A manual to digitising fNIRS probes with photogrammetry as described in Clausner et. al. (2017)

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NB: Throughout the manual, we refer to 'electrodes' when we speak about the software (as it was designed for EEG originally), and about optodes when we speak about our process.

Introduction

The aim of this manual is to give easy step-to-step instructions on how to use photogrammetry to create a 3D-model for functional near-infrared spectroscopy (fNIRS) optode position digitization. The manual will guide through the photogrammetry process as applied by Clausner et al. (2017) to digitise the locations of fNIRS probes.

Toolbox

Clausner, T., Dalal, S. S., & Crespo-García, M. (2017). Photogrammetry-Based head digitization for rapid and accurate localization of EEG electrodes and MEG fiducial markers using a single digital SLR camera. *Frontiers in neuroscience*, *11*, 264.

Required hardware and software

Software:

- Matlab 2015a *(This is crucial as it will not work in any other Matlab version!)*

- Janus3D toolbox for Matlab (https://github.com/janus3D/janus3D_toolbox)
  A new standalone version is available, which we do not describe in this manual: https://github.com/janus3D/janus3D_linux_standalone
- Agisoft Metashape (https://www.agisoft.com/)

Hardware:

- Canon D3500 or a similar DSLR camera
- Chroma key green screen
- Swivel chair (for example: IKEA Kullaberg)
- Two camera lights
- fNIRS cap (here we use Shimadzu)
- Colourful, matte stickers for the cap

1 Taking the pictures (approx. 15 minutes)

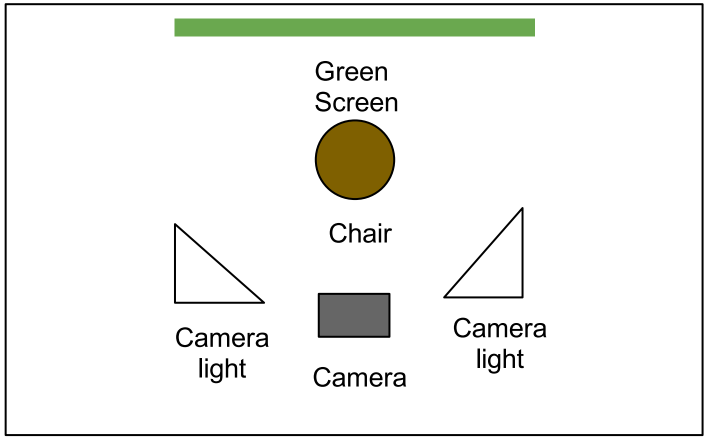


Figure 1. Schematic photogrammetry set-up

To generate a 3D model of the subject, pictures of the subject's head wearing a fNIRS/EEG cap are taken. An example of necessary equipment includes: a camera (DSLR, e.g. Canon D3500, ca. £300), a chroma-green screen (or a room divider covered with chroma green cloth), a swivel chair (with stationary feet, example here (KULLABERG swivel chair IKEA, £50) and two camera lights (example here, Amazon ESDDI Camera lights, £29,99)).[1] The set-up is illustrated in Figure 1, 2 and 3. To avoid shadows or changing lighting conditions, it is best to set up in a room with artificial light.

[1] The total estimated costs for the set-up used by us are £500 including the software.

The distance between the set-up elements may vary between subjects. As a guideline the following distances were used by us:

- Green Screen to middle of chair: 62.5 cm
- Chair to camera tripod legs: 60 cm
- Lights to camera tripod legs: 85 cm
- Height of tripod (fully extended): 133 cm
- Height of lights: 175 cm
- Green screen width: 159 cm
- Green screen height: 159 cm

Figure 2. Photogrammetry set-up

Figure 3. Photogrammetry set-up. Subjects pictured in this manual gave consent for their images to be used.

1. We used the following camera settings:
   a. Exposure index below ISO 800
   b. Aperture size at minimum f/8 to manage image noise and avoid blur
   c. Use of a remote control trigger to reduce risk of blurred photos
2. Next, mark the fNIRS cap with different **matte** coloured stickers in between the optode positions (Figure 4). This is done to increase the contrast for the later alignment in janus3D. If you are using a fNIRS cap with a salient colour contrast, you might not need extra stickers. As noted under point 4, additional stickers or markers will be necessary to aid the digitisation of anatomical landmark regions.

Figure 4. fNIRS cap with stickers

3. Based on our experience, a minimum of 50 pictures per subject is needed to generate a 3D model. We usually found more pictures would generate better models. We used three different tripod heights and took around 20 photos per height. The camera setting **should not be changed** during the shoot, only adjustments to the height and angle of the camera utilizing the flexibility of the tripod are possible. It is crucial that one set of pictures is taken at the **highest possible** tripod setting to get a top view of the head, as this is usually the most difficult to get. We started taking two sets of around 60 photos each in the actual testing situation for a more reliable outcome.

4. Adjust the fNIRS cap to the head of your subject - an adult's head will generally be between 50-60 cm head circumference, if the head is bigger or smaller, then the cap should be adjusted or changed. For an optimal outcome, the subject needs to remain as still as possible during the shoot and keep their eyes shut. After adjusting the camera to a new height setting, we found it useful to check if the subject is still visible in the live viewer of the DSLR. To do so, ask the subject to do one 360° swivel before taking the individual pictures to ensure the cap is in shot for every picture. At every height setting the subject needs to slowly turn around 15-20° by taking a tiny step to one side after every shot until back at the starting position (360° in total) (example in Figure 5). Again, this results in approximately 20 pictures for each height setting.

Figure 5. Example of a picture

5. Save the pictures in a folder labeled "pictures_subjectX" or similar onto your computer.

Note: We tried other approaches such as taking a photo series and a video sequence to extract the frames in the hope of decreasing the time spent taking photos.. However, none of these approaches resulted in a good model, as there was too much movement and blurriness in the pictures. The video approach looked good at first but the model did not have any depth and therefore could not be used for the coregistration process. Thus, we recommend using the approach described above. It should be noted, that in addition to digitising the optodes, we recommend marking common landmark regions, either with stickers or other markers, as these are necessary for further group-level processing post-janus3D. Regions include the four landmarks: nasion, inion, and the right and the left preauricular points (i.e. as described in Steinmetz et a;, 1989).

2 Creating the masks (approx. 10 minutes)

To remove unnecessary background objects in the photos masks needs to be created. The masks are created with janus3D, the free toolbox for MATLAB (Clausner, Dalal, & Crespo-García, 2017).

1. Download janus3D for MATLAB (https://github.com/janus3D/janus3D_toolbox).
2. Open MATLAB, navigate to the path of the toolbox (e.g. C/applications/janus3D-toolbox) as illustrated in figure 6. Then open a new script in the top left corner and type "janus3D" in the command box.

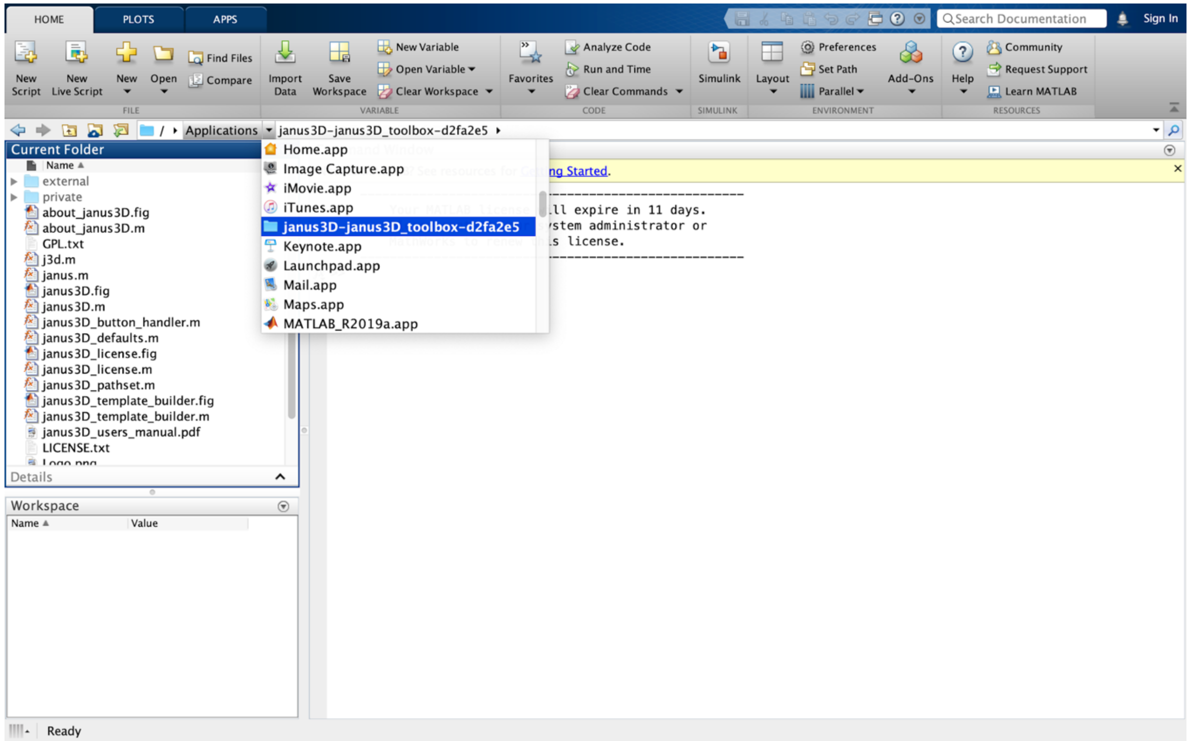


Figure 6. Navigation to toolbox path in Matlab

3. Go to "File", select "Photo Masker" (Figure 7), click on "image folder" and select the images. Then click on "mask folder" (Figure 8) and set up another folder in your "pictures_subjectX" folder labeled "masks_subjectX" or similar, where the masks will be saved to, then select the folder that you just created.

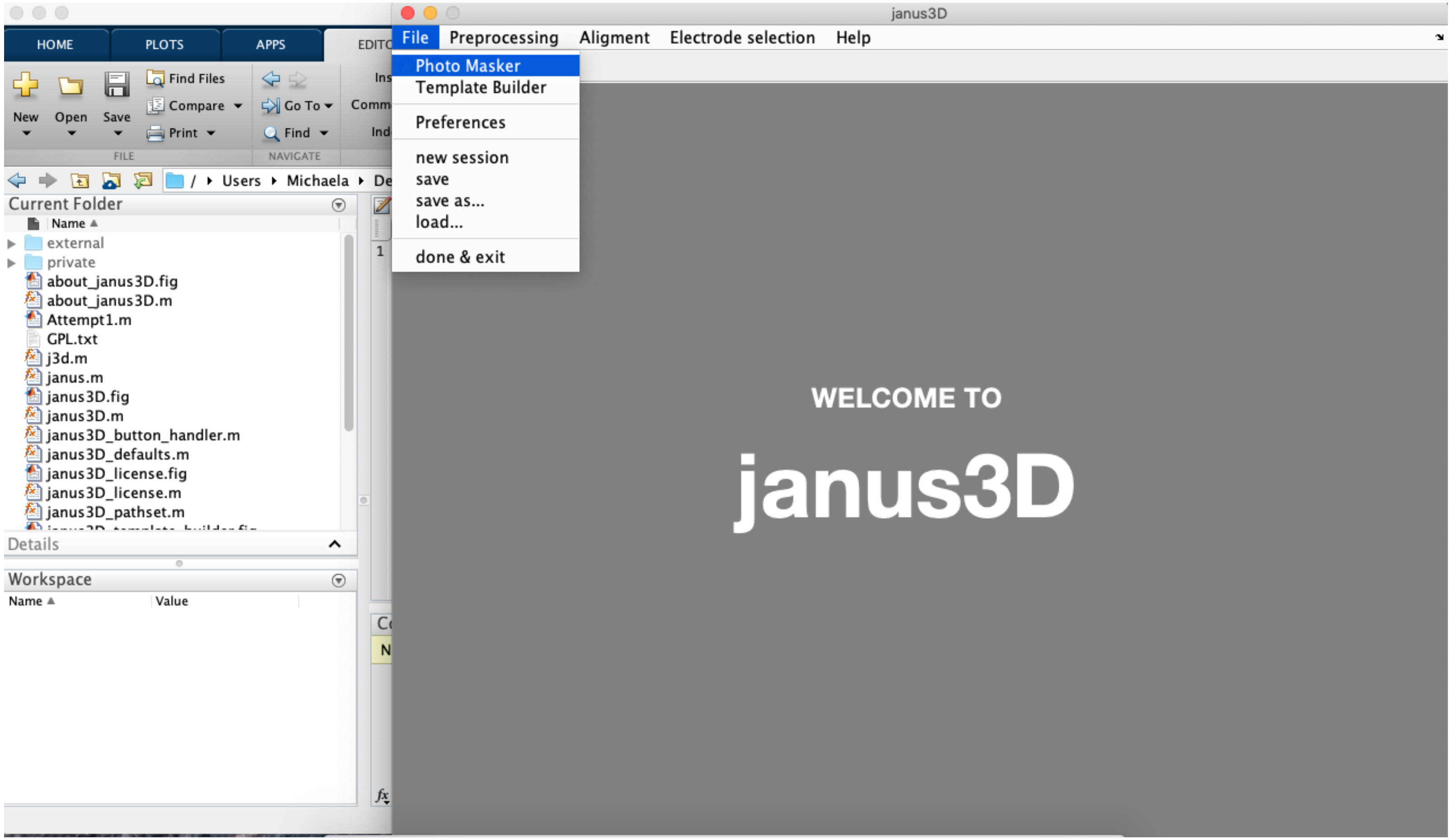


Figure 7. Selecting Photo Masker in janus3D

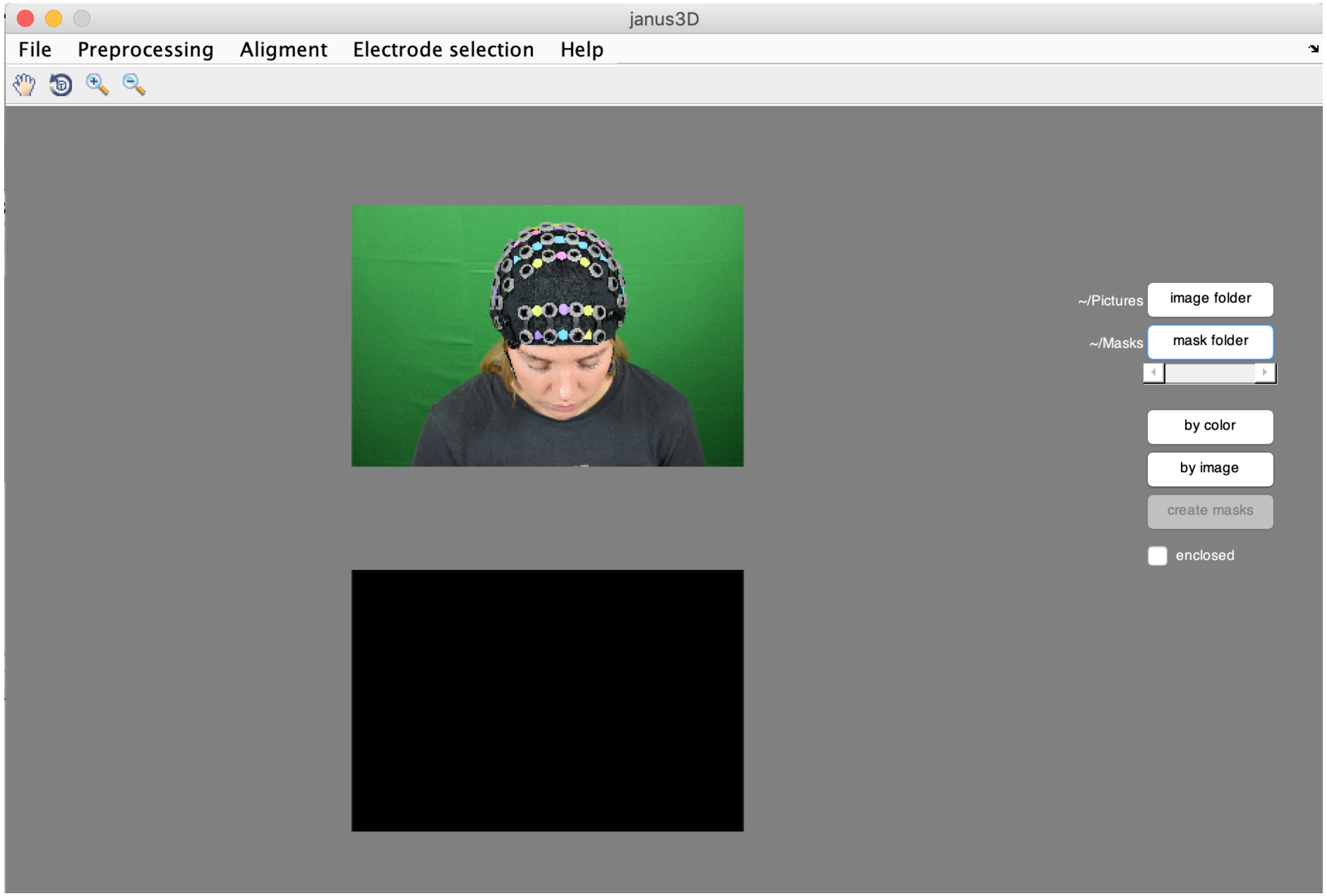


Figure 8. Creating a mask folder in janus3D

4. Click “by color” and select the green screen in the photo by drawing around the subject and drawing back to the point where you started. The idea is to sample as much of the green screen as possible (Figure 9).

