Imaging Support of Minimally Invasive Procedures

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Abstract. Since the discovery of x-rays, medical imaging has played a major role in the guidance of surgical procedures, and the advent of the computer has been a crucial factor in the rapid development of this field. As therapeutic procedures become significantly less invasive, the use of pre-operative and intra-operative images to plan and guide procedures has gained increasing importance. While image-guided surgery techniques have been in use for many years in the planning and execution of neurosurgical procedures, more recently endoscopically-guided approaches have made minimally invasive surgery feasible for other organs. The most challenging of these is the heart. Although some institutions have installed intra-operative, real-time MRI facilities, these are expensive and often impractical. So a major area of research has been the registration of pre-operative images to match the intra-operative state of organs during surgery, often with the added assistance of real time intra-operative modalities such as ultrasound and endoscopy. This paper examines the use of medical images, often integrated with electrophysiological measurements, to assist image-guided surgery in the brain for the treatment of Parkinson’s disease, and discusses the development of a virtual environment for the planning and guidance of epi- and endo-cardiac surgeries for coronary artery bypass and atrial fibrillation therapy.

1 Introduction

Minimally invasive surgical procedures are becoming increasingly common, and as a result, the use of images registered to the patient, is a prerequisite for both the planning and guidance of such operations. While many invasive procedures, (traditional coronary artery bypass for example) require relatively minor surgical intervention to effect the desired therapy or repair, the patient is often severely physically traumatized in the process of exposing the site of the therapeutic target. In one sense the objective of minimally invasive approaches is to perform the therapy without the surgery!

Minimally invasive techniques have been in use now for many years, particularly in the brain and skeletal system. The targets in these cases are relatively rigid, making the process of registering pre-operative images to the patient fairly straightforward. For other organs, for example the heart, liver, and kidney, registration is not as simple, and it is these organs that present the major challenges for imaging during minimally invasive surgery.

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2 Neuro Applications

2.1 Frame-Based Stereotactic Deep-Brain Surgery

Computerized surgical planning systems made their debut in the early 1980’s using simple programs that established coordinate systems in the brain based on frame-based fiducial markers. This approach rapidly evolved to allow images from multiple modalities to be combined, so that surgical planning could proceed using information from a combination of MRI, CT, and angiographic and functional images. Such multi-modality imaging was considered important for certain procedures, such as the insertion of probes or electrodes into the brain for recording or ablation, and the ability to simultaneously visualize the trajectory with respect to images of the blood vessels and other sensitive areas. Multi-modality imaging enabled the pathway to be planned with confidence [1;2]. Much of stereotactic neurosurgery was concerned with procedures involving the safe introduction of probes, cannulae or electrodes into the brain.

2.2 Frameless Stereotaxy

Because the attachment of a frame to the patient’s skull is itself invasive, there has been a general desire to eliminate the use of the frame from the procedure. However, without the frame to provide the fiducial markers, some other type of reference system must be employed to register the patient to the image(s). A commonly used registration method is point-matching, where homologous landmarks are identified both in the images and on the patient. Unfortunately, some variation in the identified locations of the landmark points on the patient is always present, and it is difficult to pinpoint exactly the same locations within the patient’s three-dimensional image. Point matching is often employed in conjunction with surface-matching, which is achieved using the probe to sample points on the surface of the patient, and then determining the best match of this point-cloud to an extracted surface from the 3-D patient image. Under ideal conditions, accuracy approaching that available with stereotactic frames can be achieved [3].

2.3 Integration of Physiological Information with Images

A common treatment for Parkinson’s disease involves the ablation or electrical stimulation of targets in the deep brain, either within the thalamus, the sub-thalamus, or the globus pallidus. The standard imaging modality for guiding the surgical treatment of targets in the deep brain is a T1-weighted volumetric MR image. This image however does not show the affected parts of the brain directly, nor does it demonstrate the deep-brain nuclei that constitute the targets for such therapy. Other means must be used to define the target areas within the otherwise homogeneous regions. Approaches to solve this problem include the use of atlases mapped to the patient images, using linear, piece-wise linear, or non-rigid registration. This is often complemented with information gained from electrophysiological exploration of the