論 文 の 内 容 の 要 旨

論文題目　Markerless Tracking of Brain Surface by Non-rigid Registration Combining Shape and Texture Information

(形状とテクスチャの情報を用いた非剛体レジストレーションによる脳表のマーカーレストラッキング)

氏　　名　蒋 崛

Brain shift problem during surgery is one of the most challenging tasks that Image Guidance Neurosurgery (IGNS) research is facing today. Reports have indicated brain shift is caused by various reasons such as gravity, drainage of cerebrospinal fluid (CSF), resection of tissue, swelling of brain structure and administration of drugs. According to previous researches, the maximum of brain shift can reach up to 30 mm and the main direction of brain shift is related to gravity direction. Traditional marker based tracking methods try to offer a manual way to compensate brain shift during the surgery but it is an invasive approach and locating of the markers usually need high accuracy.

In order to compensate brain shift, with the development of image technology, intraoperative image data during surgery is adopted into IGNS to assist brain surgery. The intraoperative image data acquiring technologies include intraoperative magnetic resonance (iMR), intraoperative ultra sound (iUS), and intraoperative computed tomography (iCT). Those technologies are high cost and time consuming for clinical application. Recently another technology which compensated brain shift using brain surface registration has been proposed. This technology is noninvasive, cheap and convenient for clinical application. Moreover, the volumetric brain deformation can be inferred by brain surface using mathematical model. Therefore, our research also focuses on the brain surface registration.

Firstly, we implemented a phase-shift method to measure the intraoperative brain surface with texture. The implemented phase-shift method is robust to texture variation and usually generates a dense surface. The measurement system is comprised of a high speed camera (512×512 resolution, IDP Express R2000, Photron Inc.) and a portable laser projector (848× 480 resolution, SHOWWX, MICROVISION Inc.). During measurement, 5 phase-shifted sinusoidal patterns in both vertical and horizontal direction are projected onto the brain surface and the high speed camera captured theses projected pattern images.

After calculating the pixel corresponding between the camera image plane and projector image plane, the brain surface and texture could be obtained through triangulation.

Secondly, we proposed a new non-rigid registration method by integrating shape and texture to track brain surface. Registration method using only shape, such as Iterative Closest Point (ICP) and non-rigid ICP, can cause surface sliding error along the surface since the brain surface is smooth. On the other hand, using texture information for registration can compensate the brain deformation/motion along brain surface direction but the gaps between textures could not be interpolated. Thus, by combining the texture and shape, the proposed method can register the deformed brain surfaces while reducing the surface registration sliding error. In the proposed non-rigid registration method, the texture points were extracted by Frangi filter. Then the whole brain points are divided into texture points group and shape points group. The texture points estimated the corresponding points from the texture points while the shape points estimate their corresponding points from the shape points. After finding closest point pair between the brain surface at original position and the deformed brain surface, vectors of the texture and shape correspondence are given, respectively. In order to constraint the shape deformation smoothly while rigidly, a smoothness constraint and rigidness constraint were introduced for the spatial deformation constraint. The smoothness constraint ensures consistency of transformation matrix within a local neighbor area and rigidness constraint tries to make the deformation rigidly by assuming the transformation matrix to be a rotation matrix. Finally, object motion and deformation are provided by solving a nonlinear square least problem.

Thirdly, experiments on evaluation of 3D measurement accuracy and registration accuracy were conducted in this dissertation. The 3D measurement accuracy was evaluated using 20 metal-sphere balls to evaluate the bias error and precision error. The 3D measurement results showed that both the bias error and precision error increased with the measurement distance increasing. Simulation experiments on the evaluation of curvature, texture frequency, texture direction, divergence deformation and shear deformation with cylinder have also been conducted in this dissertation. Furthermore, 5 porcine brains were tested to evaluate the non-rigid registration accuracy. The brain deformation was generated from vertical direction with displacement of 5 mm, 10 mm, 15 mm and 20 mm and horizontal direction with displacement of 5 mm, 10 mm and 15 mm. The non-rigid registration result showed that our registration Residue Error (RE) was 0.1 mm. By using the OPTOTRAK protocol, the tracking accuracy was 0.9 mm on average.

Finally, the disadvantages and limitations of the proposed methods have been discussed in this dissertation to show the feasibility of the proposed method for clinical application.