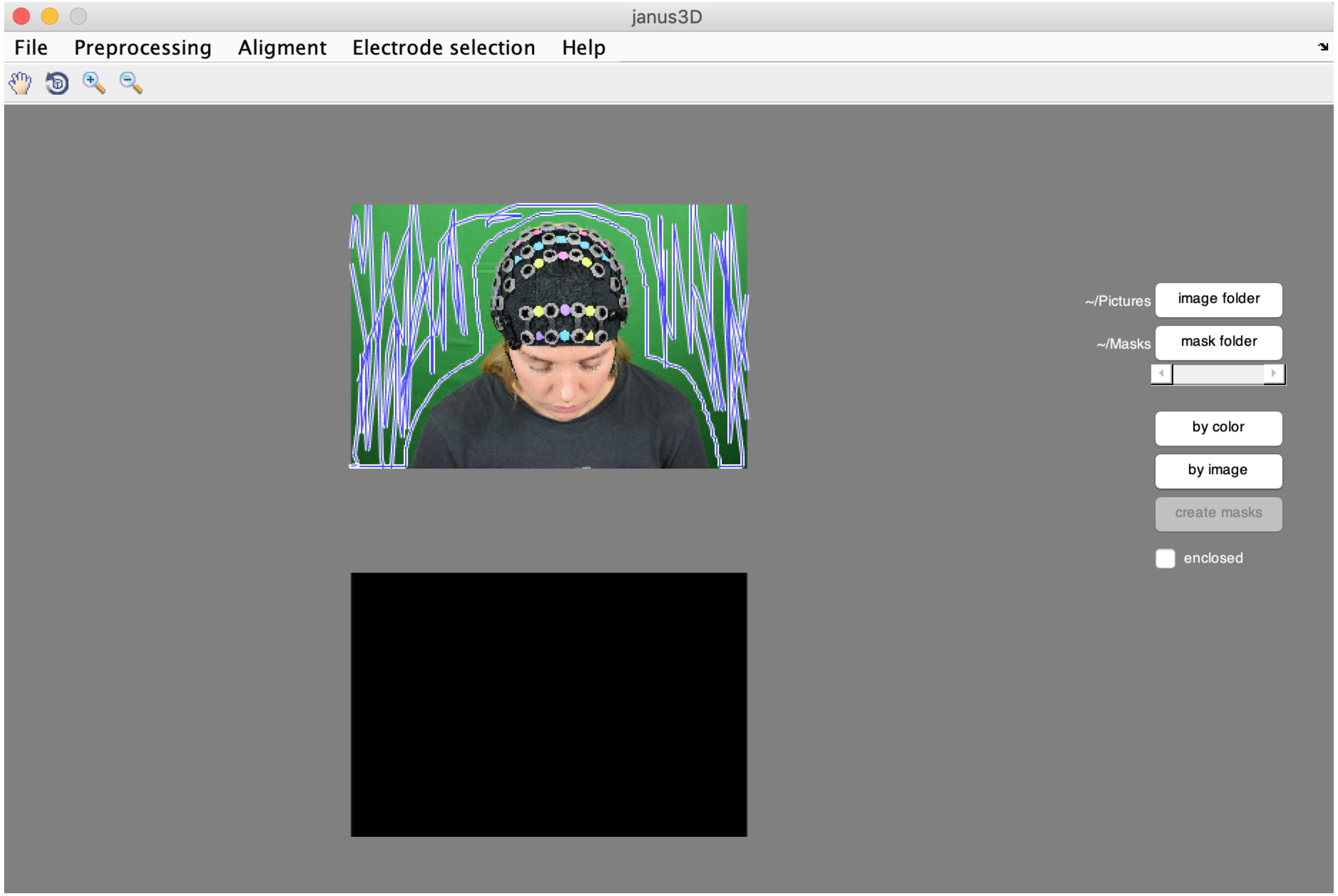


Figure 9. Sampling the green screen in janus3D

5. Double click on the picture. If the sample mask looks accurate (meaning only the background is black), click "create masks" (Figure 10). Otherwise, you can repeat this step until the mask looks accurate. The software then creates the masks for all the pictures in the folder.

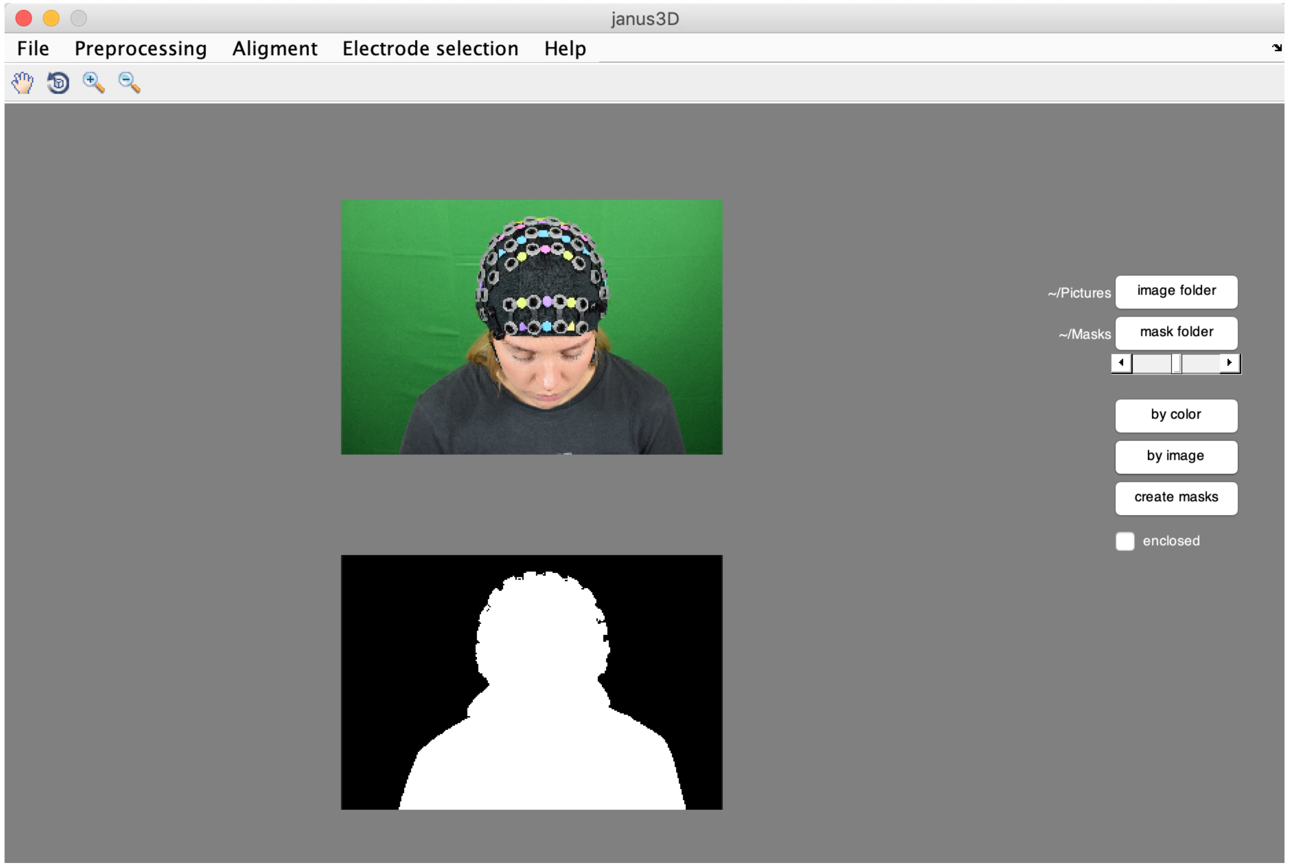


Figure 10. Creating the masks in Janus3D

3 Photogrammetry using Metashape (approx. 1-2 hours)

Next the 3D model is created using the Metashape software (Agisoft). There is a free 30-day trial available. The software is available with a reduced price educational license (ca. £70) here.

1. Open Metashape. Then right click on chunk 1, "Add photos" (Figure 11) and select all the photos in the specified folder.

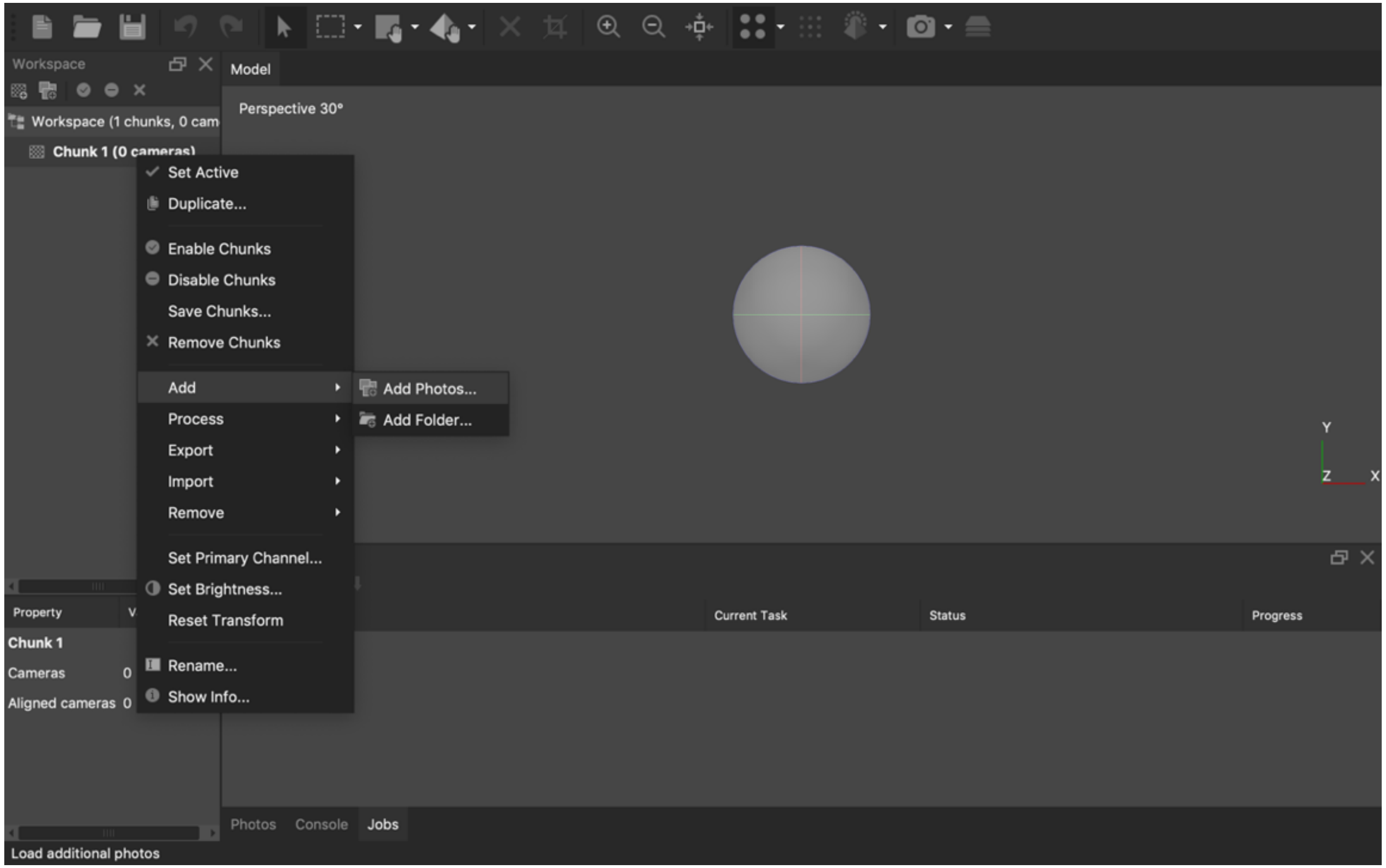


Figure 11. Adding photos in Metashape

2. Right click on chunk 1, "Import Masks" (Figure 12), select "From File" (Figure 13) and select your masks folder (double check how the masks have been named, e.g. masks.png).

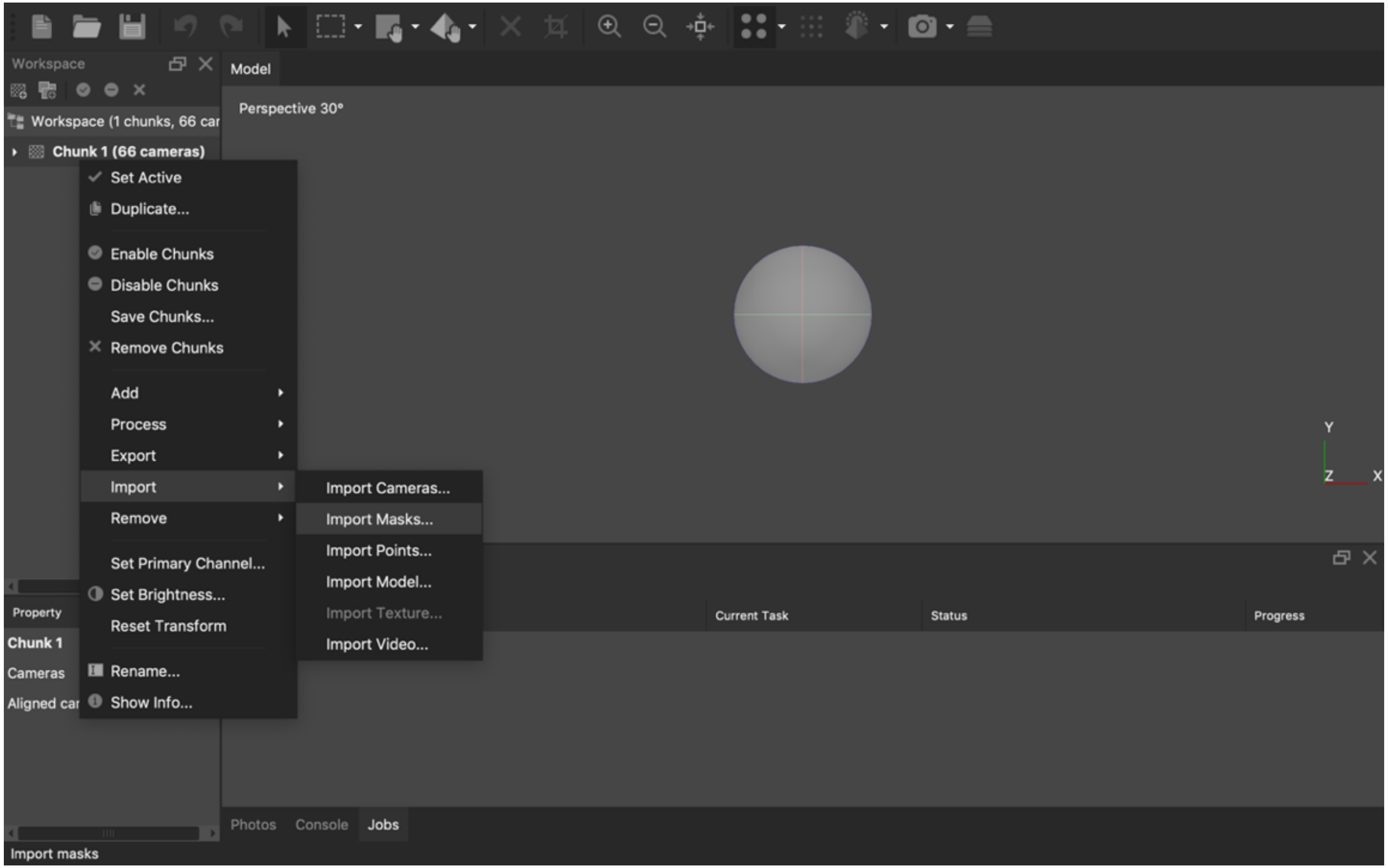


Figure 12. Importing masks in Metashape

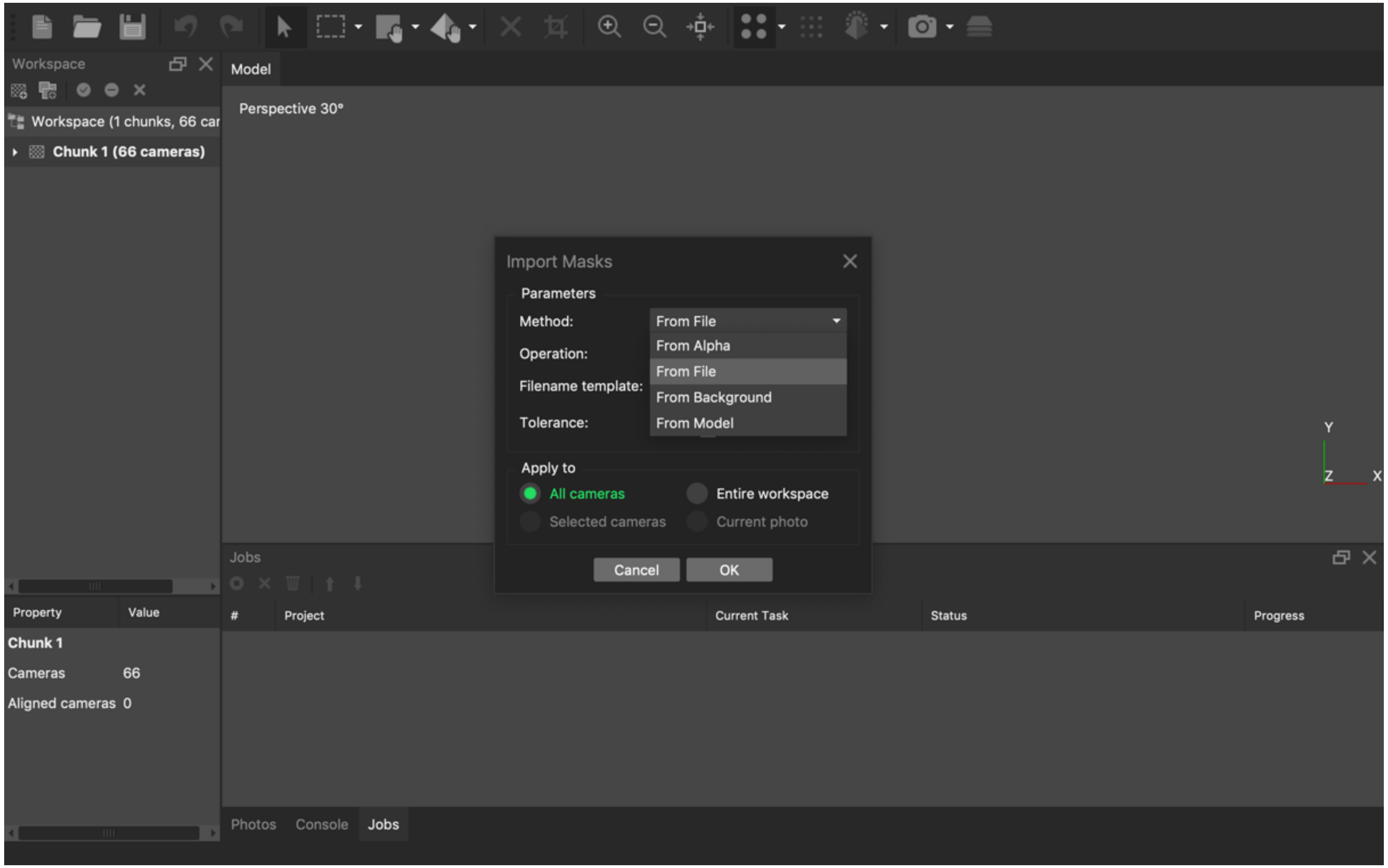


Figure 13. Importing masks from file to Metashape

3. Choose "Workflow" in the top bar, select "Align Photos" (Figure 14 and 15) (**settings**: accuracy = high, select generic preselection, key and tie point limit = 0, apply masks to key points). This can take up to 30 minutes (depending on the number and quality of the pictures and system specifications of your computer).

