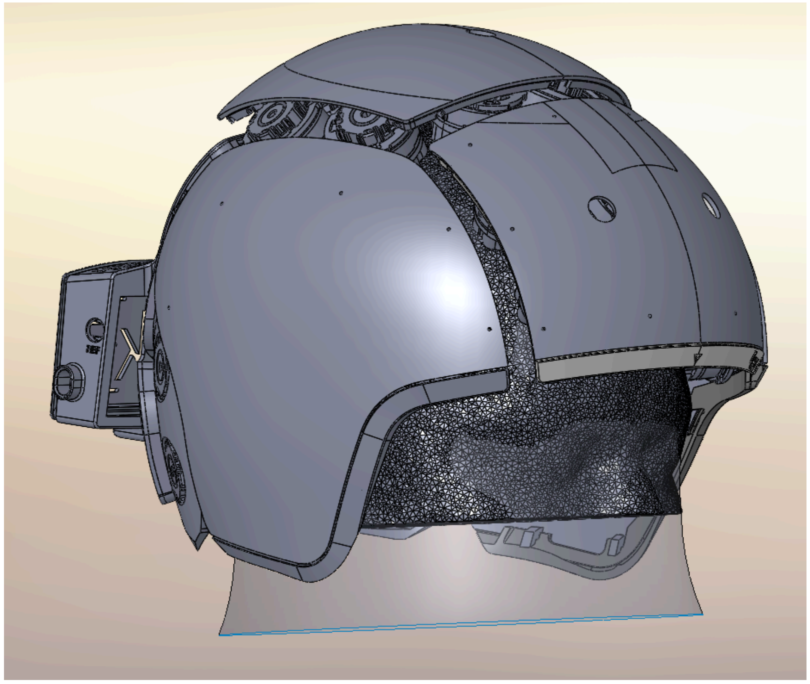
    NOTE: These files all share the same internal coordinate system, so when imported as standalone assemblies, they will be roughly aligned with each other.



b. After importing each plate subassembly, confirm that it is floating—i.e., not fixed in place. You'll know it's fixed if there's an (f) next to the name in the assembly tree. If needed, right-click and select "Float" to enable repositioning.
   i. To orient the plates, make use of plane constraints (if necessary), as well as the **Move with Triad** command. **Move with Triad** lets you easily manipulate the plate position as well as the plate rotation. This doesn't need to be perfect yet; exact positioning will be refined later once the photogrammetric model is brought in.



c. At this point, you should have a reference surface and all six Flow2 plate subassemblies roughly positioned around it. Save the updated assembly file. When complete, the setup should resemble the example shown below.

