Registration of 3D surface images with pre-operative CT/MRI for use in stereotactic robotic neurosurgery

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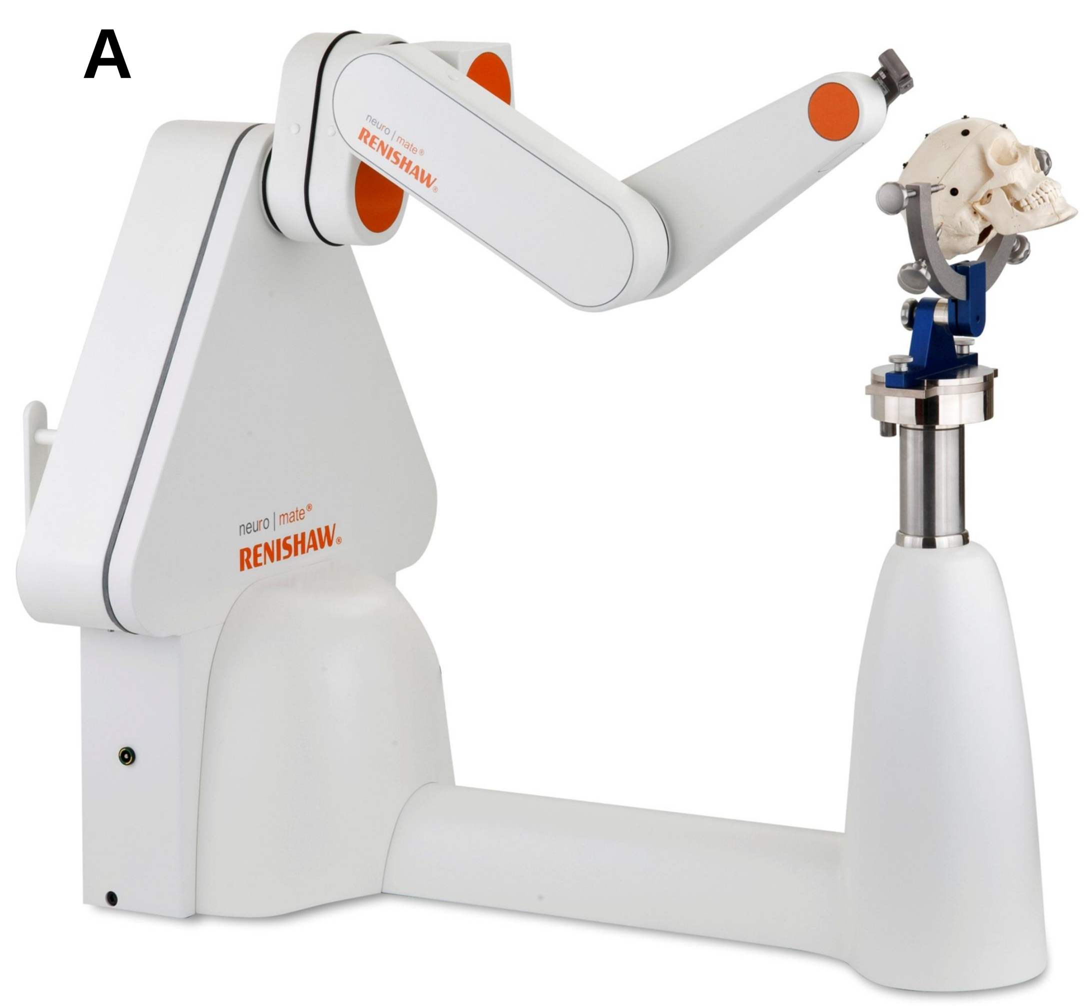
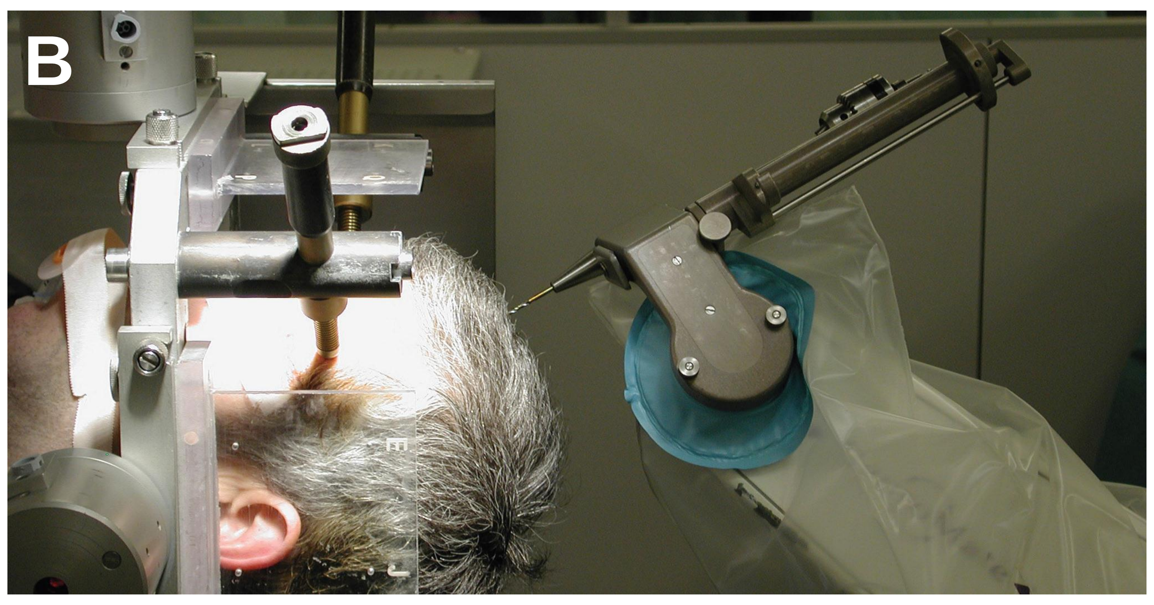
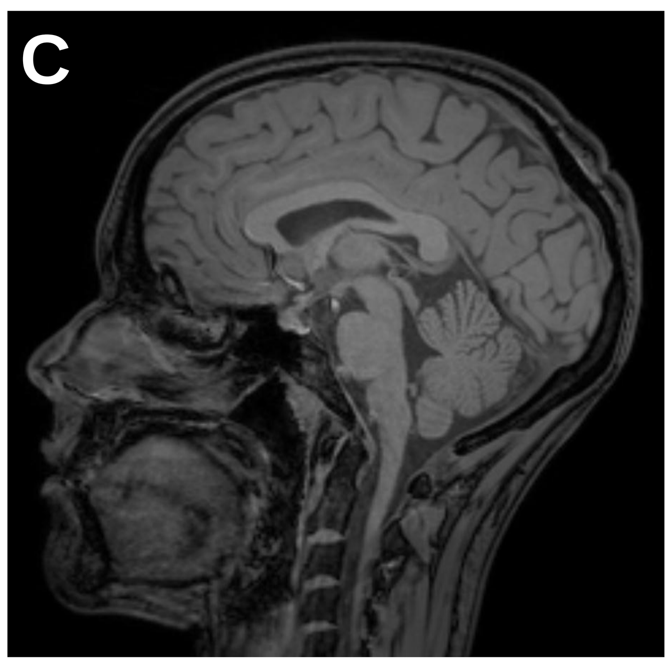
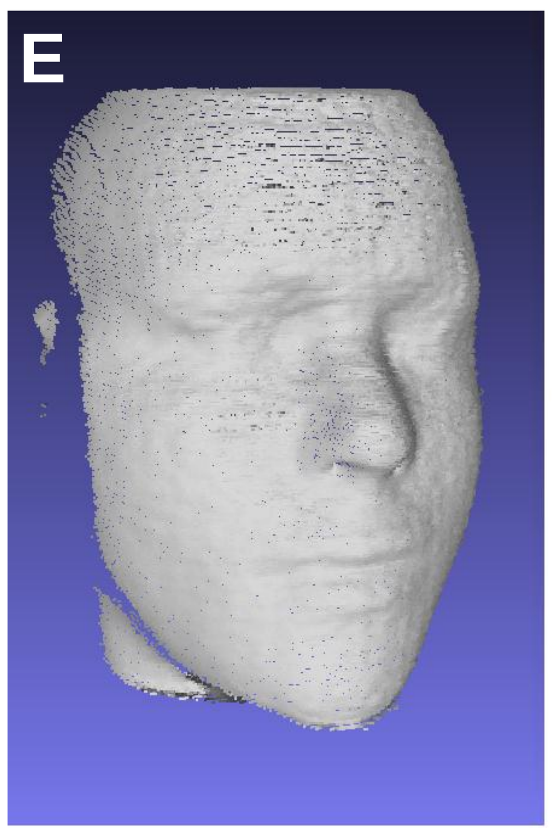
Introduction: Stereotactic neurosurgical robots (A, [1]) are used to reach and perform surgery on small targets within the brain. Targets are located on preoperative images and the robot end effector is moved to the coordinates specified: this requires the robot's coordinate system to be accurately registered with the patient's, and with the preoperative images. Registration is performed using either a stereotactic frame (B, [1]) or fiducial markers as landmarks. During surgery the patient's head is kept fixed in position. The object of this research is to perform image-based registration of the head during surgery with pre-operative CT/MRI images (C) and the robot coordinate system, allowing the head to be moved and easily re-registered at any point during surgery. Preliminary work has been done using a phantom head (D).