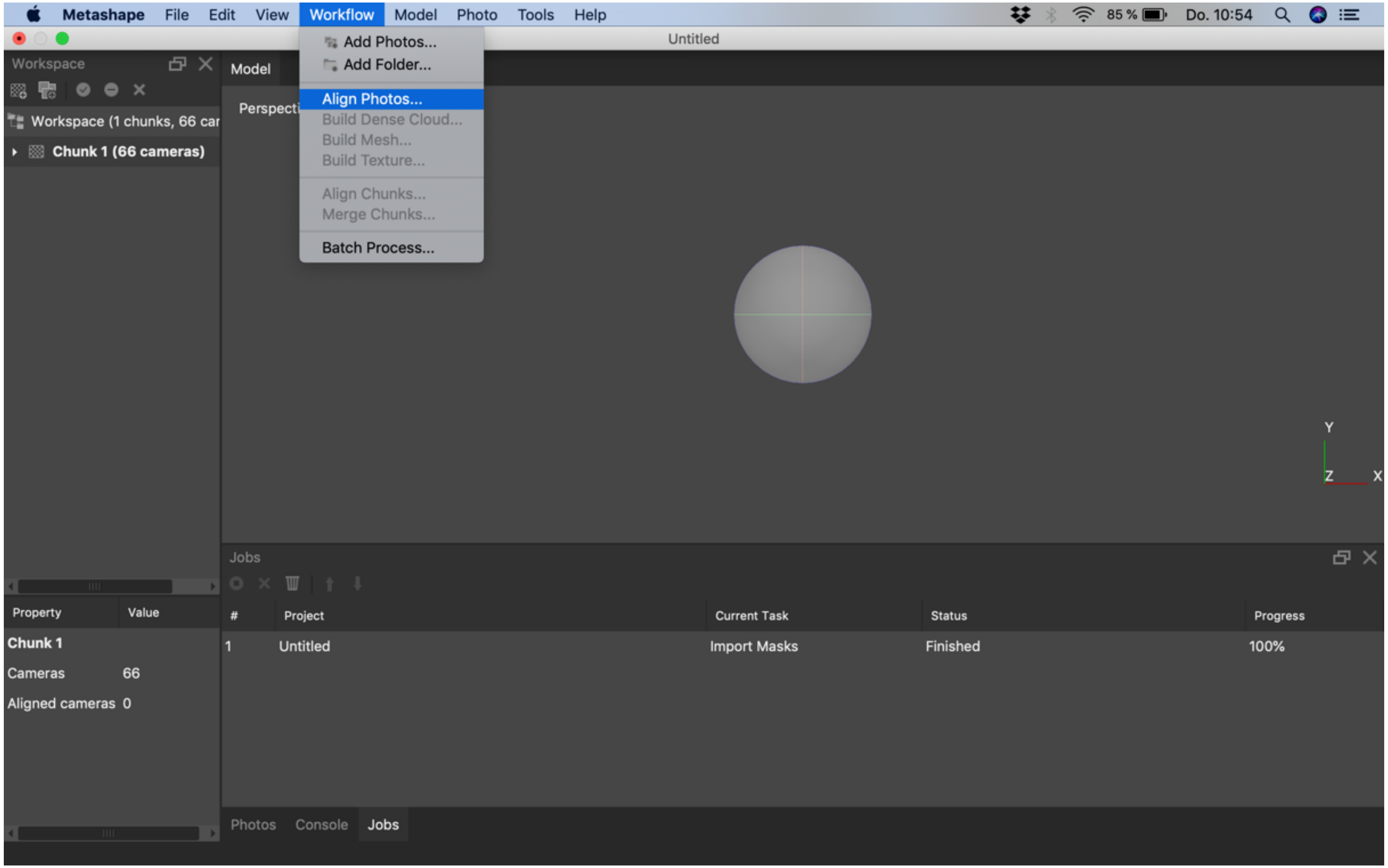


Figure 14. Aligning photos in Metashape

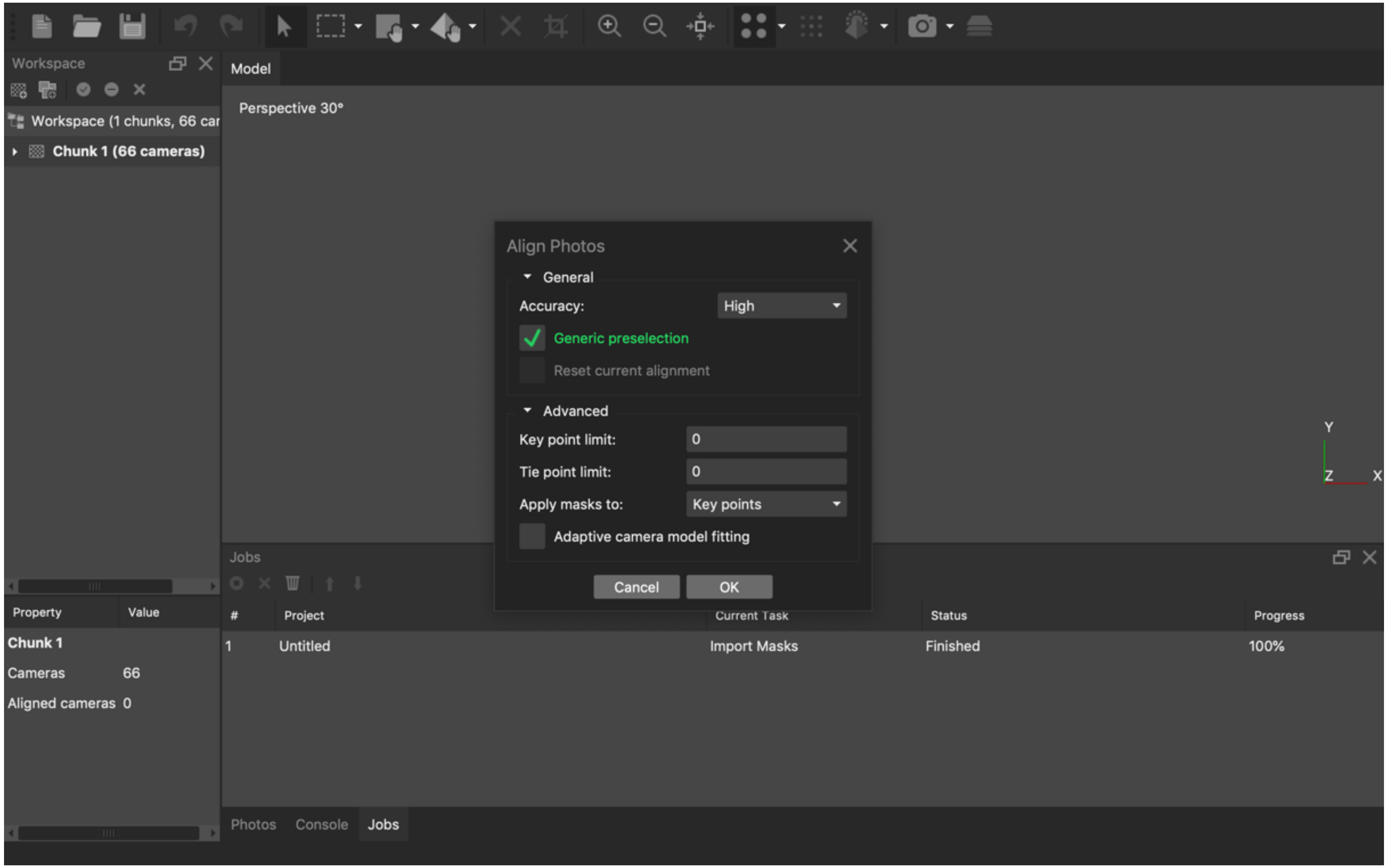


Figure 15. Settings for aligning photos in Metashape

4. The result might look similar to Figure 16. Click the camera icon at the top bar to turn off the cameras (or turn on to see if there is sufficient coverage from all possible angles). It might happen that some cameras fail to align, meaning not all photos were able to be matched with the

correct angle.. This is indicated at the bottom left of the screen. If this happens simply try aligning again or try again with a new chunk (simply right click on “Chunk” and select “New Chunk”). If only a few cameras failed to align this might not be a massive issue, but if only a few cameras aligned you might need to take new pictures. The alignment might have failed because there was too much movement during the shoot or because there are not enough pictures with overlapping points. As mentioned above it is crucial to have a sufficient number of photos, a still model and consistent lighting. Do not be discouraged if this is not working on the first try, maybe try again with a different model or with a different camera position or settings.

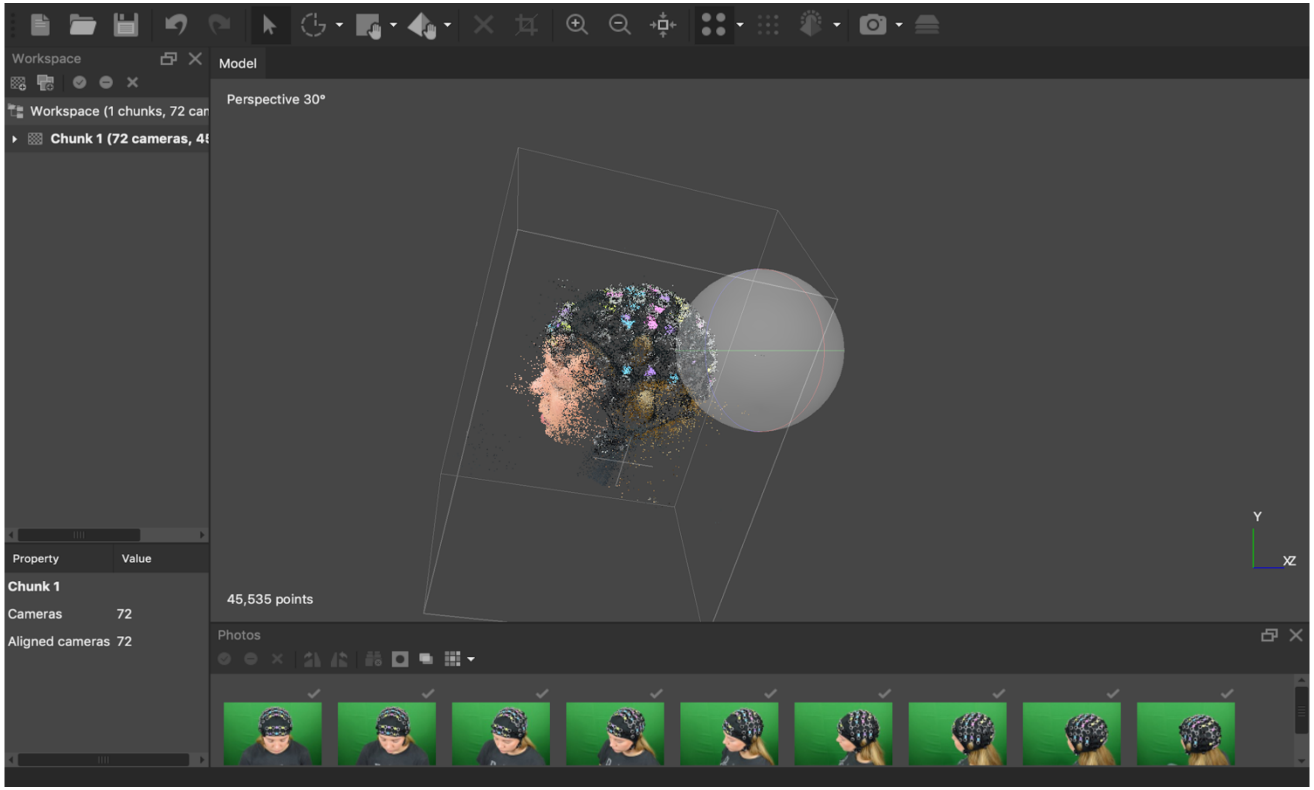


Figure 16. Results after aligning the photos in Metashape

5. Next, resize the selection box (Figure 17 and 18). You only want to have the area that you are interested in (e.g. the head) in the square. By making this selection you also reduce the processing time.

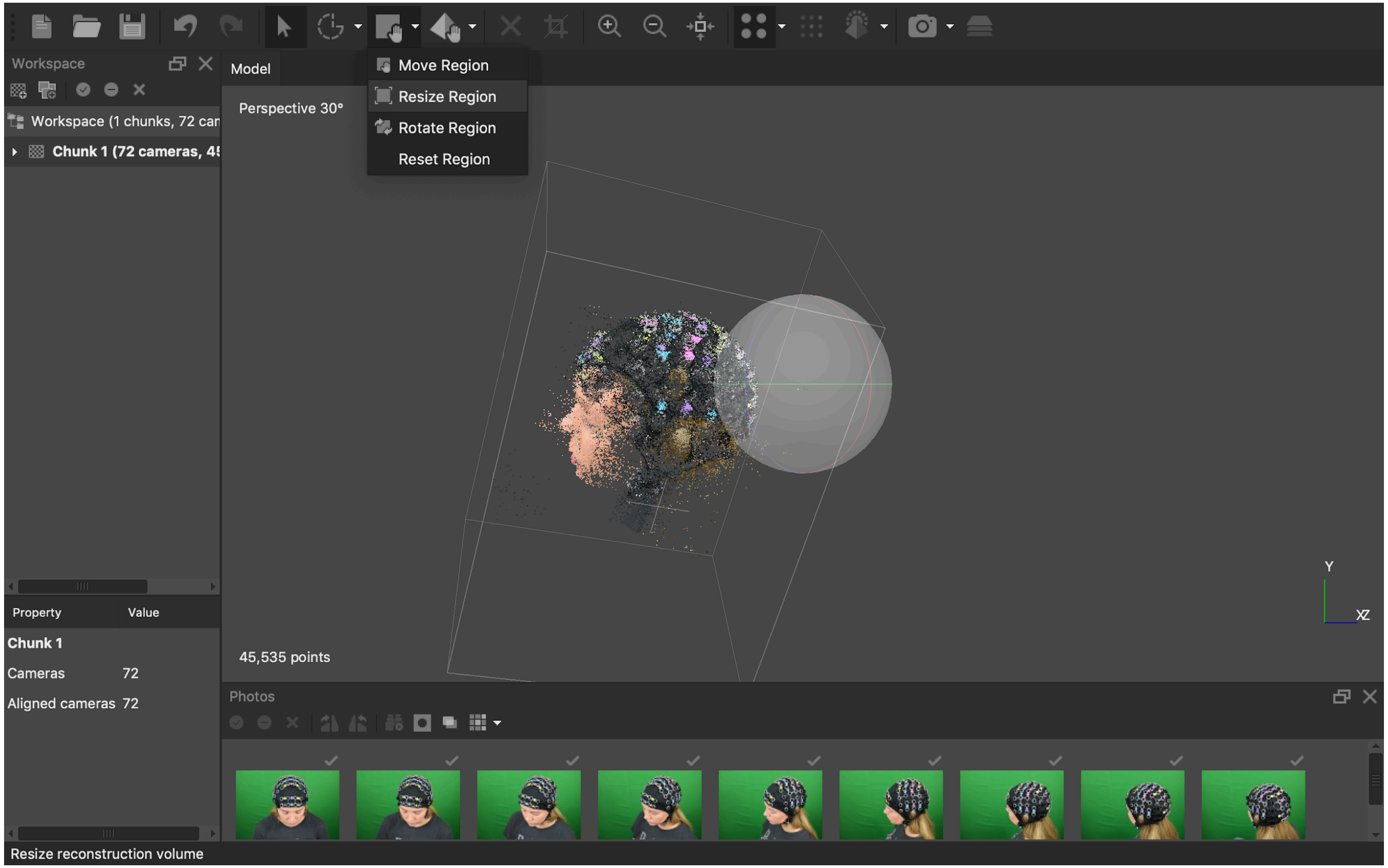


Figure 17. Resizing the region in Metashape

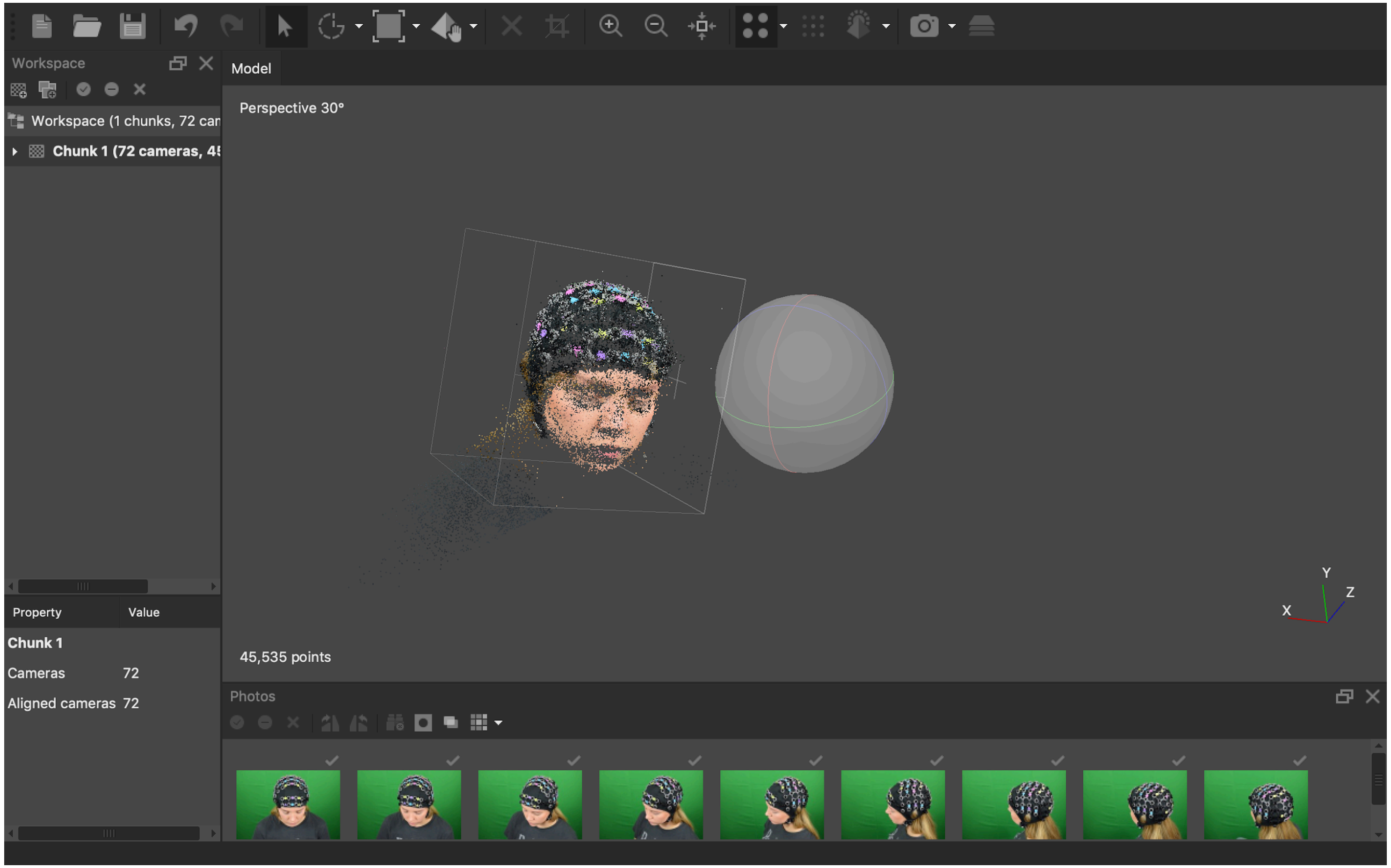


Figure 18. Resizing the region in Metashape

6. Remove all the unnecessary points. To do so choose "rectangle selection" and select "free form selection". Now use the tool to draw around the area you'd like to keep (Figure 19) (e.g. draw around the head). The tool will select the area that has been drawn around and by using "crop section" all other points will be removed. Continue doing this from every angle of the object to make sure there are no unnecessary points left.

