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A clinically valid simulator with tactile sensing to train specialists to perform cochlear implantation

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A Clinically Valid Simulator with Tactile Sensing to Train Specialists to perform Cochlear Implantation

by

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B. Eng. Electrical (Hons.)

This thesis is submitted in fulfilment of the requirements for award of the PhD degree from the University of Wollongong, Australia

School of Electrical, Computer and Telecommunications Engineering

Faculty of Informatics

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"*I saw the angel in the marble*

and carved until I set him free."

~ Michelangelo (1475 - 1564)

DECLARATION

I hereby declare that I, Catherine Angela Todd, am the sole author of this dissertation. I declare that the material contained within this thesis is my own work and that referenced work is appropriately cited. I also declare that I am not aware of any similar work undertaken prior to the submission of this thesis.

Catherine Angela Todd

June 2006

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ABSTRACT

Cochlear implantation is a maximally invasive surgical procedure aimed at overcoming human inaudibility and providing the sensation of sound to thousands of severely deaf recipients worldwide. Specialists require extensive training to perform the surgery, yet traditional approaches such as cadaver dissection and device insertion can prove costly. Alternative training schemes have not been developed, however surgical simulators that offer force feedback during anatomical model manipulation may provide the answer.

In the work, a novel approach to medical education is presented. It combines haptic technology and computer visualisation to recreate cochlear implantation in a virtual environment. The surgical simulator provides visual and haptic rendering during cochlear implant insertion into a virtual model of the human Scala Tympani. As the user inserts the sub-sampled array into a three-dimensional, reproducible representation of the Scala Tympani, collisions between the electrode and Scala Tympani walls are detected. In response, real-time forces are delivered back through the haptic device in a closed loop control system.

Insertion studies are performed to evaluate the cochlear implant insertion process. Electrode array trajectories and output forces are monitored during device insertion into a synthetic model of the Scala Tympani. The force, torque and position data produced from the experiments are used in the final stage of work for simulator validation.

A three-dimensional, surface description of the human Scala Tympani is derived from measured data and parameterised for future reproduction. It is visualised in a virtual environment, the Reachin Application Programming Interface, where visual and haptic rendering is implemented to make the insertion process interactive. Algorithms are

produced and program optimisations performed to enable real-time, dynamic manipulation of the environment. Real world physical attributes are added to the Scala Tympani surfaces and electrode carrier to make the scene more realistic.

System validation is performed by statistical and qualitative comparisons between the force profiles produced from the simulation and experimentation. The results are presented and evaluated in terms of overall system performance.

The thesis offers unique approaches for simulator design, development and validation. The significant contributions of the work are reported, as are the benefits, with recommendations for future system enhancements.

THESIS PUBLICATIONS

1. C. Todd and F. Naghdy, “Virtual Cochlear Implantation”, to be presented at the 9th International Conference on Cochlear Implants, Hofburg, Vienna, Austria, 2006.

2. C. Todd and F. Naghdy, “Cochlear Implant Insertion: A Virtual Approach for Medical Education”, presented at the 6th Annual International Meeting on Medical Simulation (IMMS 2006), pp 564-567, San Diego, California, United States of America, Society for Medical Simulation, 2006.

3. C. Todd and F. Naghdy, “Virtual Cochlear Implant Insertion for Medical Education”, presented at World Haptics Conference (WHC 2005), Piza, Italy, IEEE Computer Society, 2005.

4. C. Todd and F. Naghdy, “Parametric Model of the Scala Tympani for Haptic-Rendered Cochlear Implantation”, presented at Medicine Meets Virtual Reality 13 (MMVR 2005), pp 564-567, Long Beach, California, United States of America, IOS Press, Netherlands, 2005.

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List of Abbreviations

F_F	Force Due to Friction
F_{in}	Input Force
F_n	Normal Force
μ	Coefficient of Friction
3D	Three Dimensional
API	Application Programming Interface
AOS	Advance Off- Stylet
BM	Basilar Membrane
CI	Cochlear Implant
CP	Cochlear Partition
CT	Computed Tomography
DOF	Degree of Freedom
ENT	Ear, Nose and Throat
FEM	Finite Element Model
GUI	Graphical User Interface
IW	Inner Wall
MFS	Method of Finite Spheres
MIP	Maximum Intensity Projection
MRI	Magnetic Resonance Imaging
MRM	Magnetic Resonance Microscopy
OC	Organ of Corti
OSL	Osseous Spiral Lamina

OW	Outer Wall
ROI	Region of Interest
RW	Round Window
SFM	Scanning Force Microscopy
SIT	Standard Insertion Technique
SM	Scala Media
ST	Scala Tympani
SV	Scala Vestibuli
VBA	Visual Basic for Applications
VE	Virtual Endoscopy
VRML	Virtual Reality Modelling Language
VTK	Visualization Toolkit