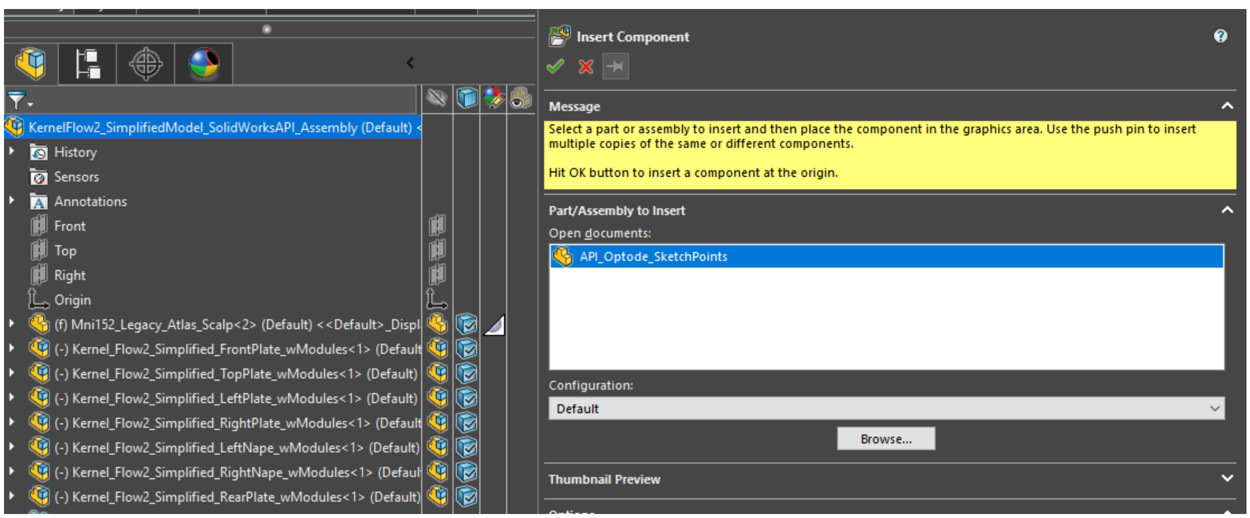


Step 3: Creating a SolidWorks Part for the Optode Sketches

This step involves setting up a dedicated SolidWorks part file to store optode sketch points. Although it's a somewhat tedious process, it only needs to be completed once per assembly configuration. Once defined, the sketch points will automatically update in response to any changes made to the underlying loft surface splines. For new participants, the full assembly can later be duplicated using SolidWorks' Pack and Go feature, preserving all feature constraints while allowing individualized surface geometries.

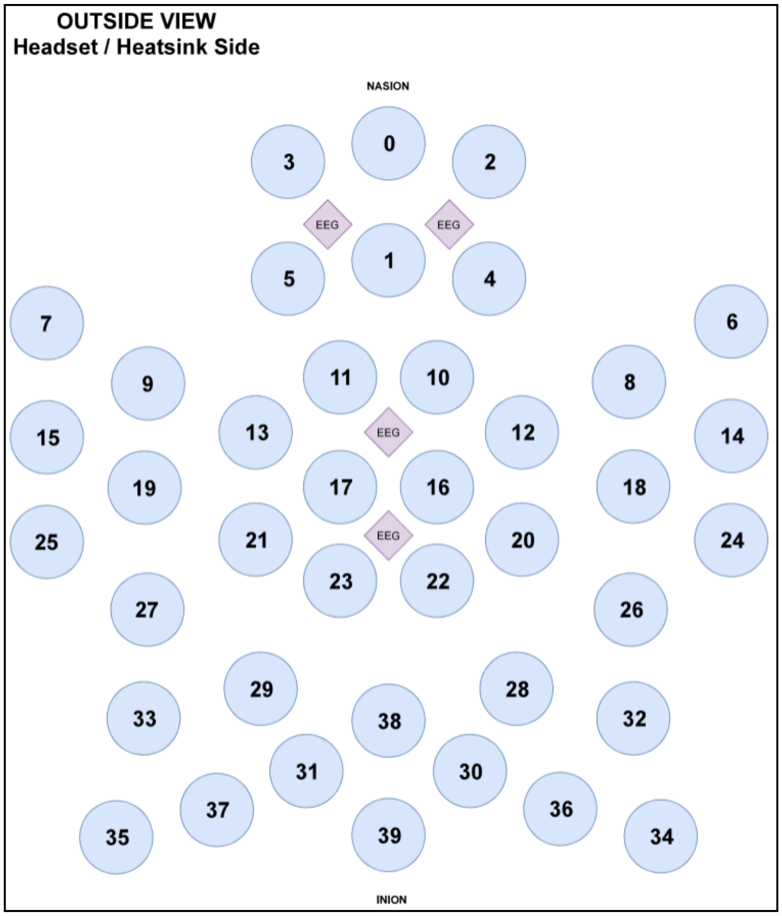
1. Create a SolidWorks Part for Optode Sketches
    a. Create a new part in SolidWorks. This part will contain the optode sketches. Save the empty file with a name like API_Optode_SketchPoints. Later, the SolidWorks API and a Python script will loop through the sketches in this file to extract coordinates. Save this currently empty file with the desired filename, such as "API_Optode_SketchPoints."

    b. Insert this new (empty) part into the working assembly containing the headform and plates. Create a mate between the origin of the new part and the assembly origin.

