PhD Thesis Title: 'Research on Spatial Registration Theory and Algorithms for Neuronavigation'

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ABSTRACT:

Image-Guided Neurosurgery System(IGNS) uses the preoperative image data of a patient to locate and guide the surgical operation. It helps the doctors to improve the quality of neurosurgery and reduce the postoperative complications. IGNS has become an indispensable instrument in minimally invasive neurosurgery. In this thesis, we analyzed the advantages and disadvantages of the spatial registration methods used in current IGNS, and carried out the researches according to the shortcoming of current surface-matching methods and the clinical needs. We proposed and tested a series of feasible methods which can be applied to clinical application, and their registration accuracies all meet clinical requirements. This thesis includes the following parts:

i) In order to solve the problem of low registration accuracy in the posterior part of the head, we proposed a spatial registration method using a high resolution portable scanner to obtain the point cloud of the patient's entire head surface to perform the spatial registration. Both the accuracy and the stability of the surface-matching method were improved. We utilized the scanner's function of recognizing specific positioning targets to implement a method that can transform the coordinates of the scanned points from the device space to the patient space without calibration and tracking. We used anatomical landmarks to register the patient space to the image space roughly. After that, we utilized the results of the coarse registration and the threshold algorithm to remove the background, noise and outliers in the scanned point cloud. Finally, we used an improved Iterative Closest Point (ICP) algorithm to finish the fine registration.

ii) In order to solve the problem that a coarse registration based on manually selected anatomical landmarks is needed in current surface-matching methods, we proposed an automatic coarse registration method based on 4-Points Congruent Sets (4PCS) algorithm to improve the stability of the coarse registration and speed up the whole registration process. The 4PCS algorithm, which is resilient to noise and outliers, is able to register two point clouds without any assumptions about starting alignment. To speed up the registration, we extracted some key points of the original point clouds in the patient space and the

image space. These key points consisted of sparse point clouds in the two spaces. The 4PCS algorithm automatically registers the two sparse point clouds and an improved ICP algorithm then finished the fine registration.

iii) A common surface-matching method is composed of a coarse registration phase and a fine registration one. We proposed an automatic surface-matching spatial registration method based on Go-ICP(Globally Optimal ICP) algorithm without coarse registration. The Go-ICP algorithm is built upon ICP algorithm, but combines it with a branch-and-bound algorithm. The ICP algorithm acts as a subroutine of Go-ICP. The branch-and-bound algorithm not only helps the ICP algorithm to jump out of local minima, but also provides a guidance for the next search of ICP algorithm. The ICP algorithm accelerates the convergence of branch-and-bound, hence improves the overall efficiency. Although the registration accuracy of this method is lower than that of the previous method, this no coarse registration method can also meet clinical requirements.

In summary, in order to solve the problem of low registration accuracy in the posterior region of the head, we proposed to use a hand-held scanner to obtain the point cloud of the entire head surface to register the two spaces. Both the registration accuracy and the stability were improved. To avoid a manual coarse registration, we proposed an automatic coarse registration method based on 4PCS algorithm, and both the stability and the automatics of the coarse registration were improved. In addition, we proposed a spatial registration method based on Go-ICP algorithm without coarse registration, and the registration accuracy could meet the clinical needs.

References to author publications that relate specifically to the dissertation:

1. Yifeng Fan, Dongsheng Jiang, Manning Wang and Zhijian Song. A new markerless patient-to-image registration method using a portable 3D scanner. Medical Physics 41(10):101910. DOI: http://dx.doi.org/10.1118/1.4895847, 2014.