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A-Mode Ultrasound Based Registration for Minimally Invasive Cochlear Implantation

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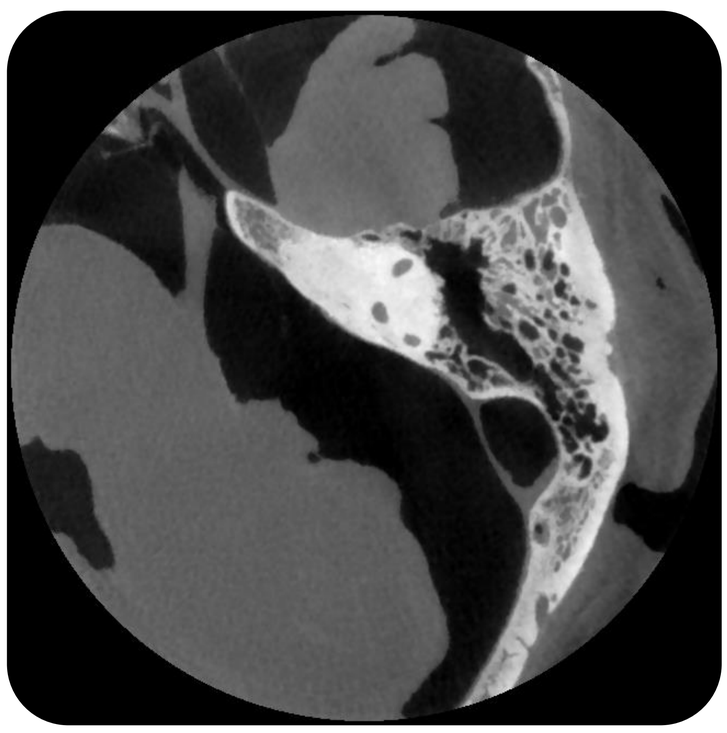
Introduction

Registration remains one of the most significant sources of error during image guided surgical procedures. Achieving an accurate registration from patient to image is particularly important during procedures in which high accuracy is required, such as minimally invasive cochlear implantation, in which a tunnel is drilled from surface of the mastoid to the inner ear, closely bypassing a number of vital structures. To date the only methods capable of providing suitable registration accuracy for this procedure utilize invasive fiducial screws. This work posits that similar accuracies are possible using non-invasive A-Mode ultrasound by identifying and addressing each of the individual sources of error that influence the registration process.

High Resolution Imaging of the Head

The ability to accurately delineate structures within medical imaging data is determined in large part by the resolution of the imaging device used. Cone beam CT provides isotropic resolutions as high as 0.1mm. The availability of high resolution images is expected to significantly lower the overall registration error by allowing accurate segmentation of the bone surface.



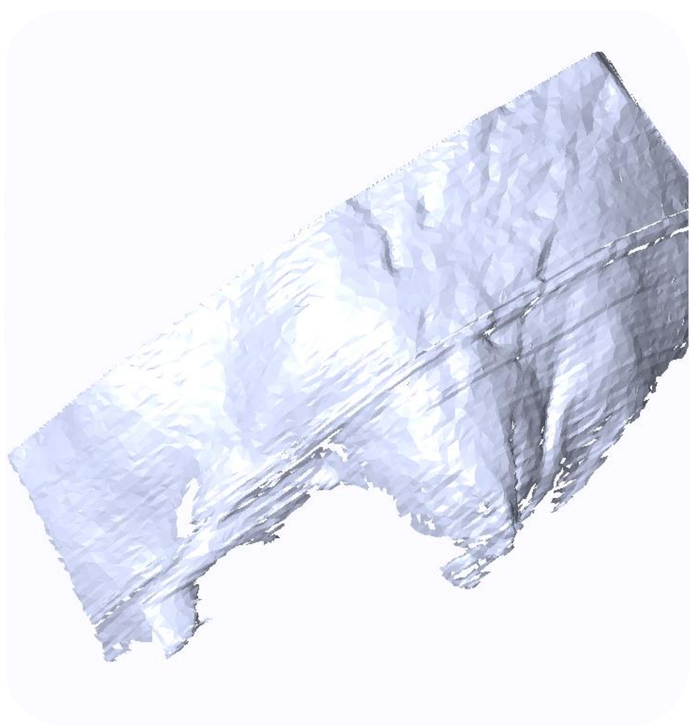
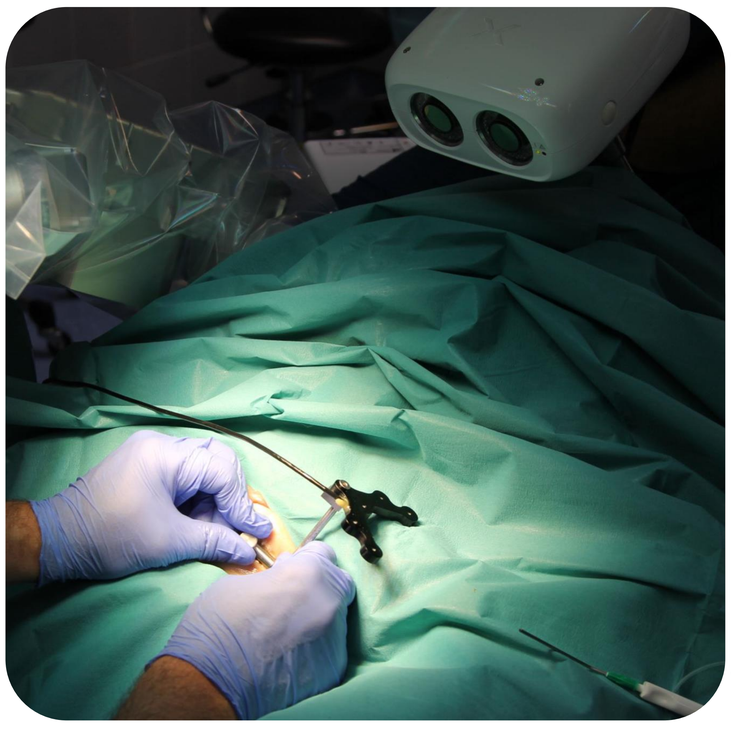


