

Chapter 5

Biomedical Information Processing and Visualization for Minimally Invasive Neurosurgery

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ABSTRACT

This chapter demonstrates a particular application of biomedical information processing and visualization techniques for minimally invasive diagnosis and therapy in neurosurgery. Computer-assisted surgical navigation provides surgeons valuable information on the precision location of surgical targets and critical areas, as well as the positions of surgical instruments. However, most navigation systems use pre-/intra-operative images, which are displayed on a two-dimensional (2D) display situated away from the surgical field. These setups force the surgeon to take extra steps to match navigation information on the display with the actual surgical target of the patient. Two typical medical information-based navigation systems for neurosurgery are described in this chapter. First, an integration system with fluorescence-based intra-operative diagnosis and laser ablation-based, high-precision, minimally invasive treatment is introduced. Second, an autostereoscopic image-guided surgical system developed for minimally invasive neurosurgery is discussed. The autostereoscopic image and corresponding augmented reality with three-dimensional (3D) image overlay have been used in open magnetic resonance imaging (MRI)-guided neurosurgery. These techniques enable intra-operative visualization of surgical targets for precision tumor resection.

INTRODUCTION

Neurosurgery is concerned with the diagnosis, treatment, and post-surgical rehabilitation of disorders that affect the nervous system. Medical information processing for image-guided

neurosurgery has been used for both diagnosis and therapy. Surgeons can perform precision tumor resection to an accuracy of millimeters using a combination of position-tracked surgical instruments and diagnostic image guidance, such as magnetic resonance (MR) and computed tomography (CT) images. However, these tra-

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ditional image setups do not allow the surgeon to directly view the surgical target in minimally invasive surgery.

Surgical navigations have been developed to provide surgeons with an augmented reality environment, which enables safe, easy, and accurate surgical diagnosis and therapy. Minimally invasive surgery requires accurate and precise image-guided surgical navigation based on pre-/intra-operative imaging. However, traditional image-guided navigation can have an error of as much as a few millimeters due to inaccurate registration of the pre-/intra-operative images (Gholipour et al., 2007; Liao et al., 2010), especially for the intra-operative issues, such as operation-related deformation and small-tumor detection.

Addressing the registration issue of intra-operative tumor and tissue deformation is a surgical navigation challenge. Although intra-operative images, such as ultrasound, can assist in the identification of target and critical areas in real-time, image resolution limits diagnosis and treatment accuracy during the operation. The use of open magnetic resonance imaging (MRI) allows for intra-operative identification of the remaining tumor tissue. However, it is difficult to resect complicated tumors with MRI guidance alone; imaging does not precisely delineate the tumor boundary or distinguish between tumor and healthy brain tissue. Finding a way to provide accurate intra-operative imaging for the remaining tumor issue or small tumors is a challenge. Magnetoencephalography (MEG) (Cohen, 1968) and functional MRI (Ogawa et al., 1990) are helpful in delineating the eloquent areas of the brain by means of functional brain mapping techniques (Muragaki et al., 2001; Fukaya et al., 2002). Although combining these techniques can provide better spatial and temporal resolution, an improvement in real-time information acquisition is required.

One technique that can address this is to illuminate brain tumor tissue with a fluorescent

marker (Regula et al., 1995). For example, the use of 5-aminolevulinic acid (5-ALA)-induced protoporphyrin IX (PpIX) fluorescence for visualization of malignant glioma tissue enables more complete tumor removal (Ciburis et al., 2003). 5-ALA is the first compound in the porphyrin synthesis pathway, which leads to hemoglobin production in mammals. Gliomas can be detected with this method because this acid is a natural biochemical precursor of hemoglobin that stimulates synthesis and leads to fluorescent porphyrin accumulation in various epithelia and cancerous tissues. The fluorescence is used to identify residual malignant glioma intra-operatively, thus improving surgical treatment accuracy (Rossi et al., 1996; Stummer et al., 1998; Stummer et al., 2000). By utilizing fluorescence illumination in microscopic surgery, the surgeon can resect the tumor more accurately (Leblond et al., 2009). However, the combination of positioning accuracy in diagnosis and tumor ablation accuracy in treatment is required to resect tumor tissue safely and precisely.

Another surgical navigation issue is how to merge computer-generated images to the real surgical environment. Augmented reality is an interesting technique that can adequately handle depth cues based on geometry, for example, relative size, motion parallax, and stereo disparity. However, incorrect visualization of the interpositioning between real and virtual objects has limited its application in minimally invasive surgery (Bajura et al., 1992; Johnson et al., 2003). In traditional augmented reality, relative position and depth information may not be correctly perceived by the observer when real and virtual images are merged, even though all positions are computed correctly. To address these issues, an autostereoscopic imaging technique has been developed and introduced in image-guided surgery (Liao et al., 2000). This autostereoscopic display reproduces 3D images using an optical lens array and a high-resolution flat display (Liao et al., Optics Express 2004; Liao et al., MICCAI 2004). The surgeon can see the 3D images on the

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