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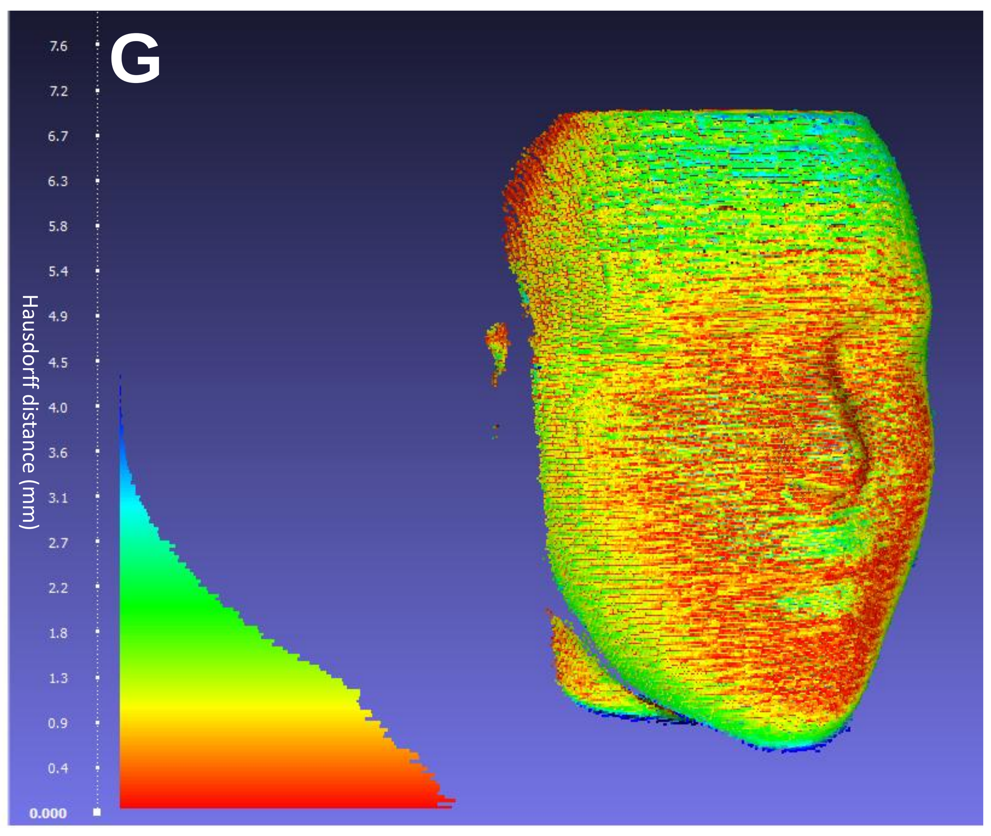
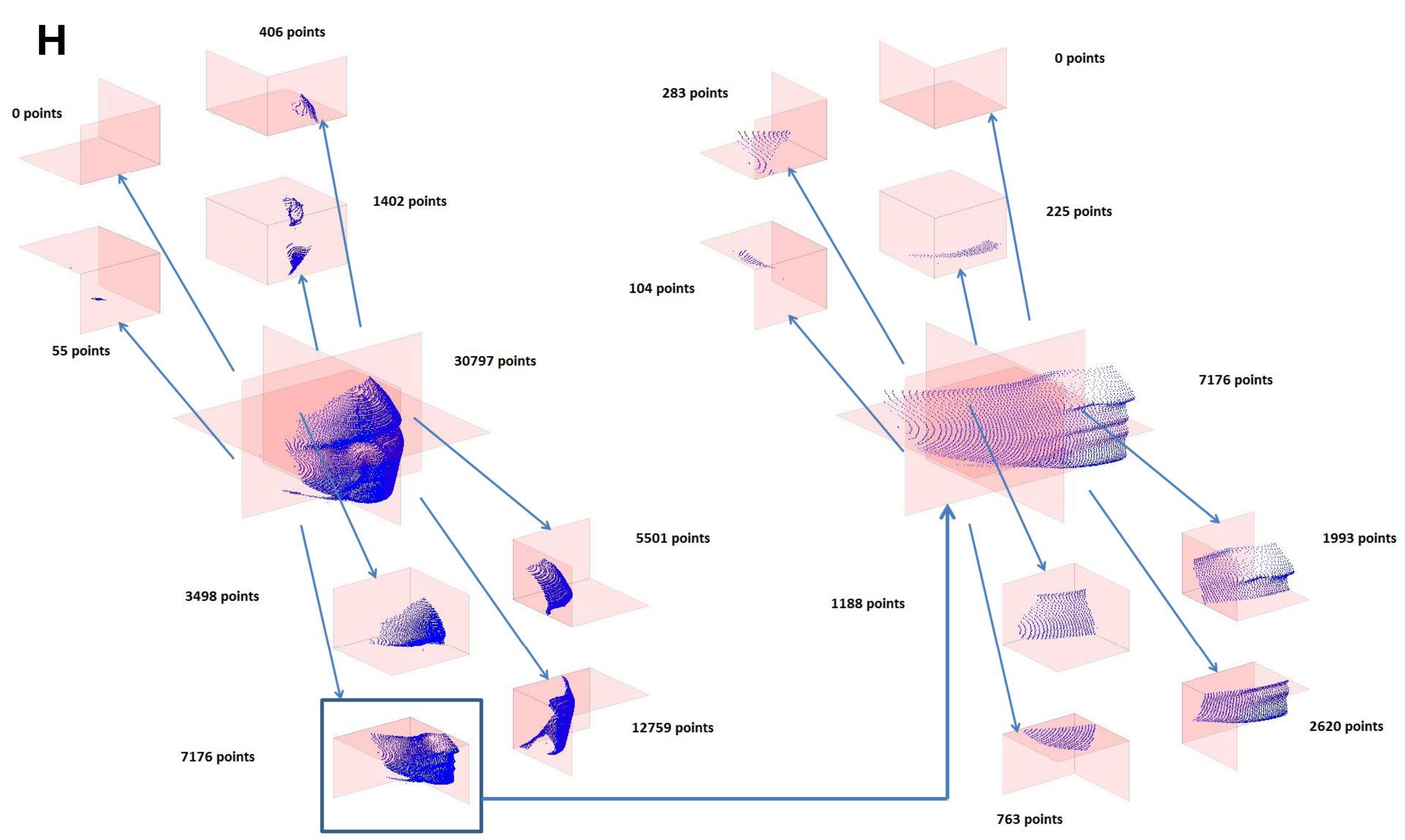
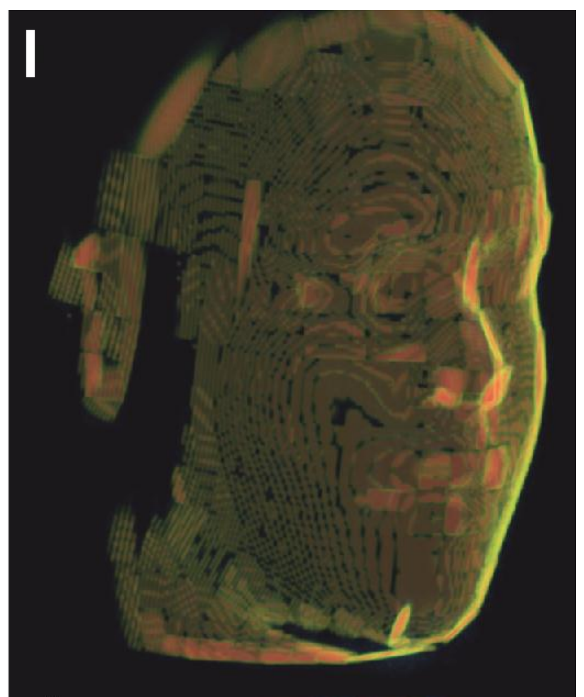


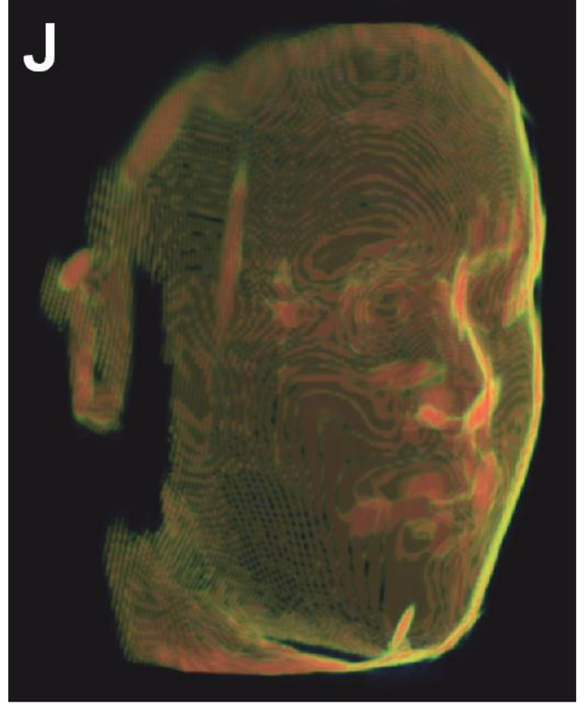
Registration: 3D imaging systems can be used to produce a point cloud of the head: a set of data points comprising the coordinates at which the surface has been measured by the system. This can be done using structured light (used here, [3]) or time-of-flight systems. The resulting point cloud must then be registered with preoperative images.

Preliminary testing of registration algorithms was done by registering point clouds (E) taken of the phantom to the ground truth (F) and measuring the Hausdorff distance between the two (G). The registration shown here was performed using the Iterative Closest Point (ICP) algorithm.