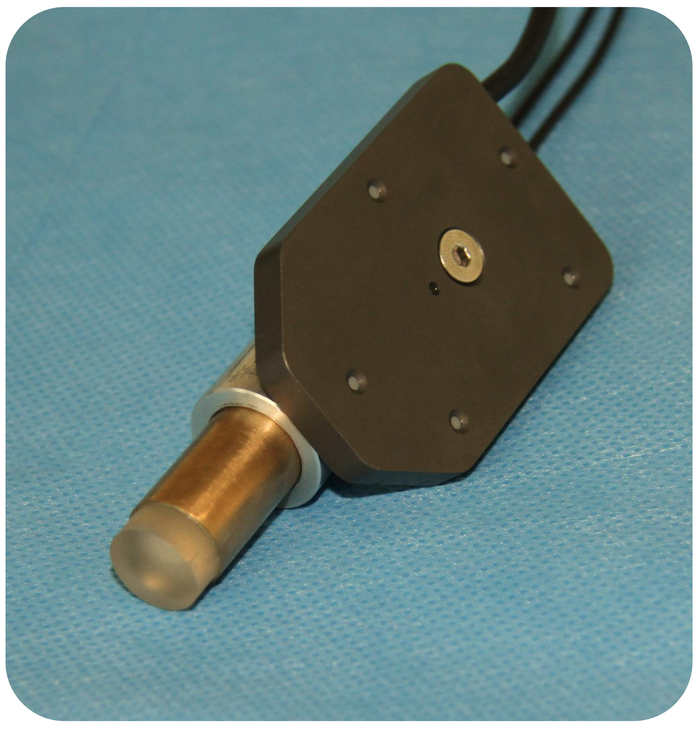
Image Segmentation and Model Creation

The segmentation of the outer surface of the skull can be completed utilizing a variety of methods, including simple thresholding and Marching Cubes image processing techniques. While this automatic approach provides reasonable accuracy, it is dependent on the selection of a suitable threshold value and, as such, more advanced methods are currently under investigation.

High Accuracy Transducer Tracking

The use of a high accuracy tracking system is expected to contribute significantly to the achievement of high accuracy ultrasound based registration. Recent evaluation of the combination of optical tracking and ultrasonic surface detection in a simple water bath phantom revealed that surfaces could be detected with accuracies of approximately 0.05 mm.