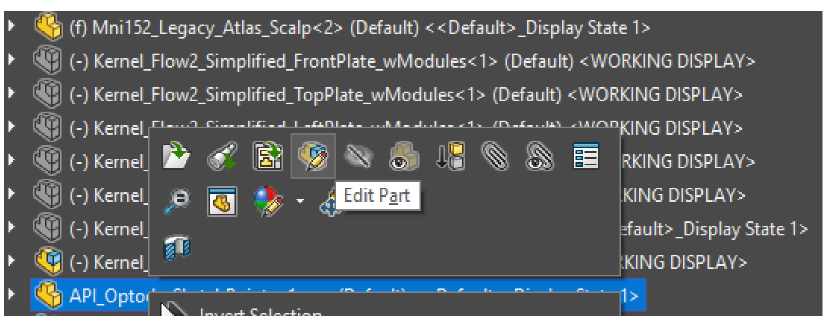


2. Use the steps below to create sketches for optode locations. The following naming convention is recommended.
    a. **Sources**: M<X>_S<Y> where <X> is the module number and <Y> is the source index (starting from 0). For example, M0_S0 is Module 0, Source 0.
    b. **Detectors**: M<X>_D<Y>, where D replaces S. For example, M0_D0 is Module 0, Detector 0.

This naming scheme can be changed, but you'll need to modify the Python script accordingly. The layout of the Flow2 modules is shown in the figure below, with module numbers as viewed from outside the headset (as if looking down on someone wearing it).



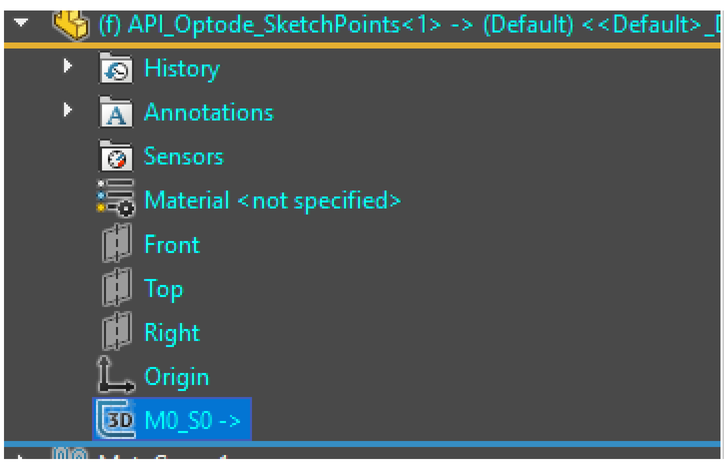
A. First click on the part in the feature tree and select **Edit Part**.



