Streamlined Cochlear Image Analysis: Enhancing an AI-Powered Tool for Large-Scale Population Statistics and Accurate 3D Modelling

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Introduction

Accurate modelling of cochlear anatomy is crucial for successful cochlear implant operation planning and therapy. Nautilus[1] is a web-based imaging pipeline for the field of otology and cochlear implantation that allows to:

- **Extract 3D models of cochlear structures** (scala tympani and vestibuli, basilar membrane…) from clinical CT/CBCT images.
- **Compute cochlear measurements** (A, B, height, two-turn length, cochlear duct length, rollercoaster, wrapping factor and ratio,…).
- **Extract geometry of the electrode array and evaluate its placement** within the cochlea (trauma estimation, localization within the cochlea…).
- **Estimate patient-specific tonotopy mapping** (Stakhovskaya 2007, Helpard 2021, Greenwood).
- **Export the data for large scale studies** and **3D printing of patient specific models** for electrode array design.

Automatic tools for inner-ear image analysis, often require manual inputs such as placement of cochlear landmarks (center, apex, round window), specify the side of the cochlea (right / left), specify the status (pre- / post-operative image).
These are time-consuming, require skill reading radiological images, and are frequently inconsistent, preventing us from processing large amounts of data.
Furthermore, uploading the entire input image to a server might raises other challenges, e.g., patient privacy concerns or slow upload times.

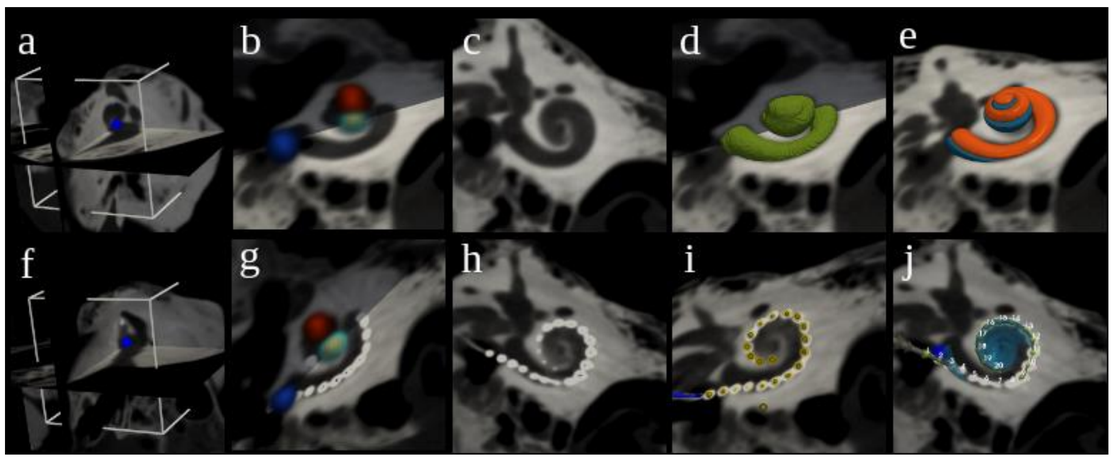
Validation

We validated our tool on a dataset of more than 1000 cochleae to demonstrate its effectiveness in processing large datasets. We took into consideration the upload time of the cropped 3D region around the cochlea compared to the entire scan, and the precision of the automatic extraction of metadata.
A study used this tool on a dataset of 1100 cochleae measured variability of common cochlear measurements[2] and discovered interesting correlations between anatomical measurements challenging the current literature.