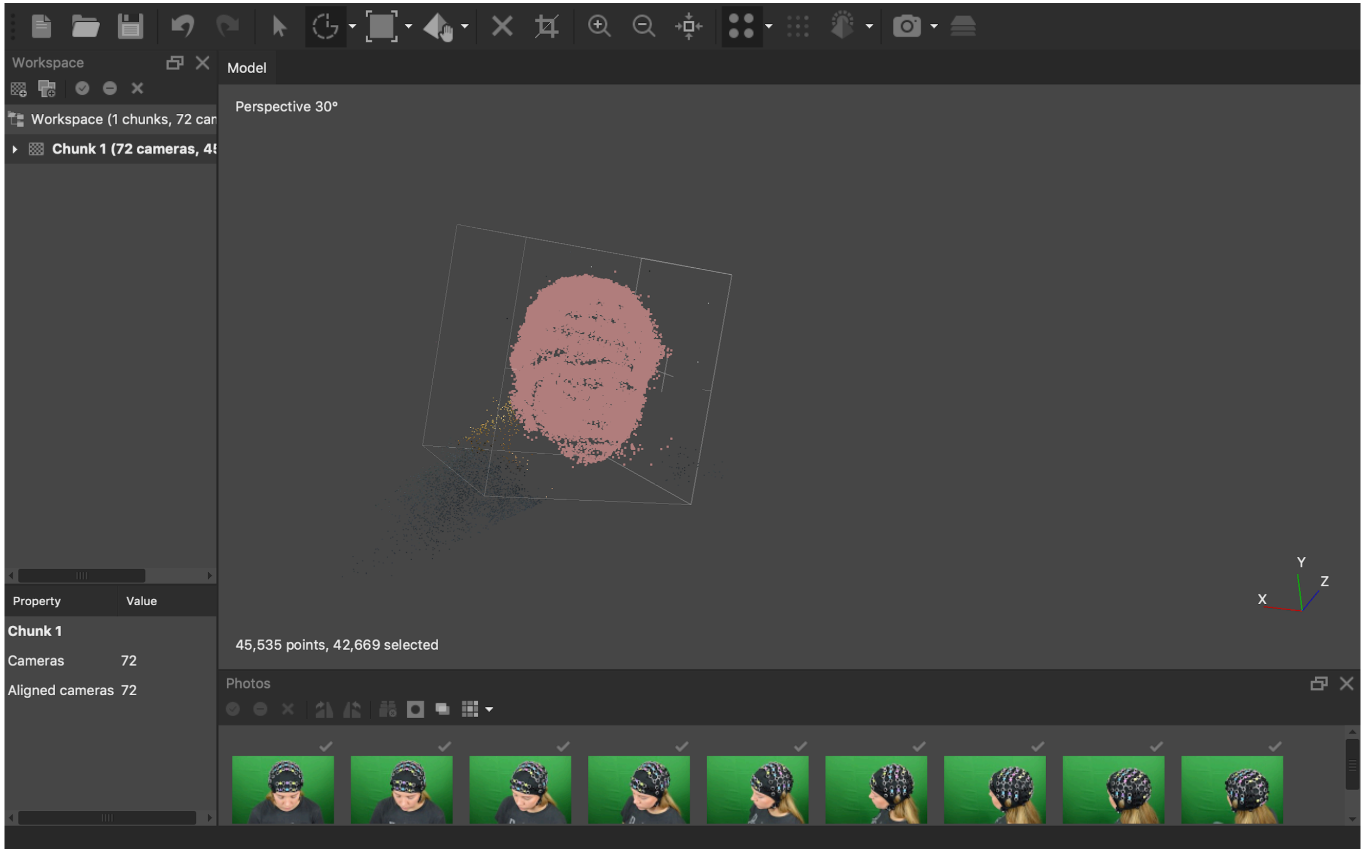


Figure 19. Removing unnecessary points in Metashape

7. Build the dense cloud (Figure 20) with the following **settings**: quality = high, depth filtering = mild, calculate point colours).

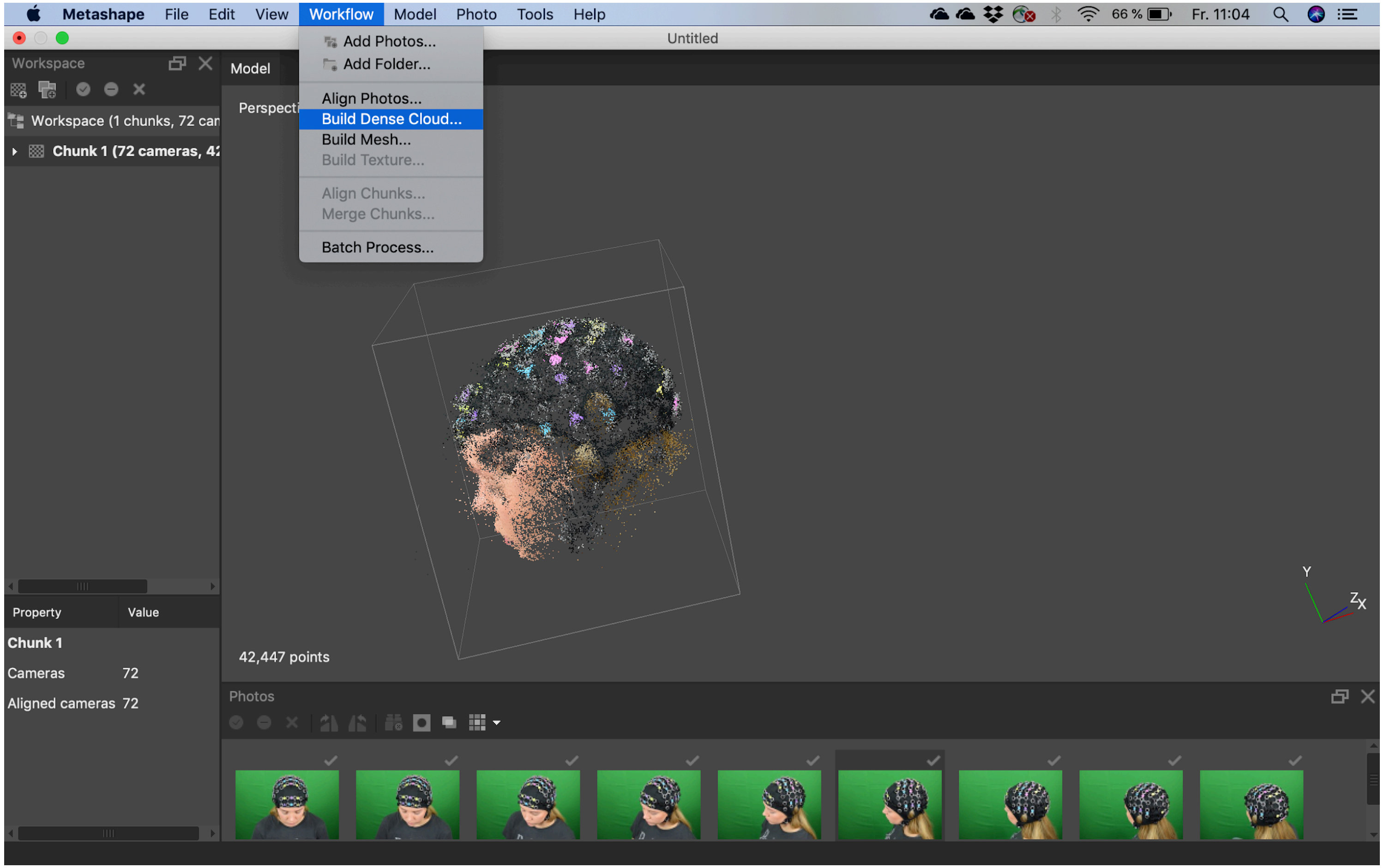


Figure 20. Building dense cloud in Metashape

8. Resize again if necessary.

9. Go to workflow, select "Build mesh" (Figure 21) (**settings**: source data = dense cloud, surface type = arbitrary, face count = high). The settings were selected by trial-and-error, so other settings may also work for you. We are open to suggestions.

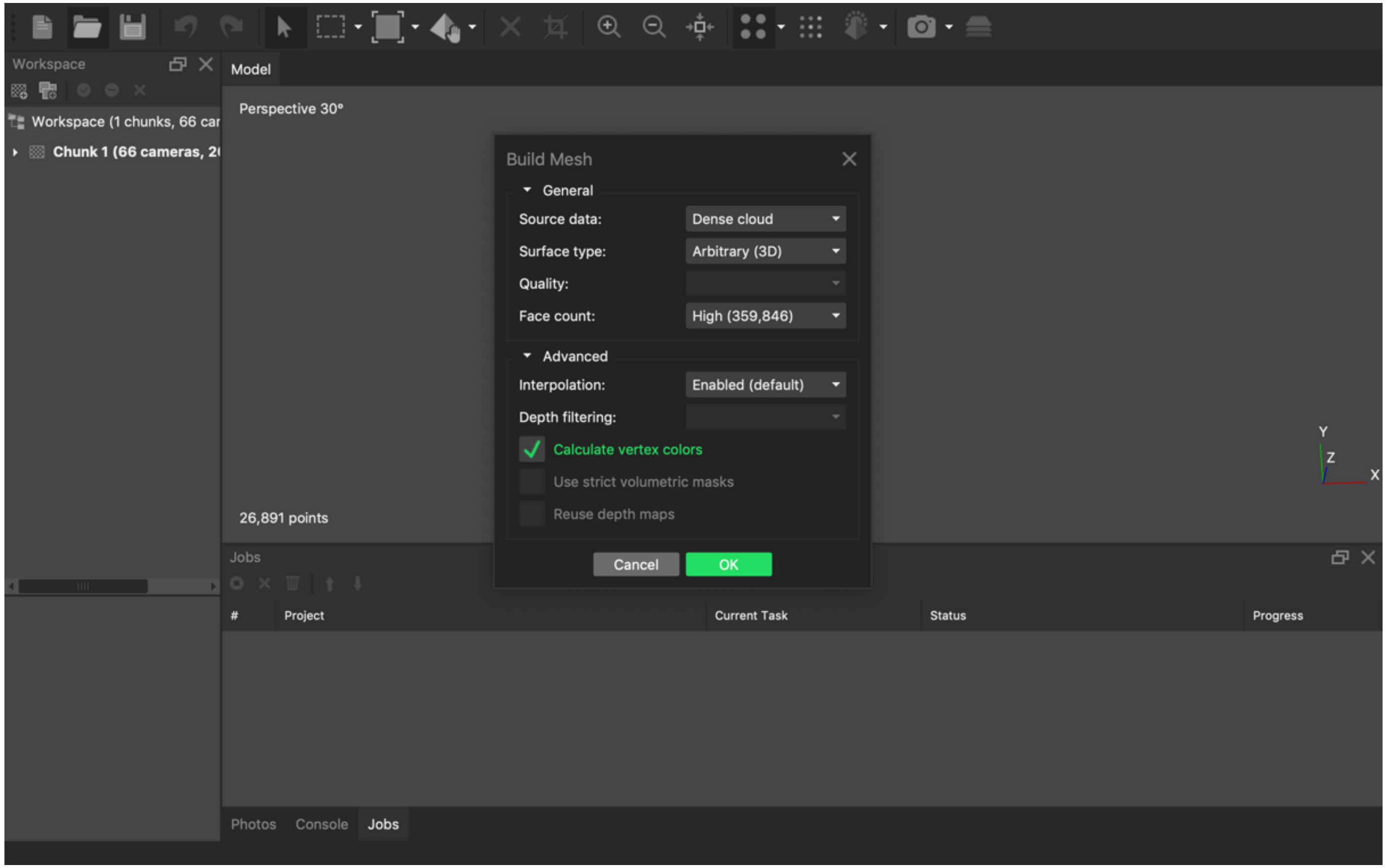


Figure 21. Building mesh in Metashape

10. Check the quality of the model by looking at different views by selecting "shaded", "solid", and "wireframe" as illustrated in figure 22 and 23.