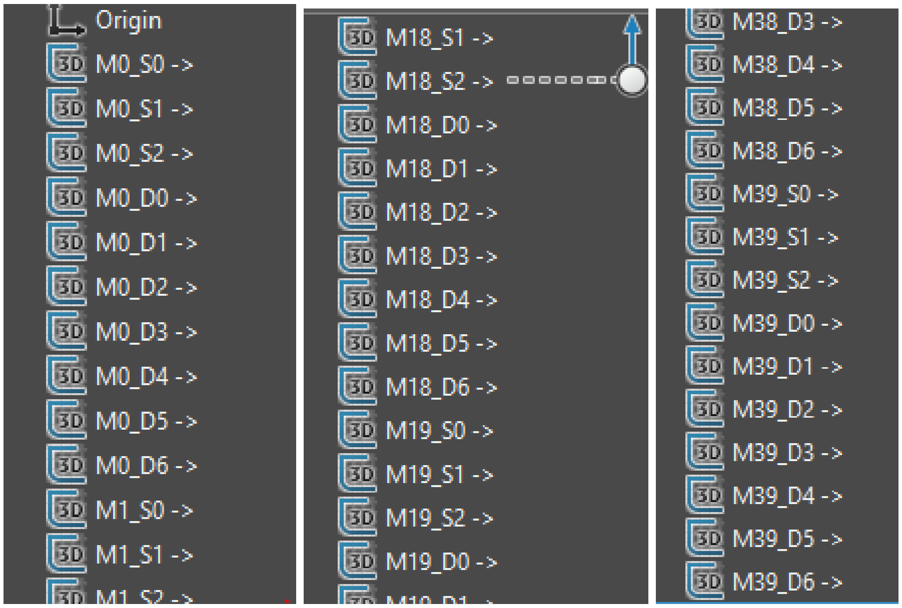
B. For each optode:
- Create a 3D sketch within the `Optode Sketch SLDPRT`. Place a point near the appropriate module, ensuring it is constrained to the surface.

- Locate the module (e.g., `M0`) and its first source optical center axis. Constrain the point to the axis. This defines the intersection between the surface and the optode axis.

- Exit the sketch and rename the feature in the tree to reflect the Module and Source/Detector label (see the naming convention above).



3. At the end of this (lengthy) process, you should see the optode points in space similar to the following screenshots.


Origin
M0_S0 ->
M0_S1 ->
M0_S2 ->
M0_D0 ->
M0_D1 ->
M0_D2 ->
M0_D3 ->
M0_D4 ->
M0_D5 ->
M0_D6 ->
M1_S0 ->
M1_S1 ->
M18_S1 ->
M18_S2 ->
M18_D0 ->
M18_D1 ->
M18_D2 ->
M18_D3 ->
M18_D4 ->
M18_D5 ->
M18_D6 ->
M19_S0 ->
M19_S1 ->
M19_S2 ->
M19_D0 ->
M38_D3 ->
M38_D4 ->
M38_D5 ->
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M39_S2 ->
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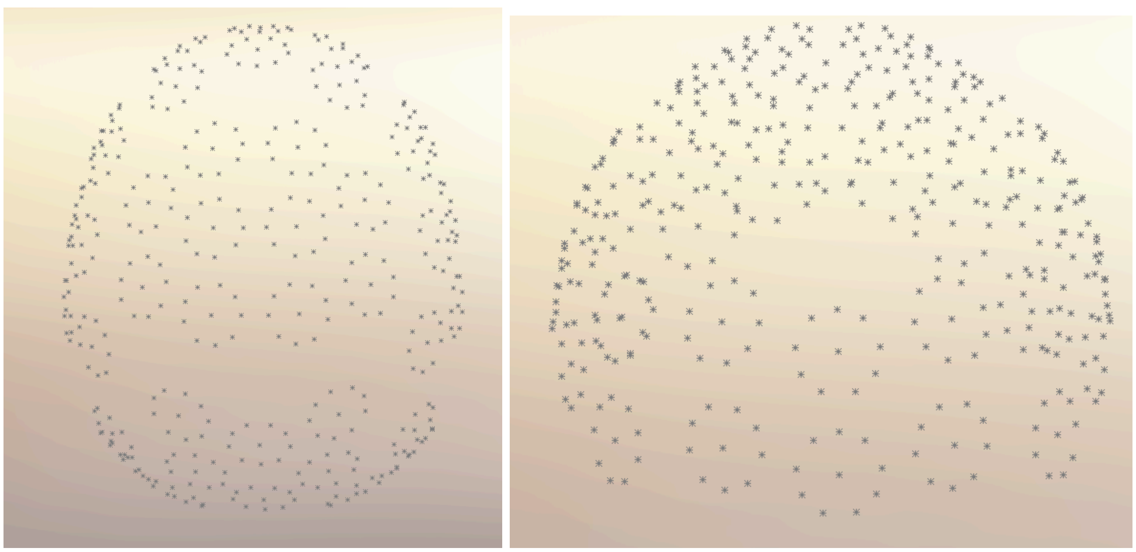
M39_D6 ->



Step 4: Photogrammetric Reconstruction of a Participant Wearing the Kernel Flow2 headset

NOTE: There are multiple options for performing the photogrammetric reconstruction. Agisoft and RealityCapture are both capable. This guide uses **RealityCapture**, which is free at the time of writing.

