Chapter 5
A Step Towards Characterization of Surgical Actions Involved in Mastoidectomy

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ABSTRACT

Mastoidectomy is a core surgical procedure in otologic surgery. It is believed that the procedure is performed by different surgeons with some variations. Also, all surgeons use a finite number of fundamental surgical actions to complete the procedure. Here, we sought to identify the fundamental surgical actions (called Action Primitives, APs) constituting mastoidectomy and determine transition boundaries between those APs. Our motivation for this work is both to delineate the APs necessary to complete a mastoidectomy and to optimize and potentially automate major components of the surgical process. Here we present a novel approach to developing methods for parsing raw data (position and orientation of the surgical tool and end-effector force) into a sequence of surgical actions (APs) that can be used by a robot in the future. In this chapter we present results from our initial investigation on detecting transition boundaries and identifying APs involved in mastoidectomy.

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1. INTRODUCTION

Treatment of a number of ear disorders including chronic middle ear infections, cholesteatoma (epithelial cyst within the middle ear), conductive hearing loss, vertigo (dizziness), and sensorineural hearing loss requires ear surgery to be undertaken. The central component of these surgeries is the mastoidectomy—a procedure that can take upwards of 2 hours. Each year about 100,000 mastoidectomy surgeries are performed within the United States (French et. al., 2008).

Mastoidectomy is a core surgical procedure in otologic surgery. It is believed that the procedure is performed by different surgeons with some variability. However, it is also believed that all surgeons use a finite number of fundamental surgical actions to complete the procedure. During mastoidectomy, the temporal bone, the bone that encases the ear, is systematically drilled away to either remove diseased tissue or provide access to the middle and/or inner ear. The procedure is akin to an archeological dig where it is vital to preserve certain noble structures that reside within the temporal bone. These structures include the facial nerve (injury results in paralysis of the face) (Green et. al., 1994), the middle ear (malleus, incus and stapes – injury results in conductive hearing loss), the inner ear (injury results in permanent hearing loss and vertigo), the floor of the cranial vault (injury results in leakage of cerebrospinal fluid) (Kerr et. al., 2005) and the internal jugular vein and carotid artery (injury results in blood loss which may be life threatening). The level of accuracy needed to prevent damage to these structures is in the order of 1mm (Schipper et. al., 2004). However, the fundamental actions that surgeons use to complete the surgery appear to be repeatable among surgeons with variation in order and style.

The mastoidectomy procedure performed by different surgeons can vary widely (Kimberly et. al., 1999). In an endeavor to standardize and automate the major components of mastoidectomy, it is first necessary to understand how a surgeon performs mastoidectomy and determine the basic sequence of surgical actions necessary to complete the procedure. The knowledge thus gained would be helpful for training of novice surgeons and comparing their skill sets with that of an experienced surgeon. Perhaps more clinically significant, by defining the actions that comprise a procedure, we may be better able to optimize the order of the actions and potentially program a robot to perform at least a part of surgical procedure in the future.

Robots have been used in operating theaters for over 20 years. Examples include active-constraint robots such as, the Acrobot (The Acrobot Company Limited, London, UK) used in preparing bone surfaces for positioning prostheses in total knee replacement surgery (Cobb et. al., 1997; Jacopec et. al., 2003), master-slave telemanipulators such as the da Vinci Surgical System® (Intuitive Surgical; Sunnyvale, CA), used in laparoscopic procedures (Guthart et. al., 2000), and autonomous robots such as the ROBODOC® (Integrated Surgical Systems; Davis, CA) used to perform total hip replacements (Paul et. al., 1992; Honl et. al., 2003). In otologic surgery, to date, robots have been used only for surface milling of the temporal bone (to a depth of 4.5 mm) to create a receiving well for the internal processor of a cochlear implant device (Federspil et. al., 2003). One of the barriers preventing further integration of robots into otologic surgery is that the surgical skills used in these types of procedures are not well quantified.

Recent efforts to evaluate surgical skill in other arenas have been successful. One such example is in the area of high-level surgical modeling where there is evidence that statistical models derived from recorded force and motion data can be used to classify surgical skill level (novice or expert) with a classification accuracy approaching 90% (Rosen et. al., 2001; Richards et. al., 2000). However, these works did not recognize the transition boundaries between the different surgical actions

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