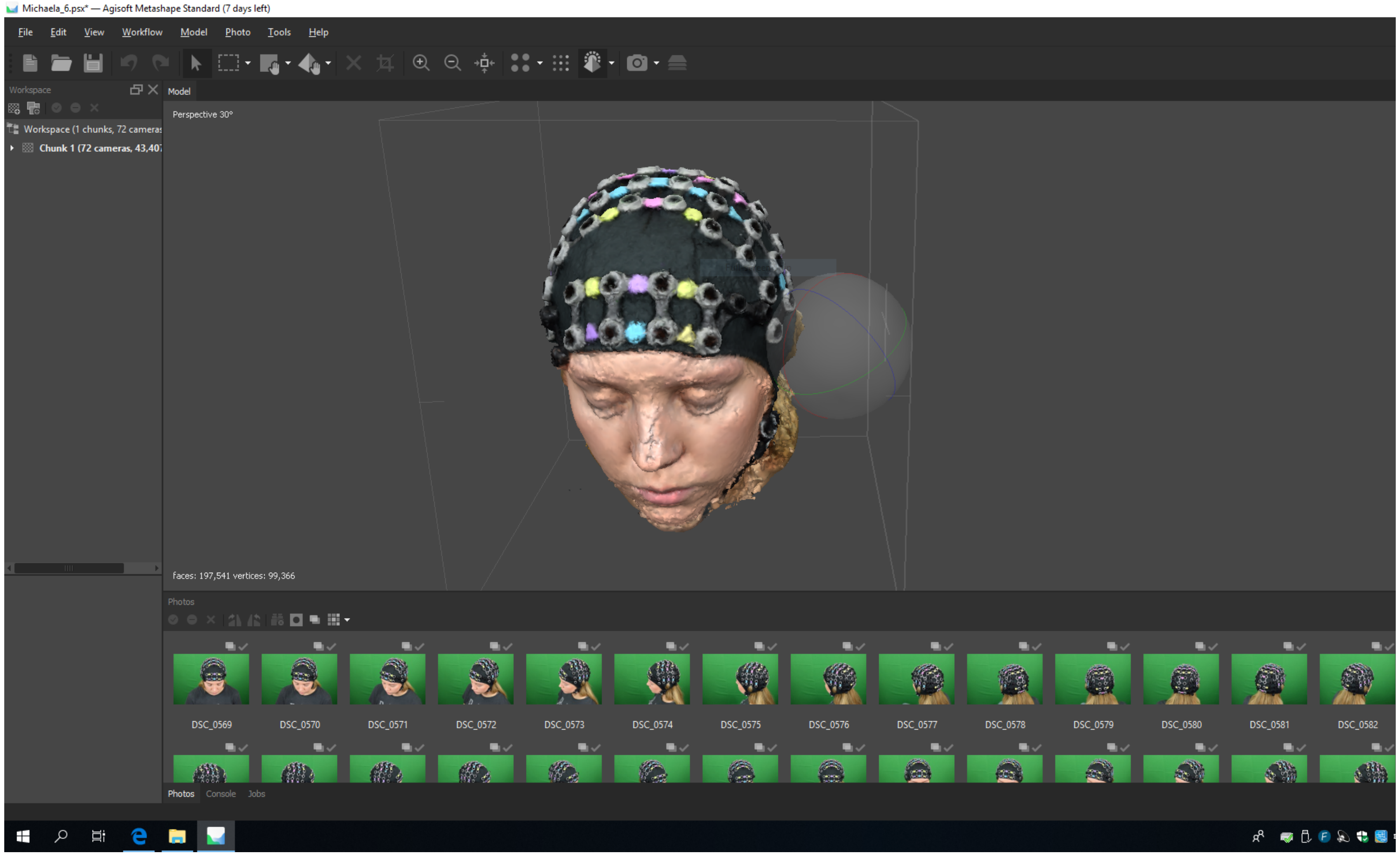


Figure 22. Checking shaded mode in Metashape

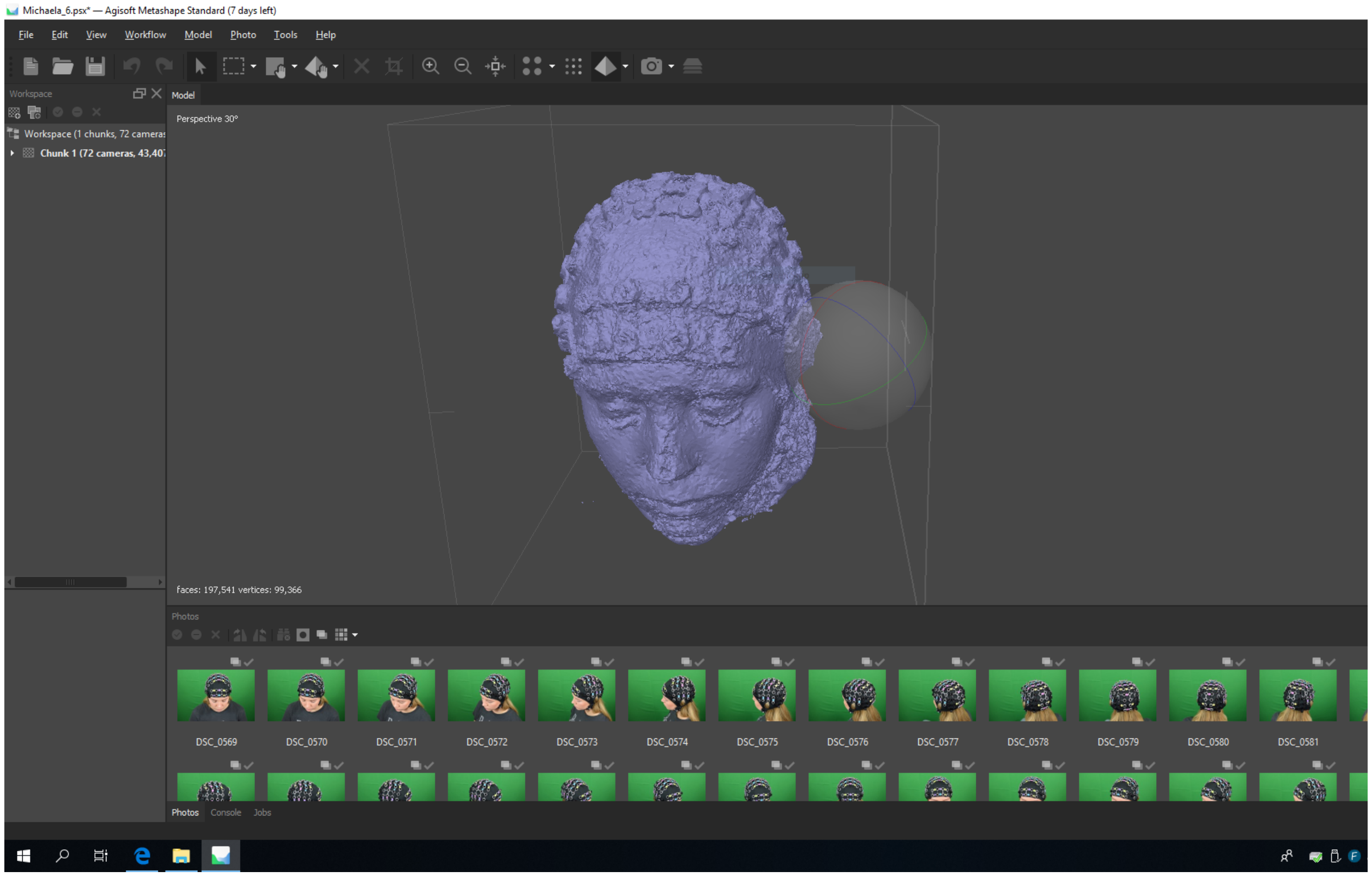


Figure 23. Checking solid mode in Metashape

11. Select "workflow", "build Texture" with settings "average" (Figure 24).

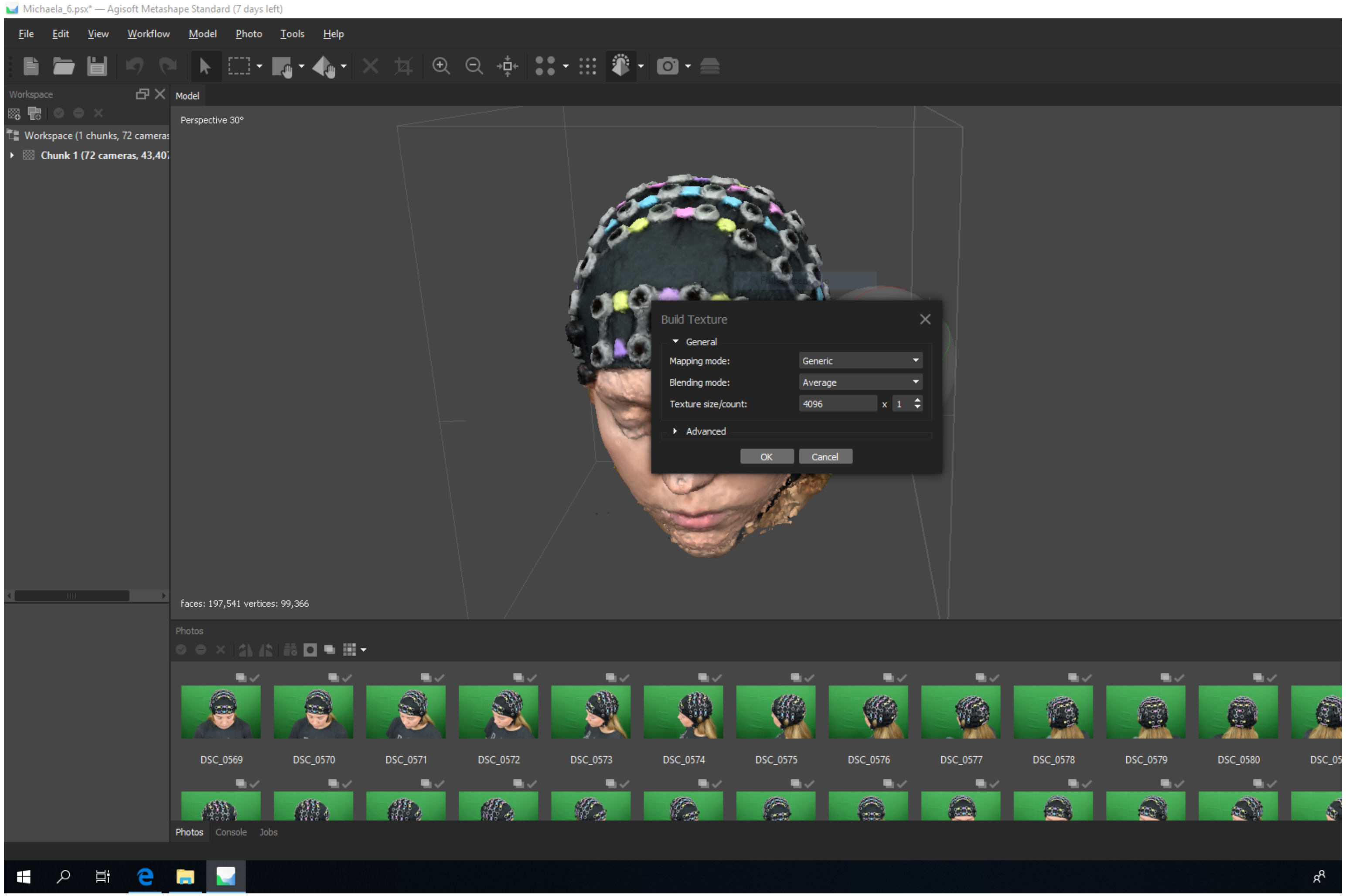


Figure 24. Building texture in metashape

12. The results might look similar to the 3D model in Figures 25, 26 and 27 if everything worked correctly. Some models might be a bit more blurry than others. In that case the quality of the pictures might have been the reason. This is not a problem if you can still see every optode holder location.

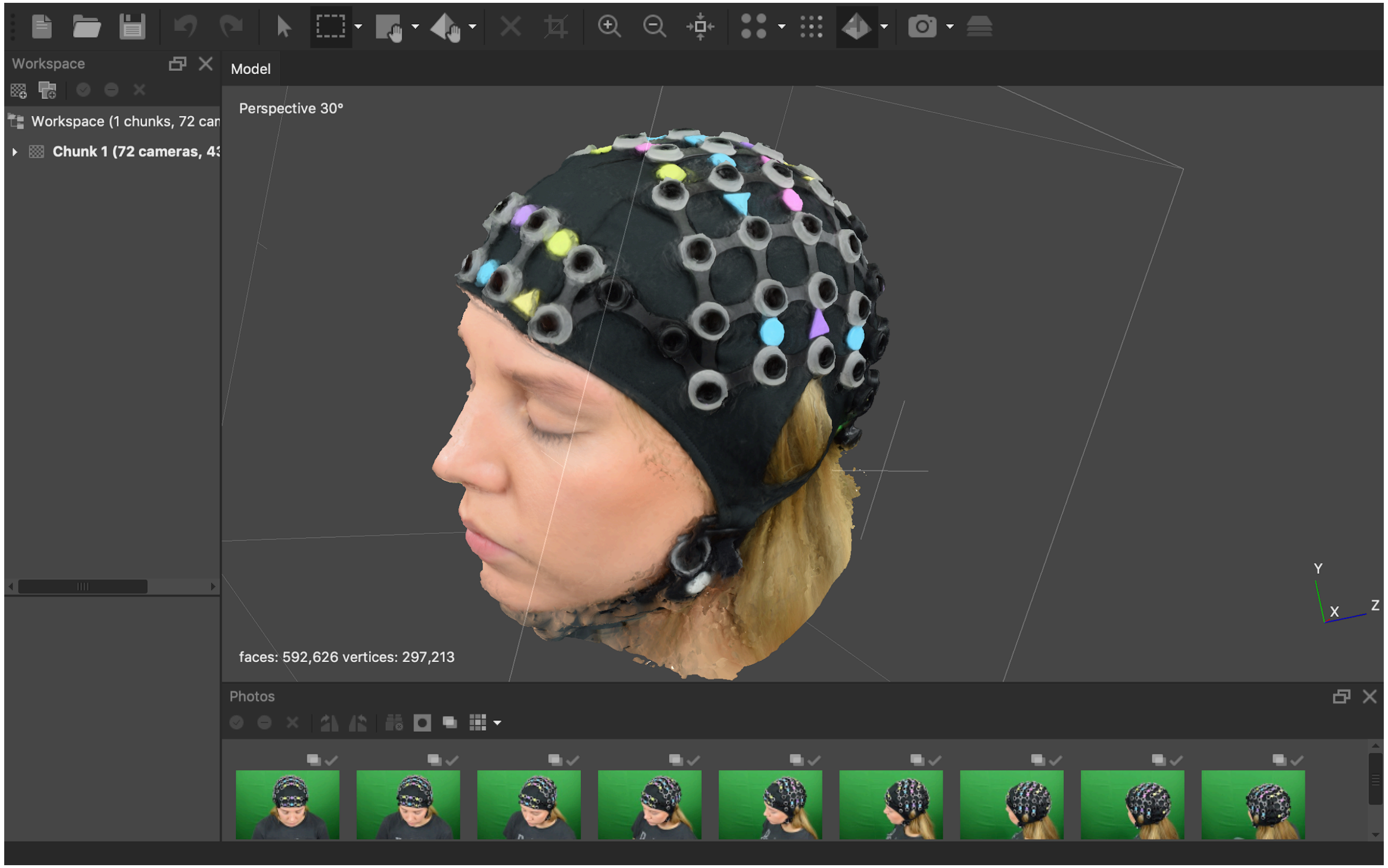


Figure 25. Final 3D model in Metashape, front view

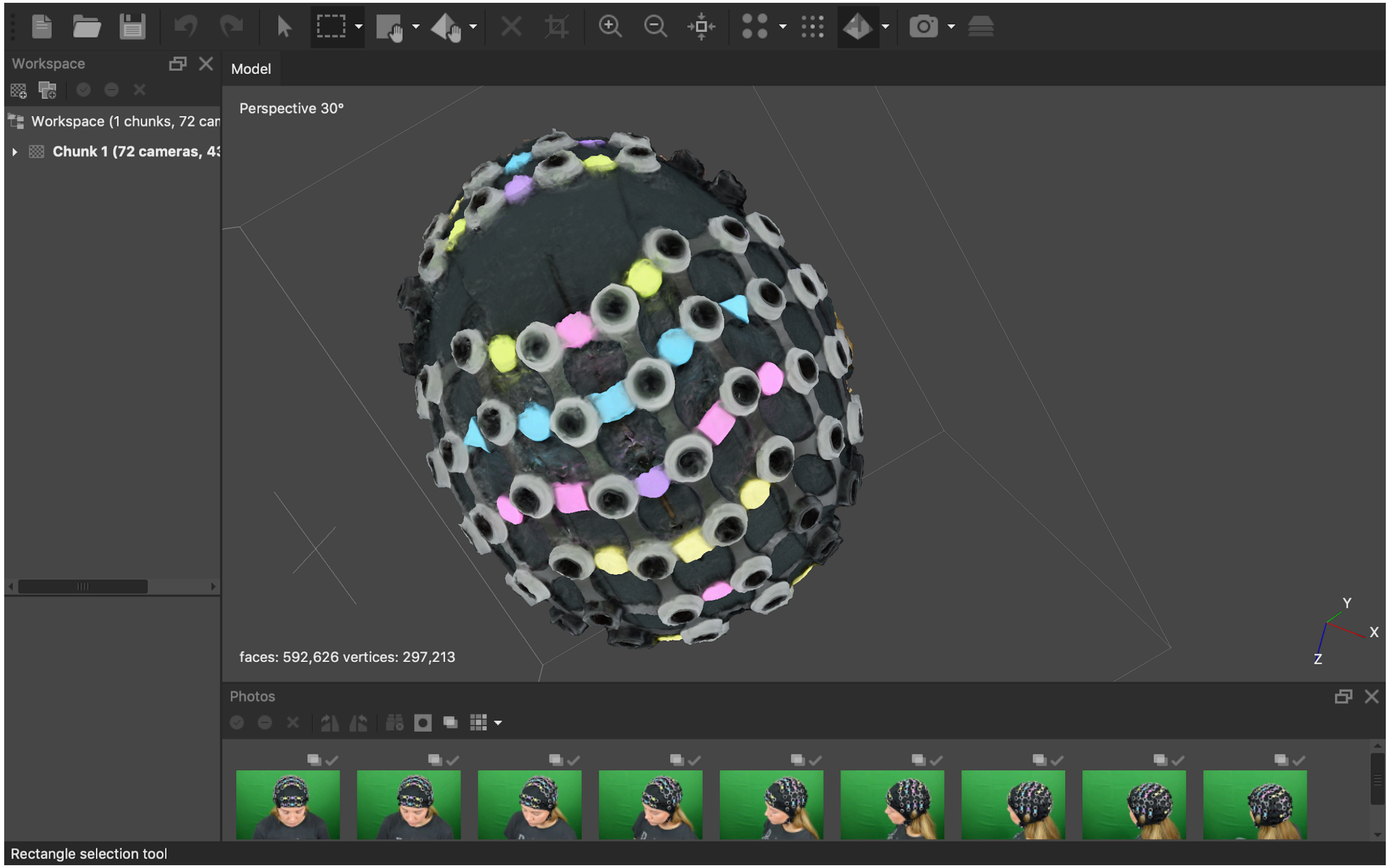


Figure 26. Final 3D model in Metashape, top view

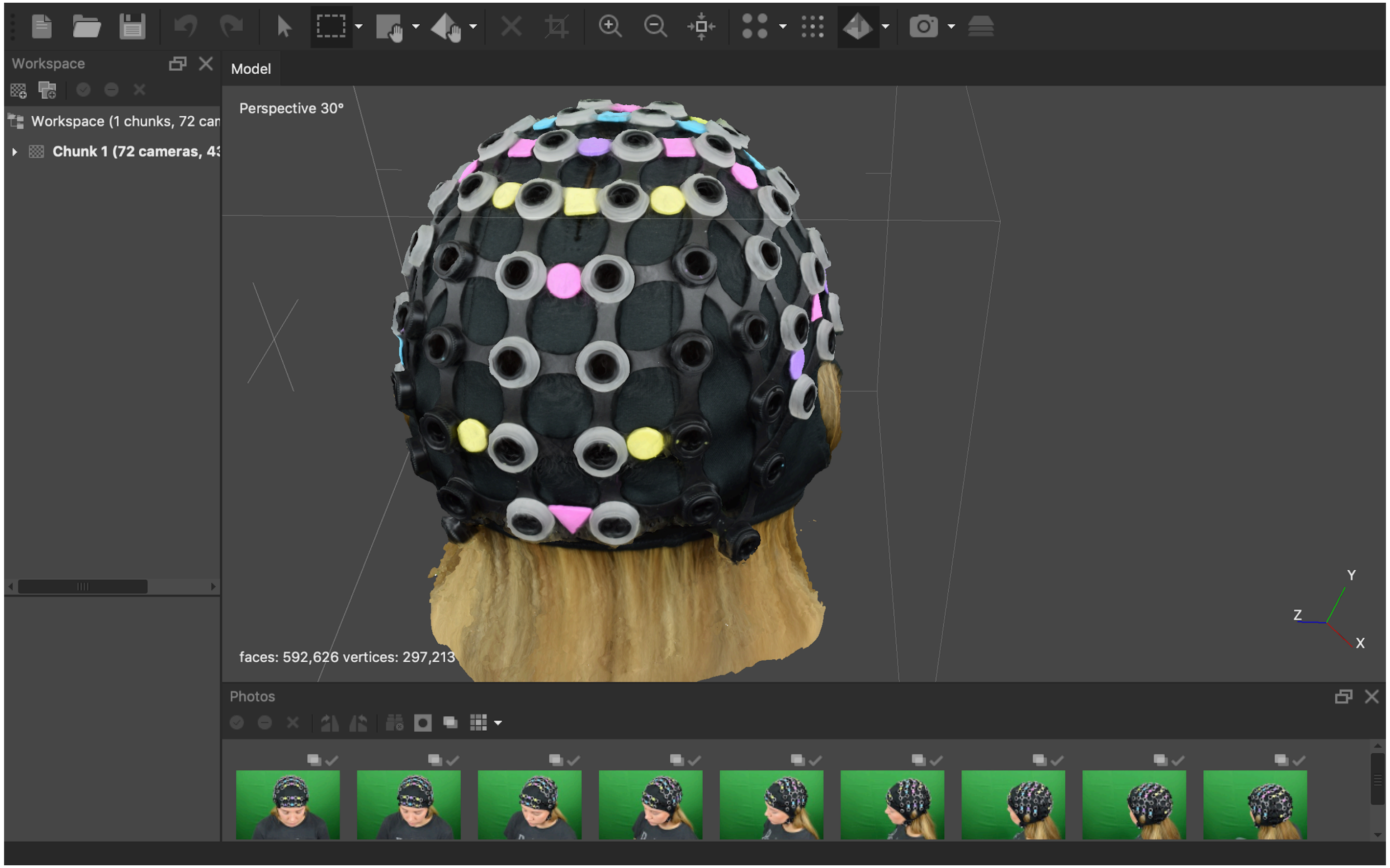


Figure 27. Final 3D model in Metashape, back view

13. Export the model from Metashape by clicking “File”, “Export”, “Model” (**settings:** deselect all except for export texture) (Figure 28 and 29).