This guide does not cover the full details of photogrammetry or RealityCapture's software features. For further learning, refer to RealityCapture's Learning Section. A brief summary of the core concepts is provided below.

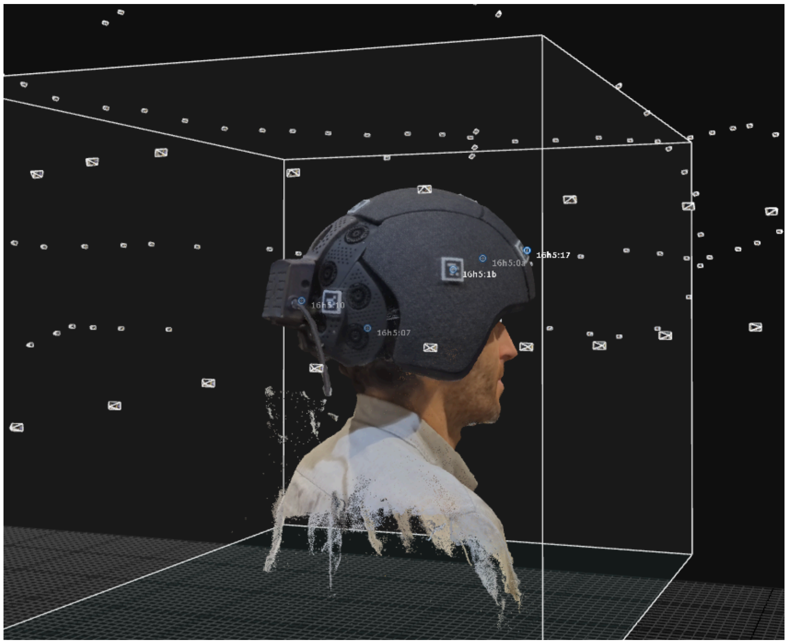
The Three Core Principles of Photogrammetry

Photogrammetry reconstructs a 3D object by combining many 2D images taken from different angles. This can be done with high-end rigs or using standard DSLR cameras and smartphones.

The three most important factors are:

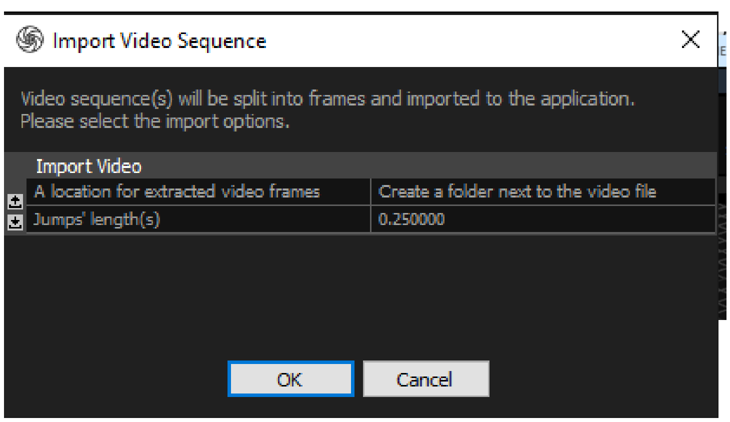
1. **Image Quality**: Images must be sharp, in focus, and free of motion blur or digital noise.
    a. If using smartphone video, ensure sufficient lighting, record at high frame rates (e.g., 60FPS), and shoot in landscape orientation.
    b. Move slowly to maintain sharpness and focus throughout the scan.
2. **Subject Coverage**: The subject must be completely covered in the image set—missing regions cannot be reconstructed later.
3. **Information Overlap**: The software uses shared visual features between images to stitch them together. AprilTags are helpful for providing consistent anchor points across images.
    a. Printed AprilTags may be mounted to the headset on cardboard pieces with adhesive (such as double-sided tape).