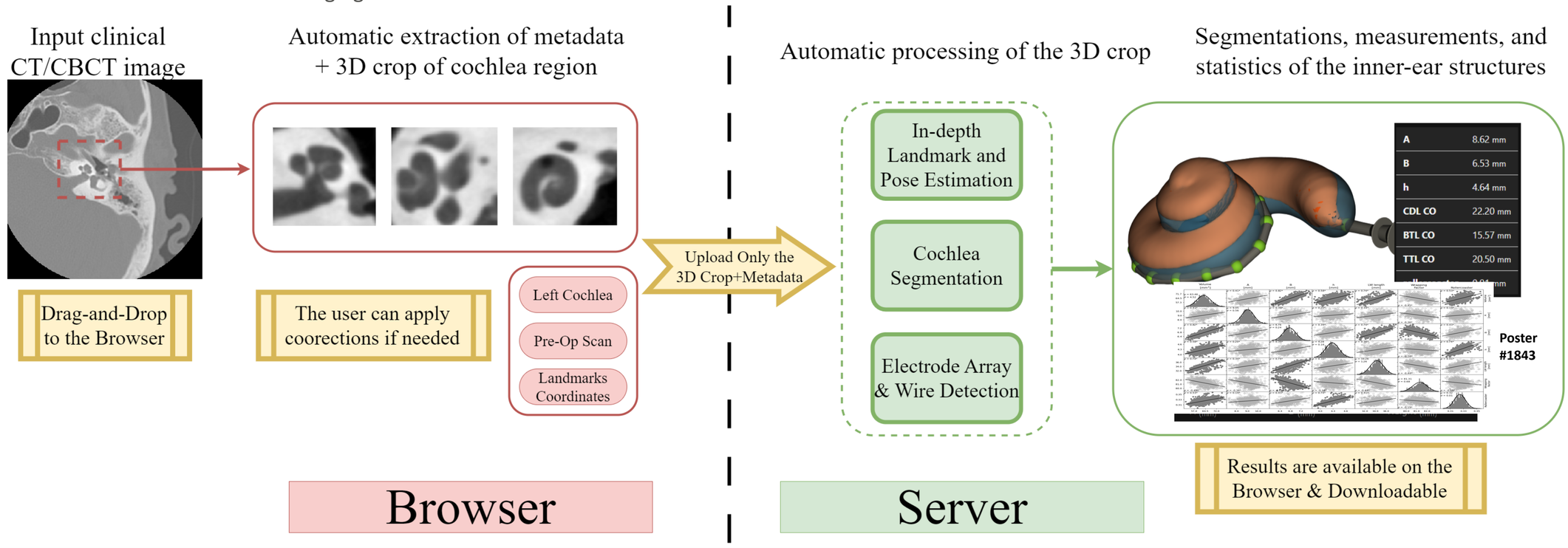
Methodology

In this work, we present a fully automated pipeline for inner-ear imaging analysis built for large-scale analysis.

- Using AI-powered and **Deep Learning** based techniques, we propose a fast and secure pipeline that requires minimum patient data upload.
- With an **intuitive user-friendly GUI** and simple drag-and-drop image files onto the web-browser window, this pipeline is open to a much wider audience, possibly with less experience in reading radiological images.
- Such a **fully automated pipeline** allows the **processing of a large amount of data** efficiently by removing the bottleneck manual inputs, satisfying the needs of "Big-Data" processing criteria, reproduce previous studies or run new ones.
- Allow interactive visualization tools and data exploration of the cochlear dataset.



Nautilus processing steps: Region of interest and metadata are detected on the pre- and post-operative images (a, f), landmarks (center, round window, apex) are detected (b, g), pre- and post-operative images are aligned (c, h), pre-operative image is segmented and 3D models are extracted (d, e), the electrode array is localized from the post-operative images (i), measurements are computed, and electrode array position can then be evaluated (j). The final data bundle can be then exported.



Results

Cochlear segmentation Dice= **86%**

Uploading time is reduced drastically.
E.g.: Entire CT scan Vs. 3D Crop
Size: ~ **200 MB** Vs. ~ **10 MB**
Time: ~**10 seconds** Vs. ~**0.5 second**

The precision of Automatic Metadata :
Left/Right cochlea classification= **98%**
Pre/Post Operational classification= **93%**
Detected ROI distance error= **2 mm**

Conclusion

Our work shows the potential of artificial intelligence techniques in advancing cochlear image analysis for implant therapy. We trained deep learning-based models on a large dataset to automate the common steps when handling cochlear images. We show that significant reduction of user interaction is possible and the analysis of clinical cochlear images can be fully automated. These state-of-the-art machine learning tools are accessible through a simple interface available through any modern web browser. The proposed solution is fast, secure and easy to use. All this combined allows processing of large datasets and opens cochlear image analysis to a much wider audience, possibly with less experience with reading of radiological images.

Nautilus extracts most of the commonly used pre-operative measurements and post-operative evaluation of the electrode placement location and patient specific tonotopy is computed. The extracted data can be exported into data bundles for further analyses. Such streamlined process lets us all revisit previous studies and support them with both smaller and much larger datasets and discover new relationships within cochlear anatomy [2][3] and challenge our assumptions.

Read more about papers using this tool

Contact us to run your next study in Nautilus

References

[1] Margeta et al. "A Web-Based Automated Image Processing Research Platform for Cochlear Implantation-Related Studies".

[2] Hussain et al (2023) "Anatomical Variations of the Human Cochlea Using an Image Analysis Tool".

[3] Danieli et al (2023) "The Effects of Multi-Mode Monophasic Stimulation with Capacitive Discharge on the Facial Nerve Stimulation Reduction in Young Children with Cochlear Implants: Intraoperative Recordings".

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