

# Registered, Sensor-Integrated Virtual Reality for Surgical Applications

Brady W. King<sup>1</sup> Luke A. Reisner<sup>1</sup> Michael D. Klein Gregory W. Auner Abhilash K. Pandya<sup>2</sup>  
Wayne State University Wayne State University Children's Hospital of Wayne State University Wayne State University  
Michigan

## ABSTRACT

Image guidance is a technique that often uses virtual reality to provide accurate localization and real-time surgical navigation. Combining image guidance with a biosensor based on Raman spectroscopy, a powerful laser-based analysis technique, would provide a surgeon both a diagnosis of tissue being analyzed (e.g. cancer) and localization information displayed within an imaging modality of choice. A virtual reality-based presentation of this type of mutual and registered information could lead to faster diagnoses and enable more accurate tissue resections.

For our system, a portable Raman probe was attached to a passively articulated mechanical arm and used to scan and classify objects within a phantom skull. We discuss the implementation of the integrated system, its accuracy, its visualization techniques, and the future steps for its development and eventual application.

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**Keywords:** Image-guided surgery, sensor integration, Raman spectroscopy, cancer diagnosis, medical robotics

## 1 INTRODUCTION

Image-guided surgery (IGS) fuses medical imaging, computer visualization, and real-time tracking of medical tools to provide the surgeon with a more detailed view of the patient's anatomy. Current techniques in image-guided surgery rely primarily on visual feedback from the surgical site. In this paper, we address the issue of extending this feedback by adding a sensing modality—Raman spectroscopy—to one of the already successful techniques of image guidance: virtual reality. It is hypothesized that other modalities of information from the surgical/tumor site based on these non-visual (biochemical) aspects will enhance the surgeon's ability to more completely define resection margins.

Conventional histopathology lacks both the capability for providing immediate feedback and the precision to quantify the extent of disease, particularly in the early stages. Final results usually require 12–24 hours. Even the examination of the more immediate frozen sections require at least 20 minutes from the time the tissue is removed until the time an answer is available. During tumor-removal surgeries (e.g. for brain cancer), this means longer operation times with the patient remaining open.

Raman spectroscopy is a technique capable of detecting normal and abnormal regions of tissue [1]. Its near-real-time analysis and the fact that it does not require sample preparation make it highly

suited for *in vivo* applications [2]. Image-guided surgery helps the surgeon position and track instruments (such as a Raman probe) inside the body [3], making it a natural complement for Raman spectroscopy. Integration of this sensing technology with IGS should help maximize its usefulness for *in vivo* applications. Thus, this paper investigates the integration of a Raman probe with an image-guided surgery system for enhanced future tissue diagnosis.

## 2 METHOD

In order to evaluate the integration of Raman spectroscopy and image-guided surgery, we developed a system utilizing several hardware and software components. A portable Raman spectrometer was attached to a passively articulated mechanical arm. We also implemented classification algorithms for Raman spectra. The results of the classification are sent to a medical visualization system. Once these systems were integrated together, testing was done with a phantom skull (shown in Figure 1). The skull was filled with various plastic and rubber objects, and CT images were obtained. The entire system was then used to scan objects in the skull, classify the resulting spectral data, and then place markers within our visualization system. Each of the subsystems is described in greater detail below.



Figure 1: The prototype Raman system

### 2.1 Tracking Arm

To track the position of a Raman spectrometer, we attached one to a passively articulated arm, an Immersion MicroScribe G2X (shown in Figure 1). This arm has five degrees of freedom and, based on our previous research [4], provides joint feedback with an accuracy of 0.87 mm. It was chosen because it is simple to use and its tracking accuracy is within acceptable limits.

We developed a software application that registers the MicroScribe with patient imaging data (via pair point matching) and tracks the location of its end-effector. The tracking is accomplished by passing the arm's angular joint feedback through a forward kinematics model of the MicroScribe using Craig's modified Denavit-Hartenberg (DH) convention [5]. The computed tracking data is relayed in real-time to our visualization system.

<sup>1</sup> E-mail: bwking@wayne.edu, lreisner@wayne.edu

<sup>2</sup> E-mail: apandya@ece.eng.wayne.edu (corresponding)

## 2.2 Raman Spectrometer

An InPhotonics Verax Raman probe (shown in Figure 1) was affixed to the MicroScribe using a simple clamping system. The end-effector of the MicroScribe was marked to ensure consistent placement, allowing the probe to be detached and reattached. The kinematic model for the MicroScribe was extended by adding an extra transformation from the end-effector to the tip of the Raman probe. This transformation allows the probe to be tracked in our visualization system relative to the skull's CT scan data.