When capturing a smartphone video, perform a 360 degree scan of the user wearing the headset, ideally completing multiple spiral passes, varying the camera angle up and down to capture more geometry. An extracted frame from a scan is shown, in addition to evidence of the spiral pattern.

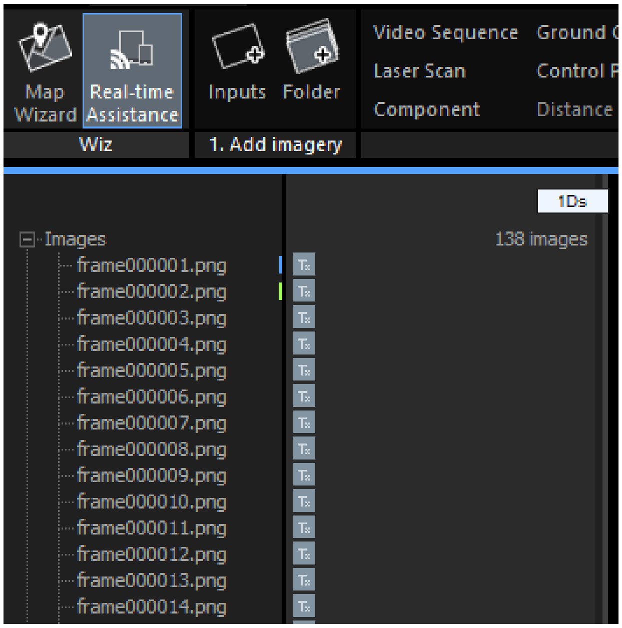


The instructions below are for processing the video in Reality Capture and exporting a 3D textured wavefront (OBJ) object.

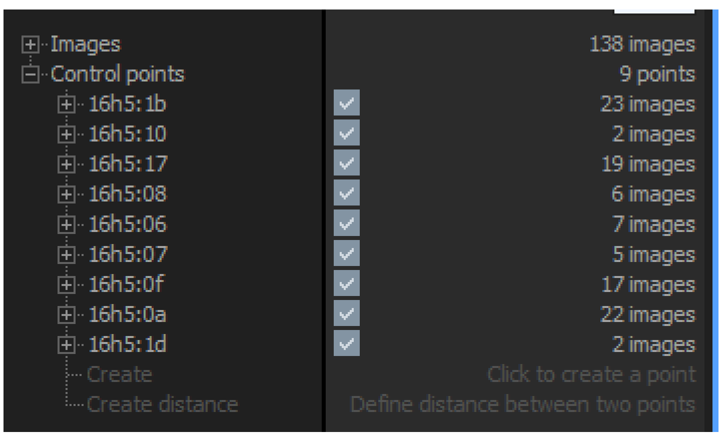
1. Open RealityCapture and import a **Video Sequence** from the **Import & Metadata** tab. A general standard for frame separation is 0.25s.



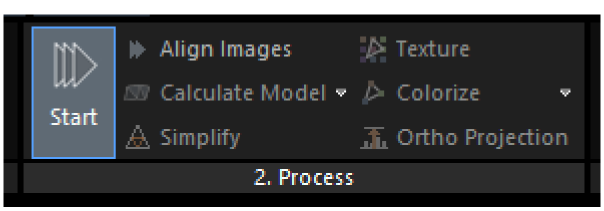
The captured images will be shown under the **Images** section of the RealityCapture feature tree.