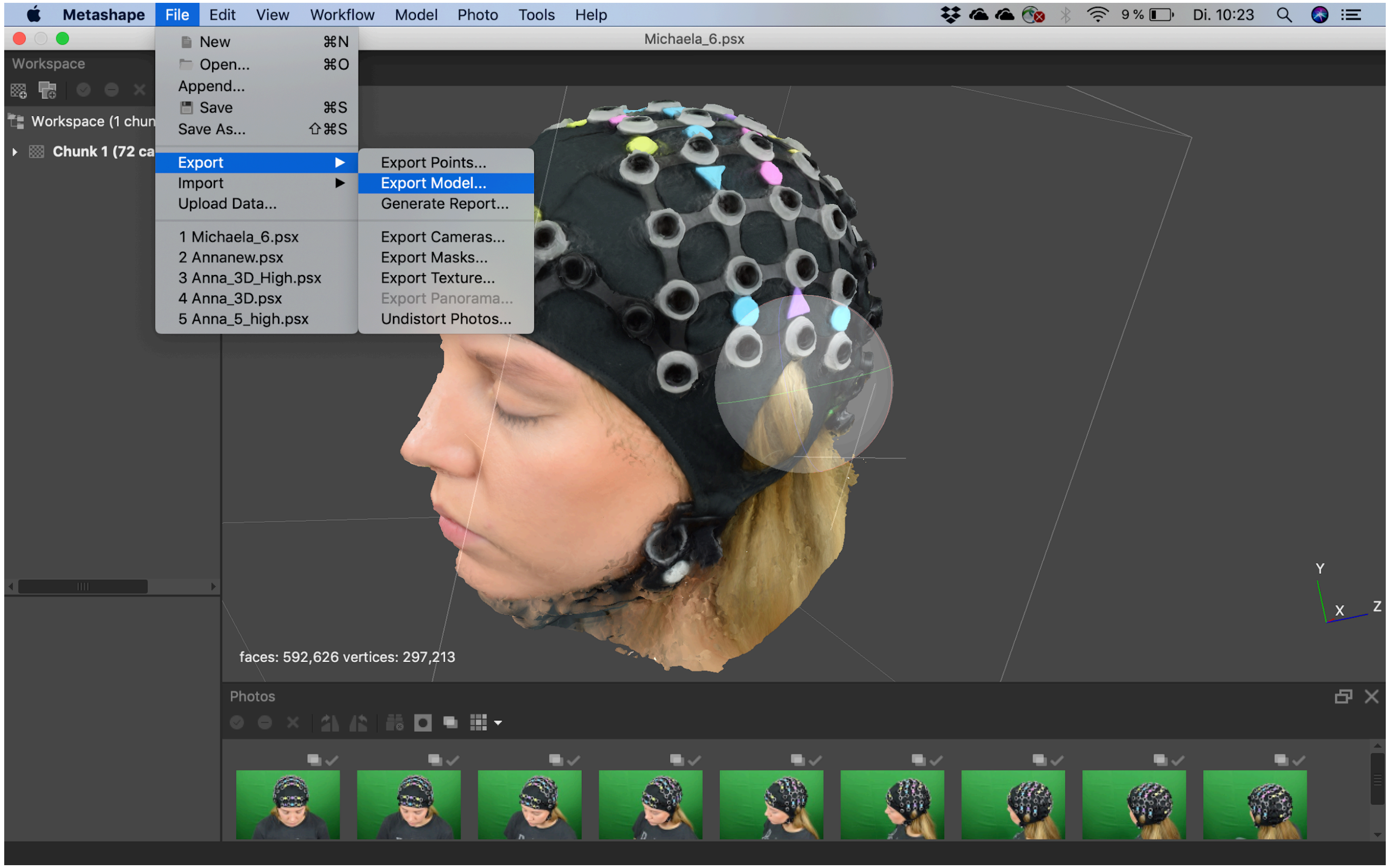


Figure 28. Exporting the model from Metashape

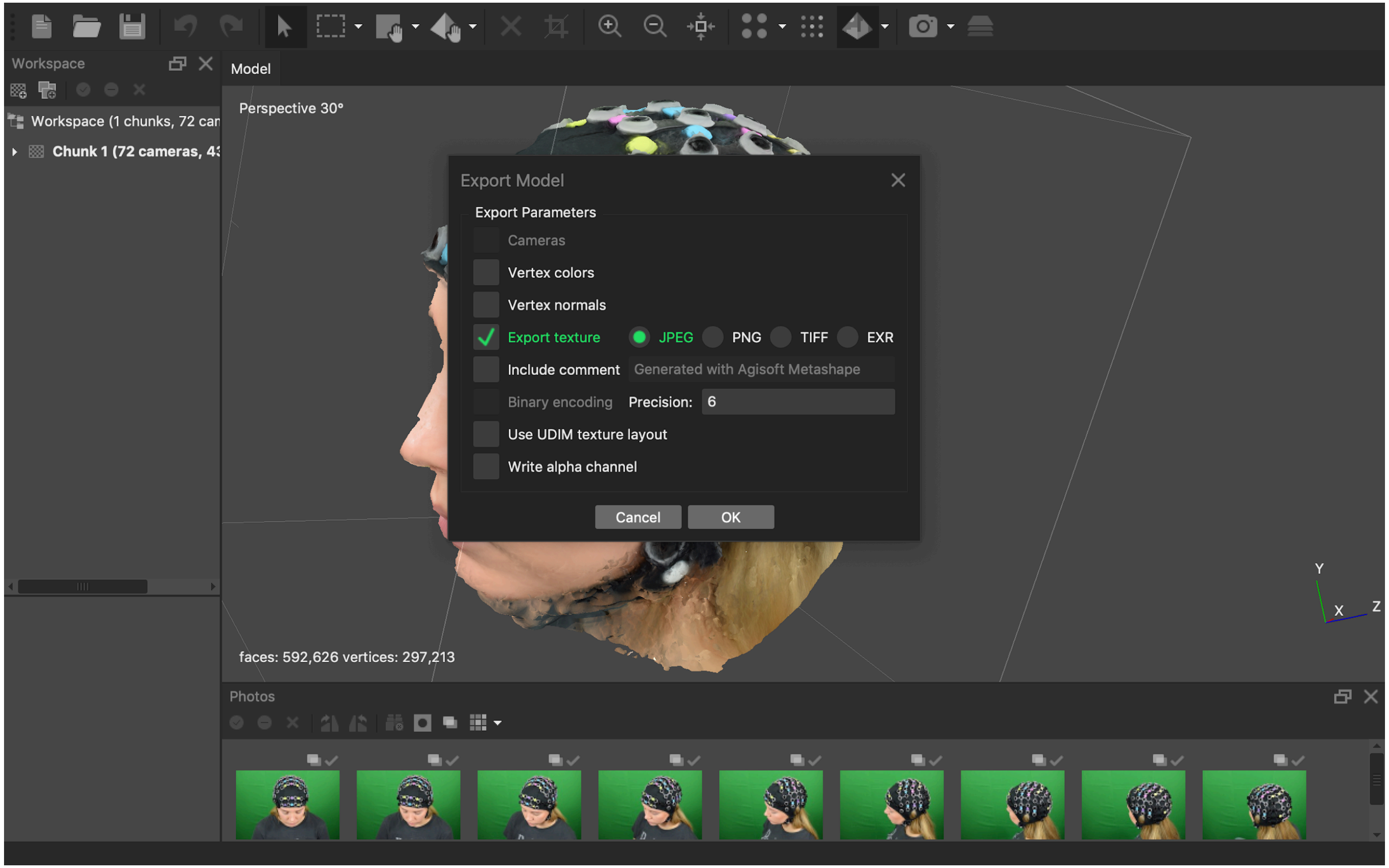


Figure 29. Exporting the model from Metashape

Note: This procedure works in the exact same manner for EEG caps. Due to the higher contrast of the cap the results might even look a little better (Figure 30 and 31).

Figure 30. Photogrammetry with EEG cap. The subject gave consent for these images to be shared.

4 Co-registering the head model and the anatomical scans in janus 3D (approx. 30 minutes)

A manual on how to coregister the 3D model and the anatomical scans in janus3D can be found here. Our own procedure following the manual is summarized below.

1. Open janus3D in Matlab as described in 2.2. Choose "Preprocessing", click "Model" and choose your 3D model .obj file (Figure 32).

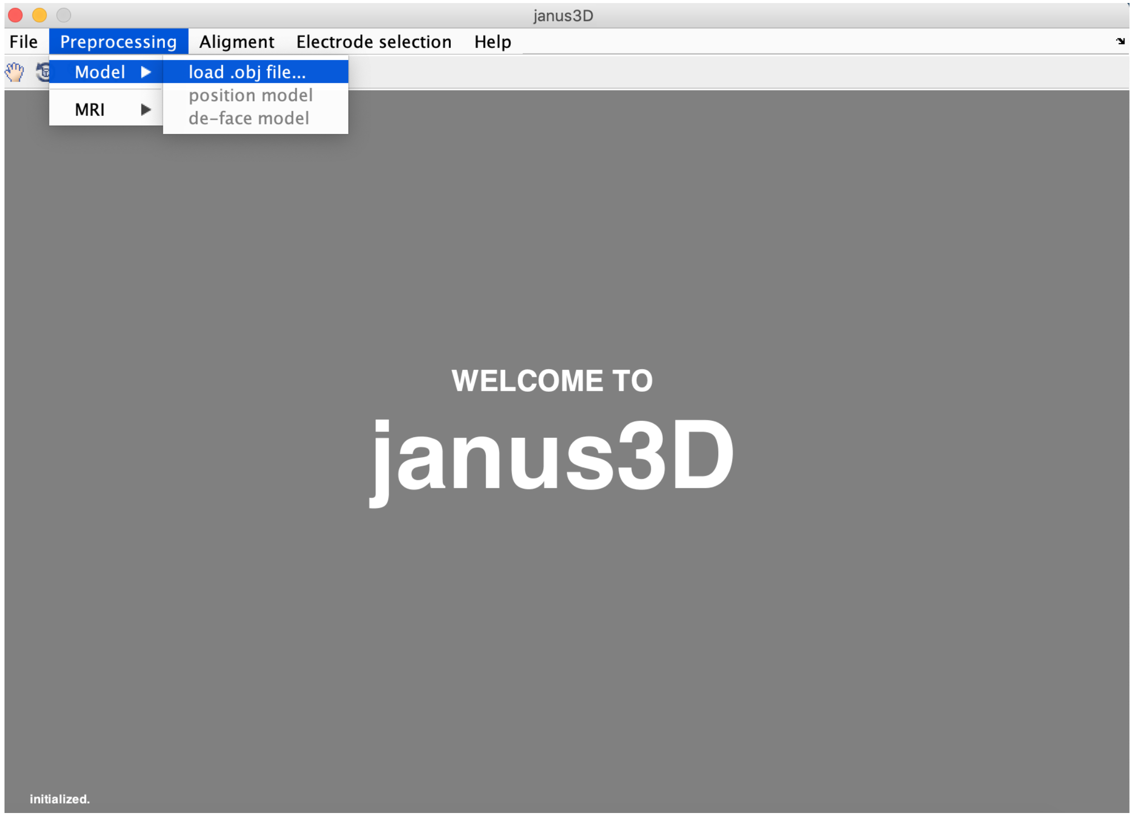


Figure 32. Opening 3D model in janus3D

2. Choose "Preprocessing", "Model", "position model". The 3D model comes in arbitrary space, while the MRI Model can be in native or in MNI space (in our experience, the anatomical scans in MNI space would not align - however, we are curious to hear about other researchers' experiences). Use the MRI scan in native space for alignment with the 3D model. The 3D model and MRI scan can be aligned manually by rotating the model until they are in the same position. Start by clicking "leftside" and rotate your model by typing in an angle (e.g. 10) in the angle section. After each input press enter, instead of "OK", as this will end the positioning. Keep in mind that everytime you press enter, the model will rotate 10° (or what angle you have typed in) from its newest position. Rotate your model until the head is in an upright position (Figure 33). Continue clicking "topside" and go on until the nose is pointing at the top of the screen (Figure 34). Then click "backside" and check if the head is upright (Figure 35). Last check the position by clicking "perspective". Your head should look at the bottom left corner (Figure 36). If the position looks good press "OK".