## 2.3 Raman Classification

Many techniques have been developed for the classification of Raman spectra. For our implementation, we used a method based on artificial neural networks, which have been shown to perform well for Raman classification [6]. The final output was the classification of the scanned tissue/material and a percentage indicating the confidence of the neural network.

A variety of preprocessing tasks are performed on the raw Raman spectral data, including background fluorescence subtraction (via adaptive polynomial fitting), median noise filtering, normalization, and peak extraction. Due to the high dimensionality of Raman spectra, we used principle component analysis to select the most significant spectral peaks for algorithm consideration.

## 2.4 Visualization

The visualization for our image-guided surgery system is implemented using 3D Slicer, an open-source application for displaying medical data. 3D Slicer provides a virtual reality environment in which various imaging modalities (e.g. CT or MRI data) can be presented. The software includes the ability to display the locations of objects with respect to 3D models that are derived from segmentation of the medical imaging.

We modified 3D Slicer in several ways to adapt it to our application. First, we developed a TCP/IP interface that receives the tracking data for the MicroScribe and displays its position in the VR environment relative to the medical imaging data. This allows us to track the Raman probe in real-time. Second, we developed a way to place colored markers that indicate tissue/material classification on the medical imaging data. The combination of these modifications enables us to denote the location and classification of tissue/material scanned with the probe in near-real-time.

## 3 RESULTS

As described in the Method section, we used the completed system to scan objects within a phantom skull. The MicroScribe and probe were positioned manually and tracked in real-time during this test. The collected Raman spectra were classified and displayed as colored markers in our visualization system. This is shown in Figure 2.

The system performed as expected. The tracking of the probe, the classification of the Raman spectra, and the display of the colored markers all occurred in real-time. The only major delay was caused by the scanning of the tissue by the Raman probe, which requires at least 5 seconds to produce a scan with a reasonable signal-to-noise ratio.

The Raman scans were able to distinguish between the plastic and the rubber objects. The corresponding markers in the visualization display correctly reflected the classifications that were made. The positions of the markers were also accurate with respect to the locations from which scans were taken. Since the

setup of the system is very similar to that of our previous work [4], we estimate that the probe tracking accuracy is around 1 mm.

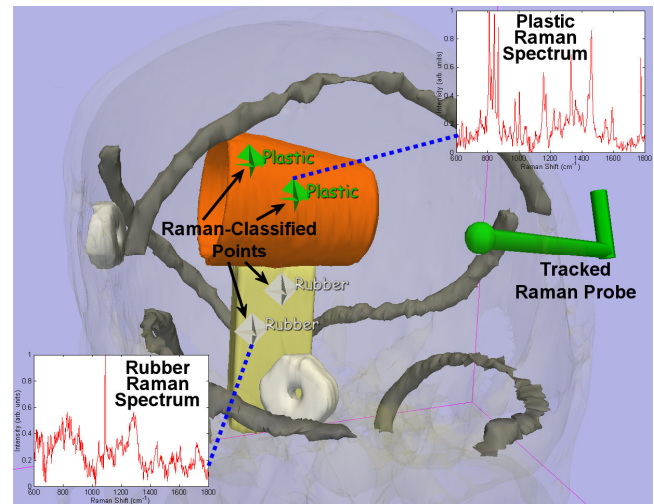


Figure 2: A screenshot of our visualization system

## 4 DISCUSSION

This paper demonstrates that Raman spectroscopy and image-guided surgery can be combined to provide a powerful diagnostic system. Even though we've used a phantom model, the underlying technologies have been previously shown to work with human tissue. With further research, we believe this system will be suitable for human applications. For now, we will continue to develop and test the system using phantom models. In the future, we plan to evaluate the system with animal testing. Eventually, we hope to apply our work to human cases.

To our knowledge, there have been no other prototypes in the literature that attempt to combine Raman spectroscopy and image-guided surgery. We conjecture that a system based on these technologies could eventually provide many benefits in the surgical environment. These benefits could include faster diagnoses and more accurate resections, hence producing better patient outcomes. In addition, we plan to eventually integrate this work with a medical robot (the Aesop 3000) to take advantage of its accurate positioning capabilities.

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