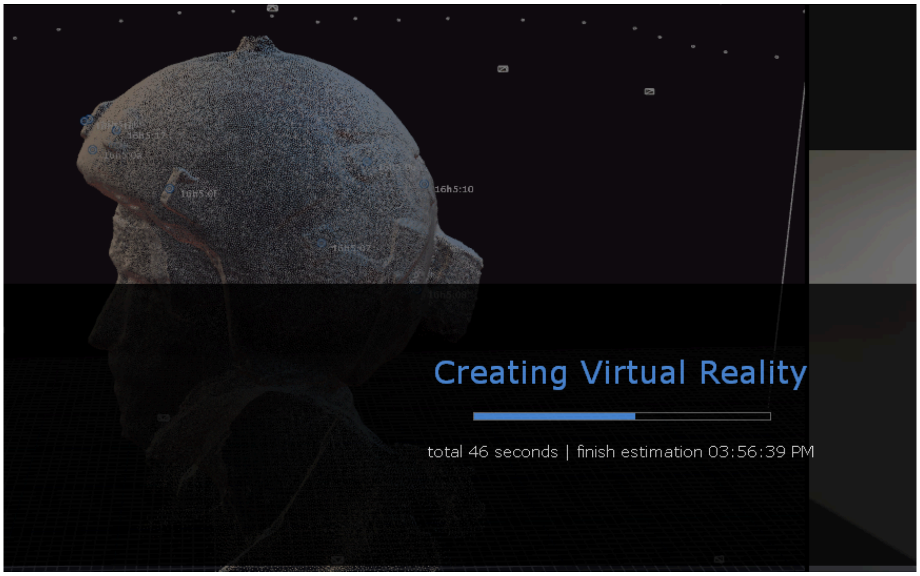


2. Go to the **Alignment** tab and open **Detect Markers**. Choose the correct AprilTag used on the headset under Marker type. Click **Detect**. Detected tags will appear under Control points.

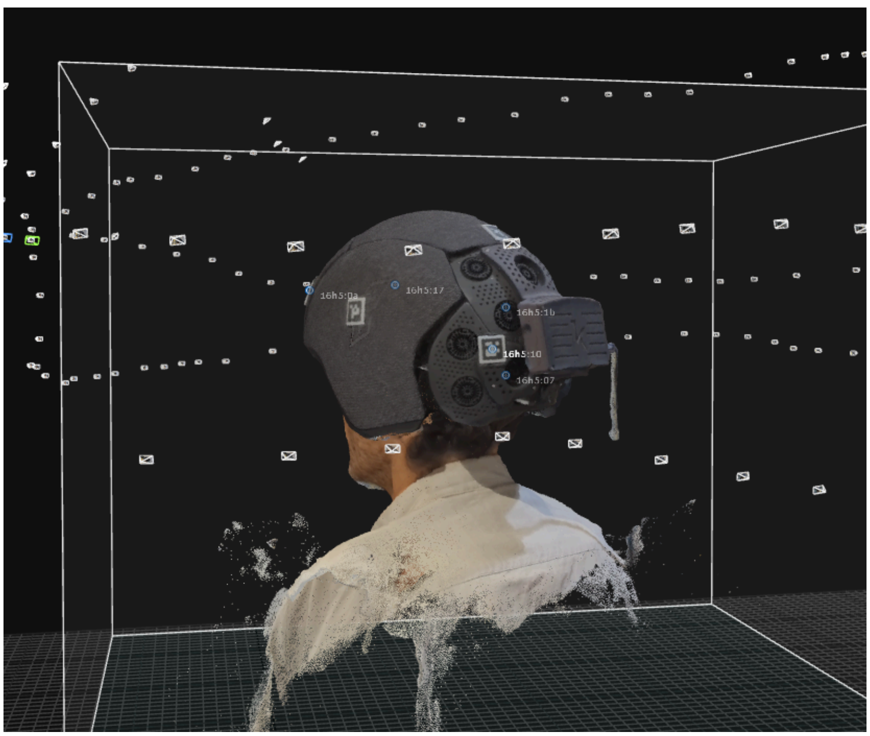


3. In the **Workflow** tab, click the **Start** button to start the photogrammetric recreation process. The process may take several minutes depending on the number of frames, and the system performance.