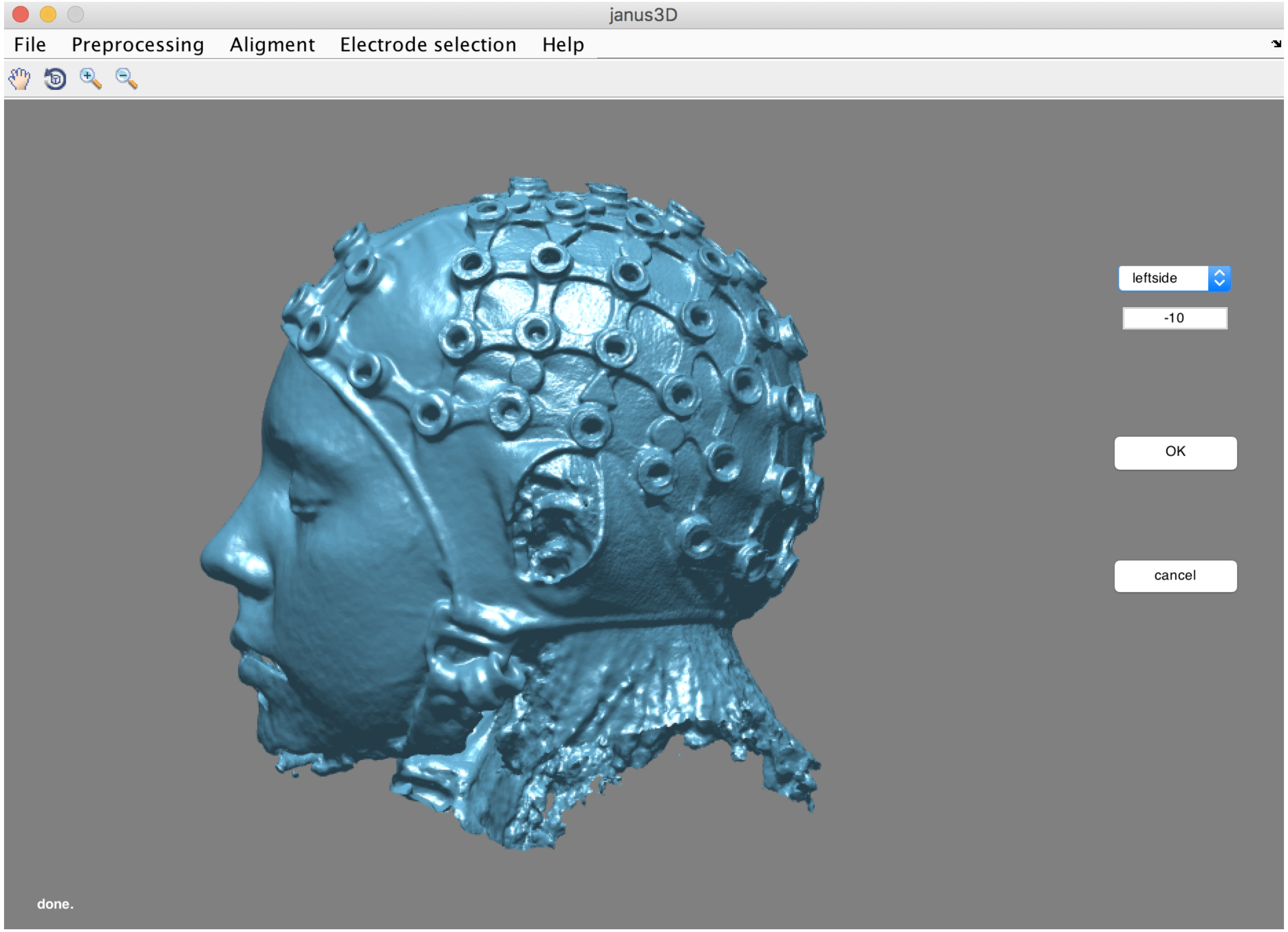


Figure 33. Required position of 3D model in "leftside" view

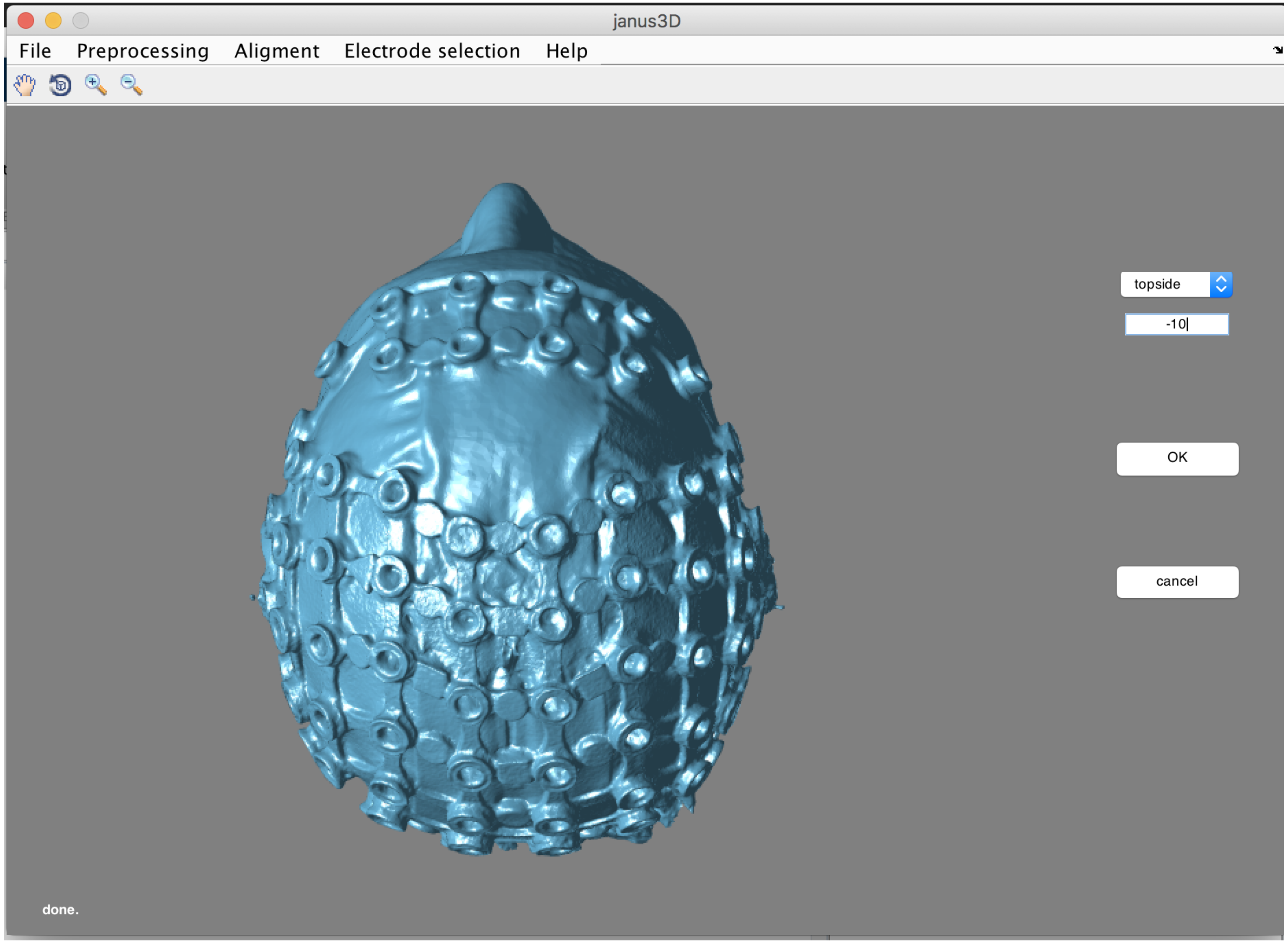
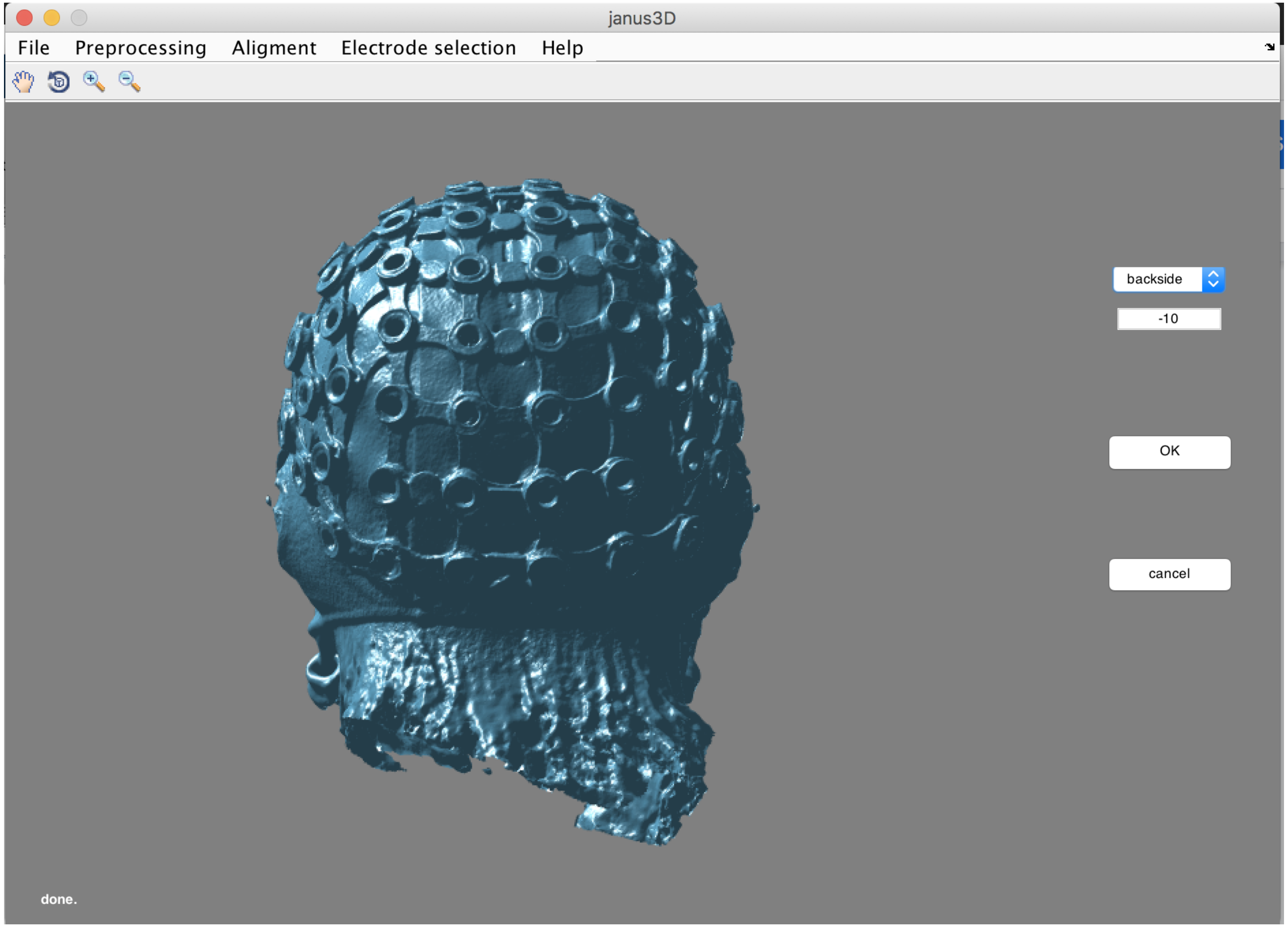


Figure 34. Required position of 3D model in "topside" view



Figuree 35. Required position of 3D model in "backside" view

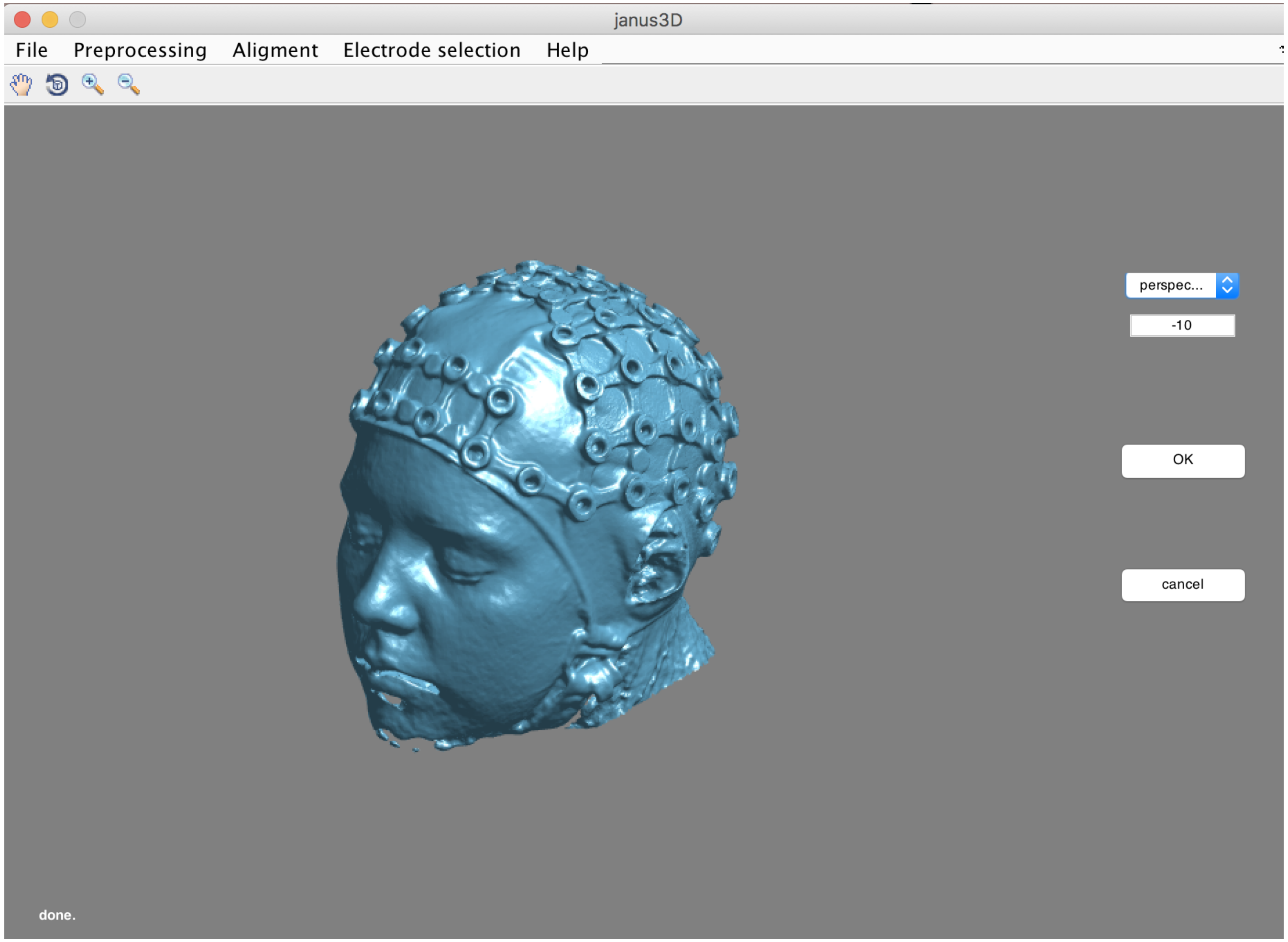


Figure 36. Required final position after alignment of the model

3. Now upload your MRI scan by clicking "Preprocessing", "MRI", choose your anatomical MRI nifti (.nii) file.

4. Next you need to select the "de-face" option in janus3D. We are not actually defacing (only the setting is labeled that way), but selecting the face of the subject in the 3D model and the MRI scan to later align the models. Therefore start with the 3D model by clicking "Preprocessing", "Model", "de-face". Now click "select by points" and left click on every point you'd like to select around the face (Figure 37). Press "select by points" again when done. Then press OK.

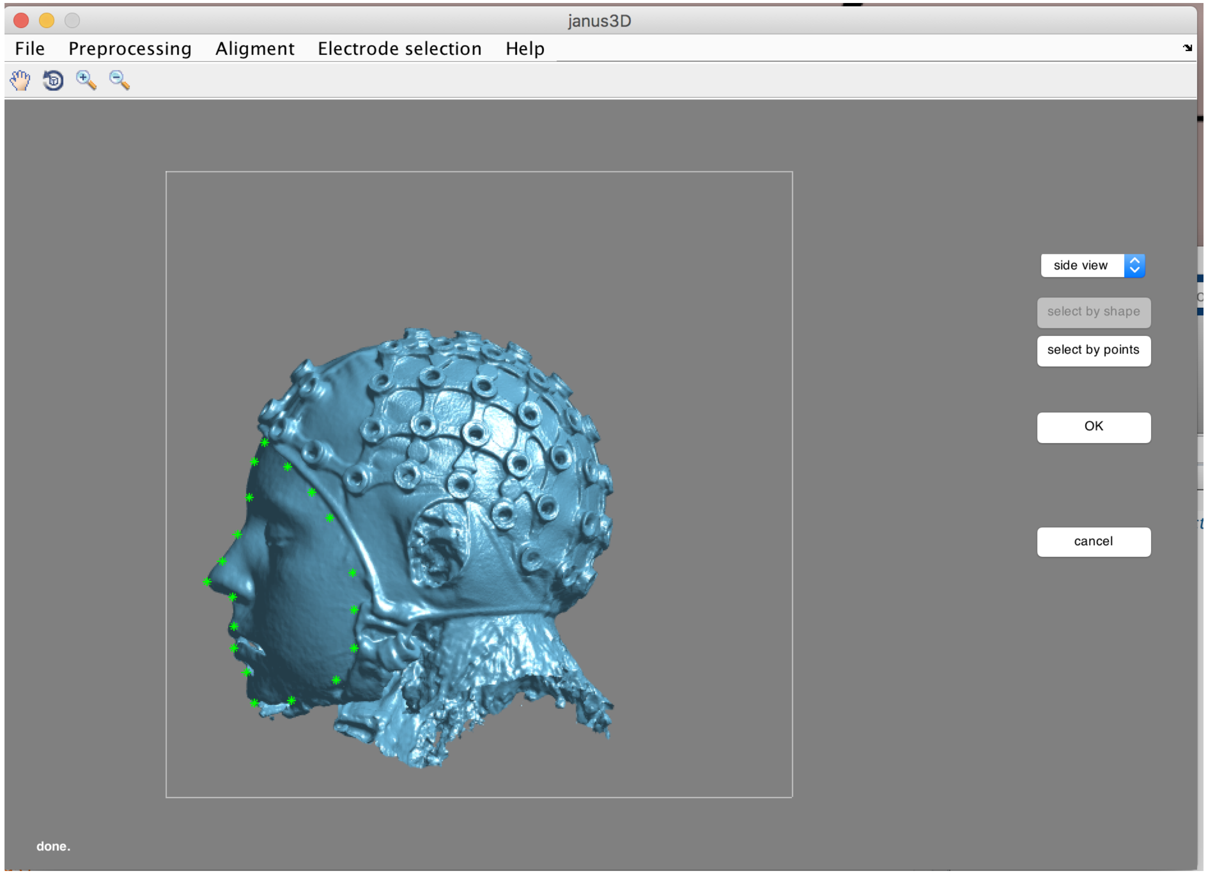


Figure 37. De-facing model in janus3D

5. Now "deface" your MRI model by clicking "preprocessing", "MRI", "deface". You can now choose the option "by shape" which lets you take your previous selected face and move it on top of your MRI scan face (Figure 38). Press "by shape" again when done. Then press OK.

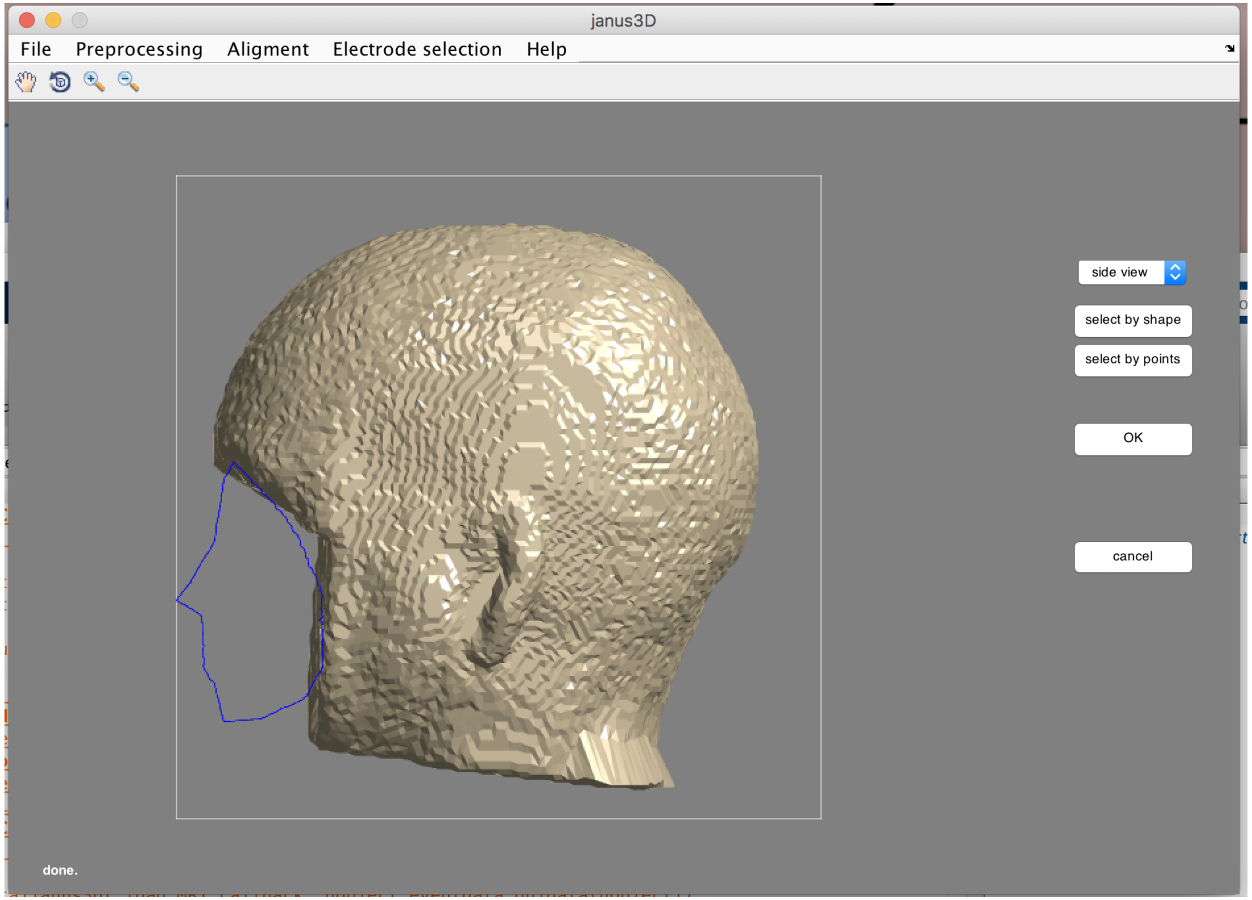


Figure 38. Defacing the MRI scan

6. Now choose “Align model”. You can choose either one of the two sets of settings. You might want to try what settings work best for your model.
7. Figure 39 shows the manual alignment of the model and the scan. If your MRI scan is not defaced, this will work better. You will be able to manually correct it after the manual alignment, so it is not an issue if the alignment does not look perfect yet. If the alignment does not work, the issue might be the de-facing process, so you might want to try this again.