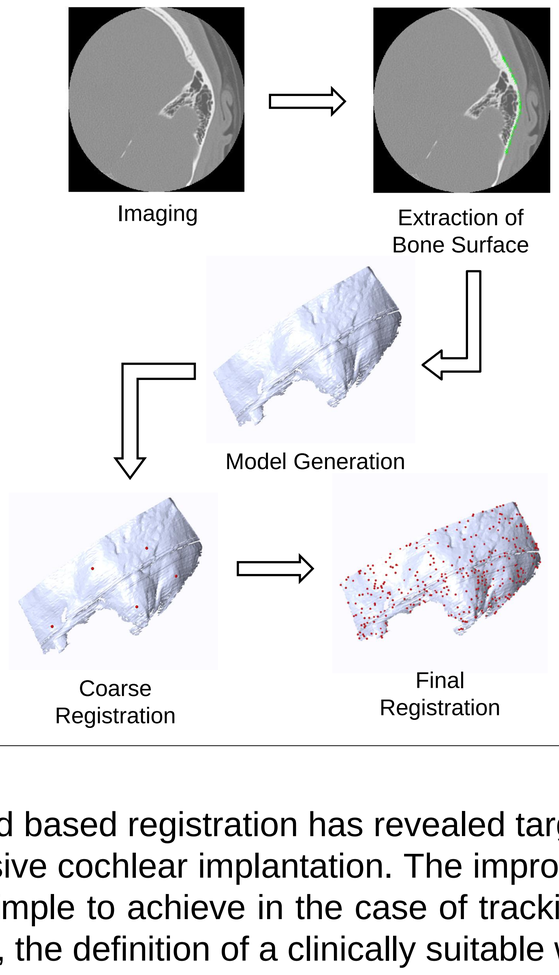


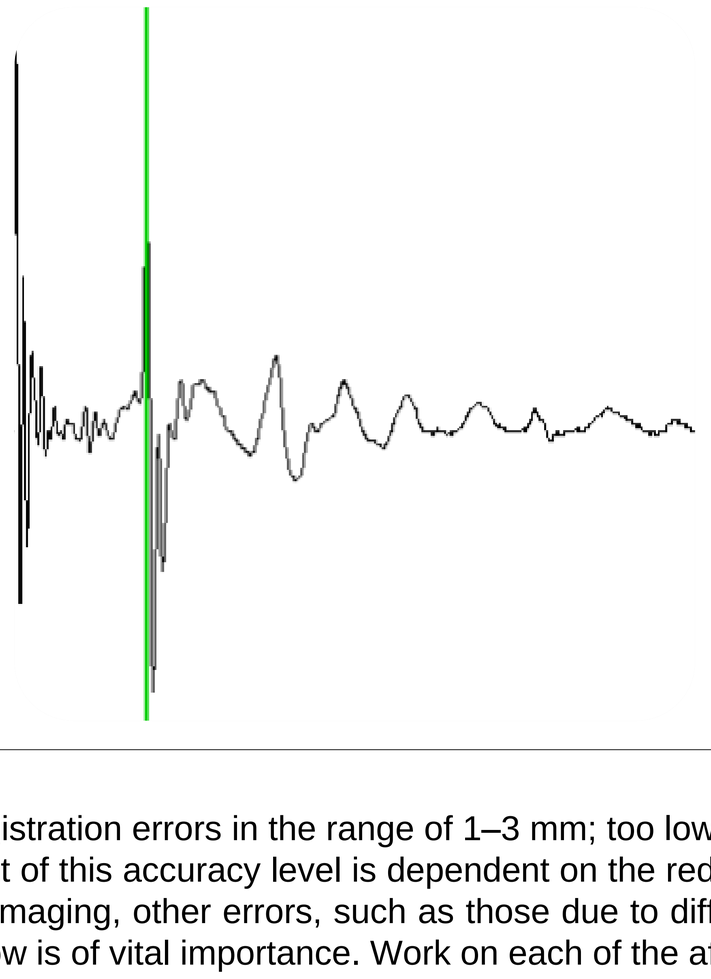
Probe Design and Signal Calibration

A custom ultrasonic transducer, designed specifically for the detection of bone/soft tissue interfaces at depths between 0.5 mm and 10 mm, was recently developed in collaboration with experts at Optel Ltd, Wroclaw, Poland. Depth calibration can be achieved through the utilization of calibration phantoms of known thickness and material.

Probe Alignment and Intra-Operative Workflow

The intra-operative workflow must be fast and simple for the surgeon to perform. The proposed workflow involves an initial coarse registration of four landmarks, followed by the iterative acquisition of additional surface points and matching. This allows feedback to be provided to the surgeon about the ideal probe orientation during the process; reducing error and increasing usability.





Tissue Type and Speed of Sound Variation

Sound velocity varies greatly between the various tissue types found within the human body. These variations lead to deviations in the detected bone surface depth, introducing further error. The effects of these errors can be reduced by utilizing weighted surface matching techniques; the significance of regions in which these errors are high may be reduced, ensuring higher registration accuracy.

Discussion

Previous work on A-Mode ultrasound based registration has revealed target registration errors in the range of 1–3 mm; too low to be suitable for high accuracy applications such as minimally invasive cochlear implantation. The improvement of this accuracy level is dependent on the reduction of errors from a variety of sources. While improvements are simple to achieve in the case of tracking or imaging, other errors, such as those due to differences in sound velocity, must be dealt with indirectly. Furthermore, the definition of a clinically suitable workflow is of vital importance. Work on each of the aforementioned areas is ongoing.