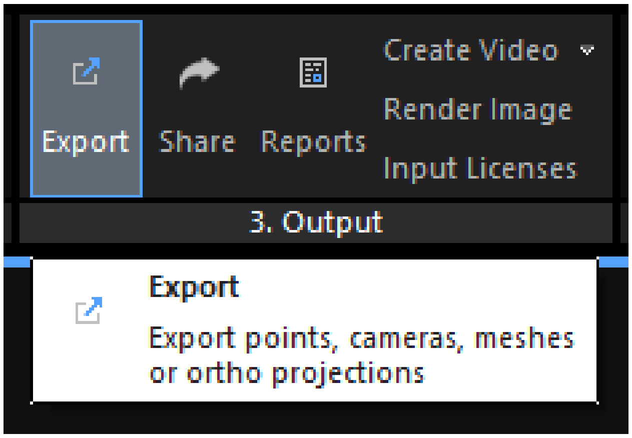


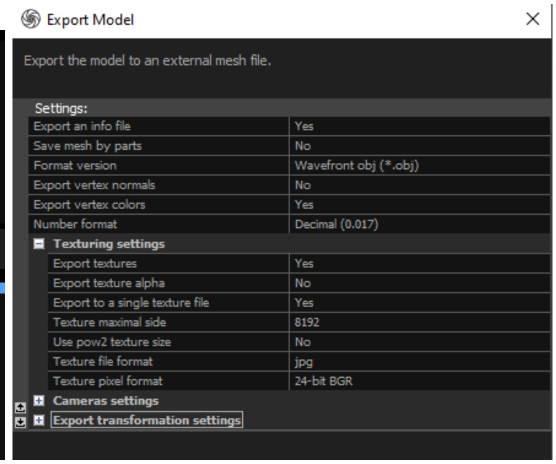


A successful reconstruction will yield a 3D textured model in the 3D view of the GUI.



4. Once complete, a **3D textured model** should appear in the 3D view. To export the model, click **Export** from the **Workflow -> Output** UI element and select the Wavefront Object option and select your desired location.





Step 5: Import & Align Reconstruction in SolidWorks

1. Import Scan: Open the newly created .OBJ file in SolidWorks and save it as a new SLDPRT.

2. Import Into Assembly
    a. Add the part into the previously created SolidWorks assembly.
    b. Use the **Scale** command and **Move with Triad** to adjust the size and position of the imported scan until it overlaps accurately with the existing assembly. Use features of the headset as well as anatomical landmarks like the nasion and eye sockets to guide alignment.
    c. Adjust each individual plate location to match the reconstruction, taking care to align the heatsink features as well as the outside ridges and edges of the plates, as well as plate covers.

d. Once successfully aligned, force SolidWorks to update the locations of the optode positions by using the command **Rebuild** (or CTRL + B).

e. The optode locations will be updated to new positions on the headform surface.

Step 6: Extracting & Visualizing Optode Locations

NOTE: This step uses the SolidWorks API via Python to extract coordinates. Setting up the proper environment (e.g., Python packages, SolidWorks installation, API access) is outside the scope of this guide.

A sample Python script to extract the coordinates from SolidWorks can be downloaded from docs.kernel.com/docs/determining-3d-positions.

A sample script to visualize the extracted coordinates can also be downloaded from docs.kernel.com/docs/determining-3d-positions. Verify that the file location is correct, as well as the file name.

On executing the script, a browser window will appear with the coordinates in 3D, as shown below. The plate may take 30-45 seconds to properly load.