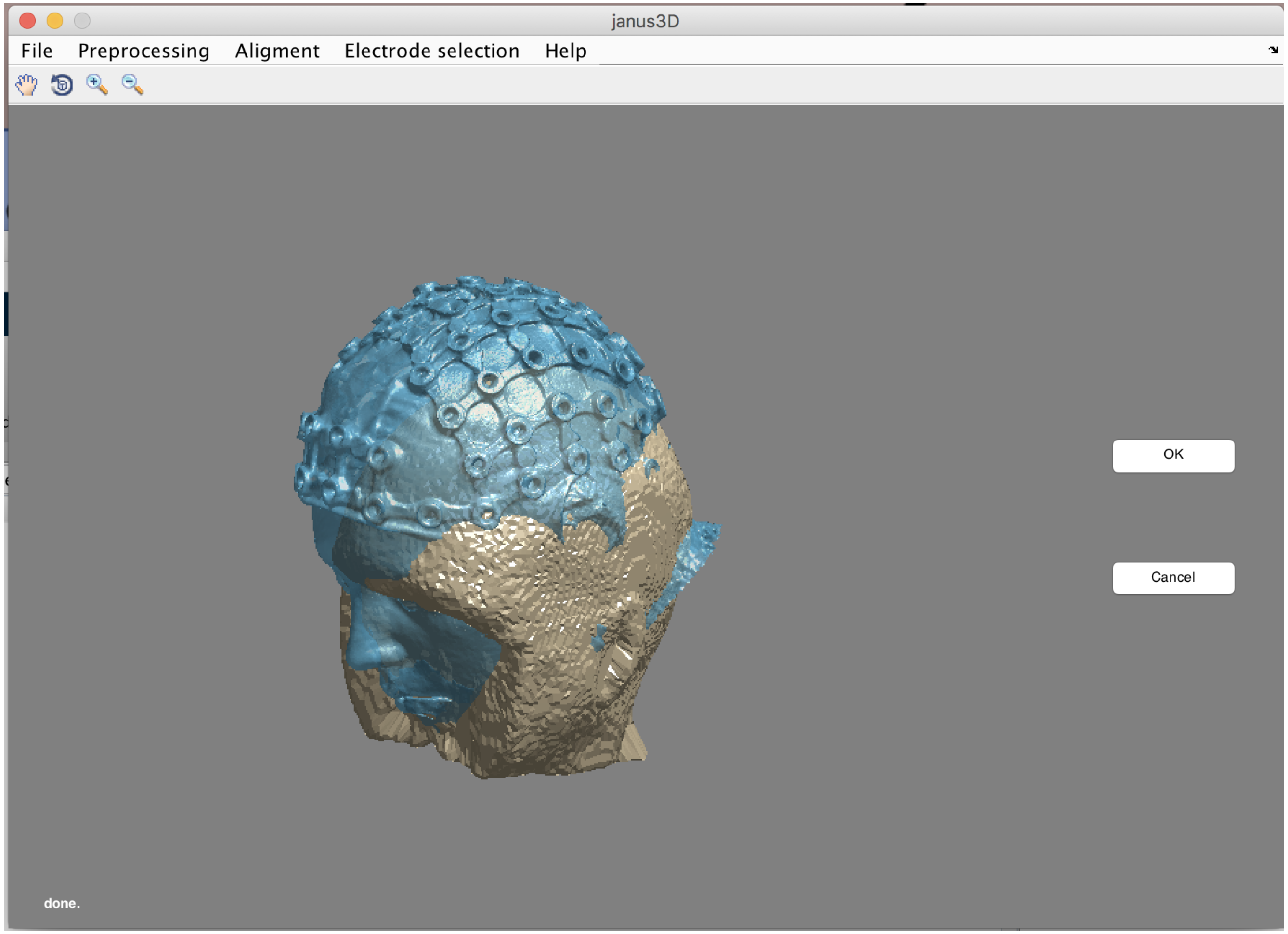


Figure 39. Alignment of the 3D model and MRI scan

8. Correct the alignment if necessary. On the right side of the screen you will find the T (location), R (rotation) and scale (size) settings to move your 3D model (Figure 40). Adjust the model until it fits onto your MRI scan. If you need to use the scale option to increase the size of your

model, start with a low number such as 1.1 which will increase the size by 10% and see whether this may already be enough. Use the ear or the nose as a landmark. Press OK when done.

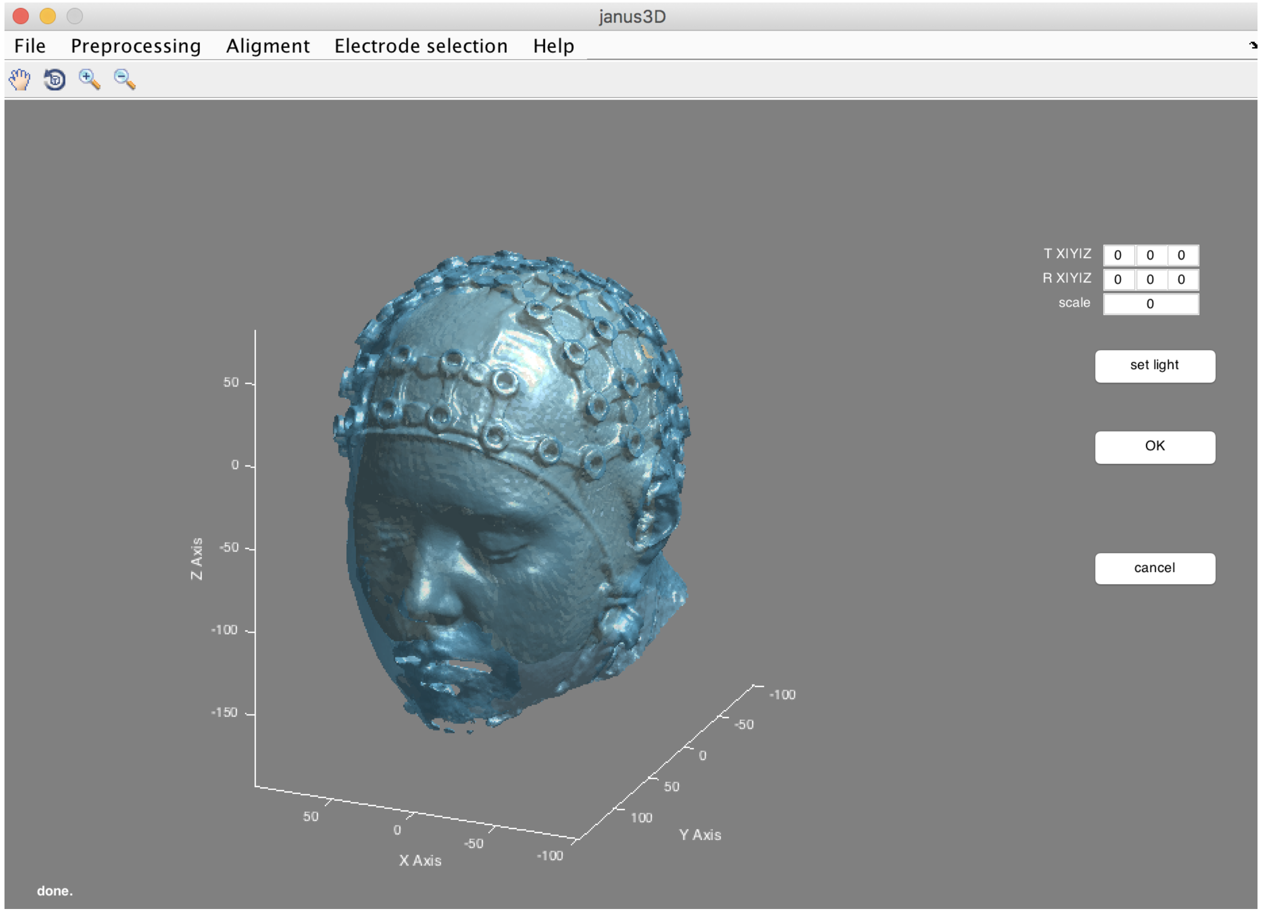


Figure 40. Manuel correction of alignment

9. Now select "electrode selection". You can choose between manual or automatic detection depending on the contrast of your model. With a rather high contrast between the electrode position and the cap the automatic detection works well. Otherwise you might need to use the manual

detection (i.e. you can expect this for optodes, depending on the contrast of the cap). This will also allow you to add labels to your optode positions.

10. For automatic detection adjust the lighting if necessary and press accept to manually select one optode position. Then double click. The software will now automatically detect the positions. If the software did not detect all positions or some errors occurred click "collect" and manually correct the positions by left clicking for adding and right clicking for deleting. You want to select the center of each optode position.

    Note: We mainly did the optode detection manually (Figure 41). To do so, first add your texture. Click "add texture" and select your exported .png file from Metashape. Then press "free" and click on your desired position, then enter a label in the label field and press enter. Do not click "Add", as this will end your process. After detection of all your optodes press "merge" and then press "add", otherwise your optodes will only show on the model but not on the scan. If you accidentally placed an optode, right click to remove it. An optode is placed with every click, even if you do not see it.

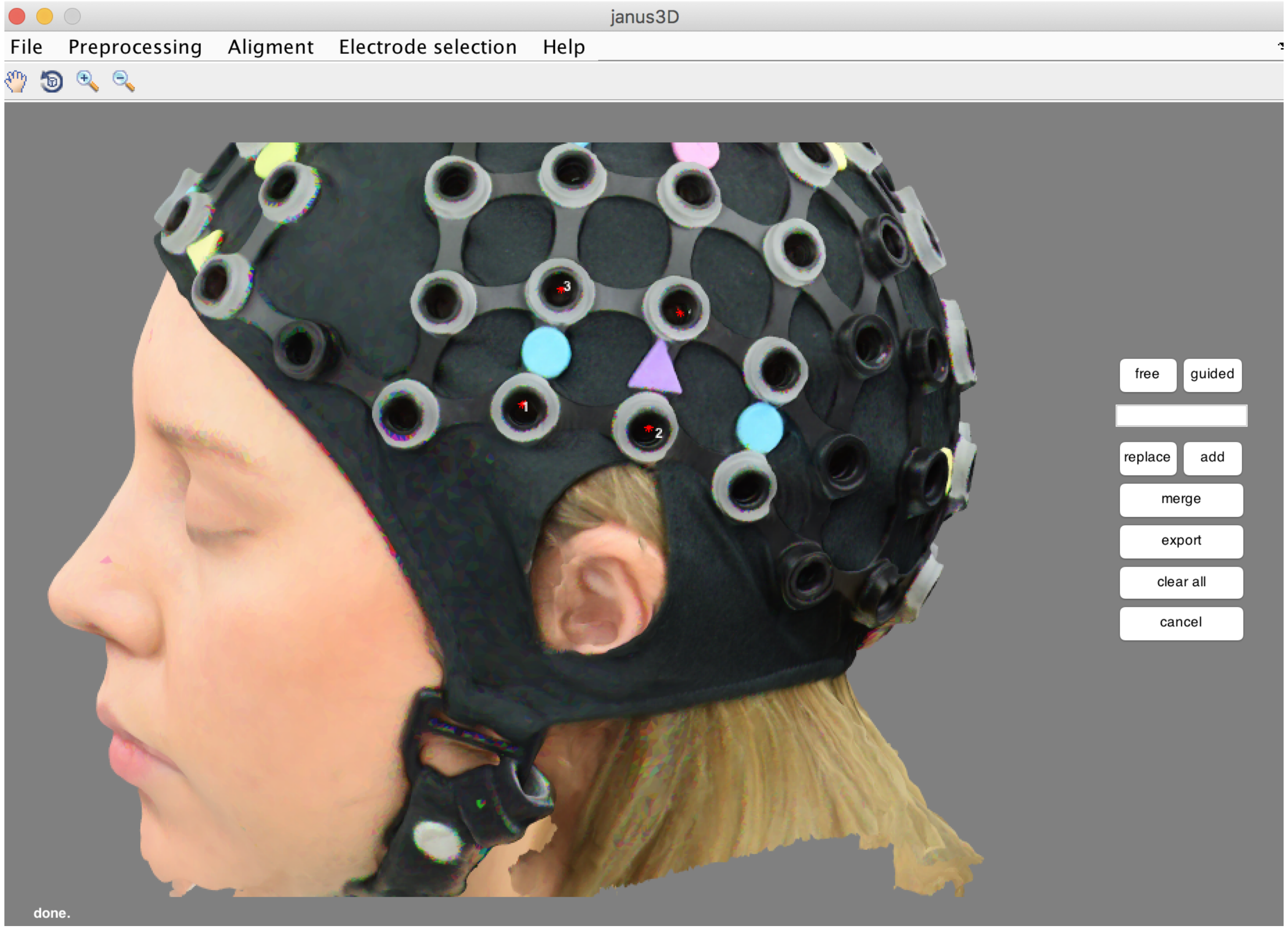


Figure 41. Manual optode selection

11. Choose "Electrode selection", "Show electrodes" to view the final optode positioning (Figure 42).

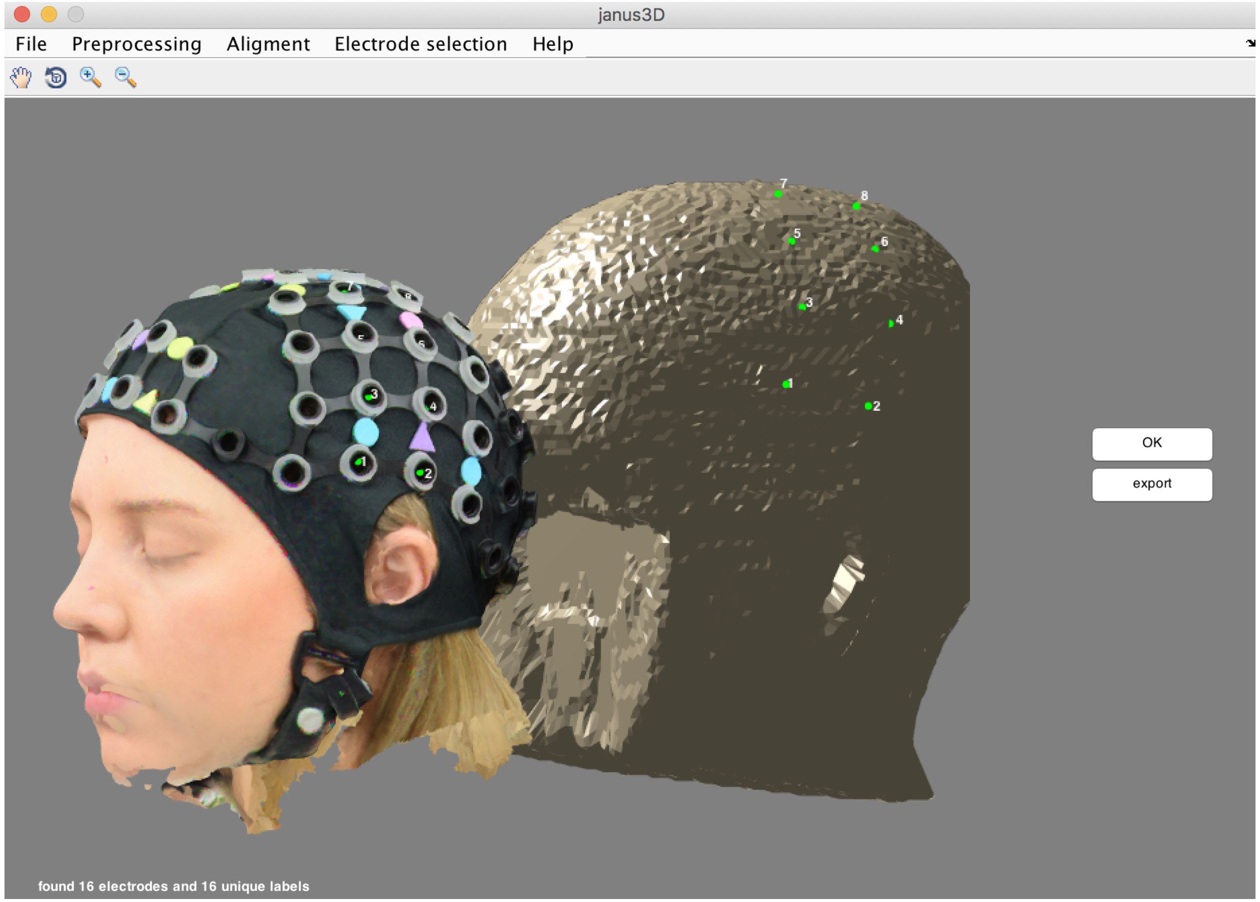


Figure 42. Final result of coregistration in janus3D

12. Export as .mat file. To do so, click on "export" on the "Show electrodes" screen. Do not export the optodes from the "manual detection" screen.
13. Next, open the generated .mat file in Matlab and use the following (or similar) code to extract the labels and positions as a .csv file. This file will allow the spm-fnirs toolbox to read the positions of your optodes. Instructions to the spm-fnirs toolbox can be found here.

colNames ={'Optodes'};

cell2table(Electrodes.MRI.label(:, 1));

Properties.VariableNames{'Var1'} = 'Optodes';

cell2table(num2cell(Electrodes.MRI.points(:, 1:3)));

c= [a b];

writetable(c, 'sub_X_ses_X_optodes_mri.csv')

5 Issues we encountered and how to address them

Using janus3D and Metashape for the Photogrammetry requires some patience and trial-and-error. It took us a bit of time to find the right settings and angle for the pictures and Metashape, and a few more days to coregister the 3D model with the MRI brain scans in janus3D. Also this procedure is time intensive. You may expect the whole process, from taking pictures, to building the model, to coregistering the brain scans to take anywhere between one to three hours, depending on the capacity of your computer.

The most frequently encountered issues at each step are listed below:

1. **Taking the pictures**

   Getting the right angle at the top of the head was difficult, especially for taller subjects. This worked better when the subject was sitting rather close to the camera.

2. **Creating the model in Metashape**

   Getting the right settings and aligning the cameras was complicated at first. We did get good results with the final settings as described here.

3. **Coregisteration in janus3D**

The coregistration in janus3D only works with Matlab version 2015a due to the software requirements of janus3D. This version isn't available on the Matlab website anymore but the IT at your institution might be able to help. We also received a lot of errors at the beginning because our model did not have enough 'faces'. We solved this with changing the settings in Metashape.

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References

Agisoft. (8. July 2019). *Agisoft*. Retrieved from https://www.agisoft.com/downloads/installer/.

Clausner, T., Dalal, S., & Crespo-García, M. (2017). Photogrammetry-based head digitization for rapid and accurate localization of EEG electrodes and MEG fiducial markers using a single digital SLR camera. *Frontiers in Neuroscience*, 1-12.

Janus3D. (8. July 2019). *Github*. Retrieved from https://github.com/janus3D/janus3D_toolbox/blob/master/janus3D_users_manual.pdf.

Steinmetz, H., Fürst, G., & Meyer, B. U. (1989). Craniocerebral topography within the international 10–20 system. *Electroencephalography and clinical neurophysiology*, *72*(6), 499-506.