3D Normal Distribution Transform (3D-NDT): Another method of registration uses a probability distribution function representation of the point cloud [3]. The cloud is split into eight equal cells. Each cell containing more than a threshold number of points is then split recursively until each cell contains fewer points than the threshold. The points within each cell are then modelled as a normal distribution and the individual cell distributions are combined to make the 3D-NDT. The distributions can either stop at the cell boundary (I), or overlap (J).







Conclusion: Point clouds of a phantom head have been produced using a 3D surface capture system and successfully registered with the ground truth using ICP. 3D-NDTs have been created from point clouds using various methods. More work must be done to determine the best registration method for this purpose, including testing 3D-NDT registration. During surgery it may only be possible to image part of the head, as the face is commonly covered with surgical drapes; further work will be needed to determine the best way to perform registration without facial features to act as landmarks. It will also be necessary to test the success of the registration algorithms at registering a point cloud to MRI/CT data as well as at registering two point clouds. Work on obstacle avoidance for the robot is also planned.

References: [1] http://www.renishaw.com/en/neuromate-stereotactic-robot--10712. Accessed 09.06.14.
[2] Basevi, H. R., Guggenheim, J. A., Dehghani, H., & Styles, I. B. 2013. Simultaneous multiple view high resolution surface geometry acquisition using structured light and mirrors. Optics express, 21(6), 7222-7239.
[3] Magnusson, M. 2009. The three-dimensional normal-distributions transform: an efficient representation for registration, surface analysis, and loop detection. Örebro universitet.

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