Motion Planning System for Minimally Invasive Surgery

Hanees Haniffa, Jerzy Rozenblit, PhD, Jianfeng Peng
jr@ece.arizona.edu
The Department of Electrical and Computer Engineering
The University of Arizona

Allan Hamilton, MD, FACS, Mohamad Salkini, MD
allan@surgery.arizona.edu
Arizona Surgical Technology and Education Center
The University of Arizona

Abstract

Minimally invasive procedures are highly effective when performed by well trained surgeons. However, with the subjective nature of surgical training and performance assessment, it is difficult to determine when a trainee surgeon has attained a satisfactory level of competency. We propose a computer-based training and performance assessment system where we apply configuration space based techniques to determine optimal paths for the maneuver of surgical instruments to perform predefined tasks.

1. Introduction

Medical training currently lags behind in the application of state-of-the-art technologies to enhance safety and efficiency. The emergence of new surgical techniques enhanced by sophisticated surgical tools and imaging systems, calls for a shift in paradigm in medical practice, to incorporate more computer-based training, assessment, and guidance and warning systems.

We focus our work on training and performance assessment in laparoscopic surgery. In laparoscopy surgeons lose many of the tactile and visual cues that they rely upon in conventional surgery. We propose a design that addresses many of the limitations of existing solutions and advances the state of the art in surgical training and assessment. We propose a computer-based platform where sensor tracking permits motion information to be gathered about surgical instruments used in a procedure. Our design features the embedding of micro-sensors into the instruments employed for training. The detection and recording of instrument movement would permit our system to measure a trainee's progress in acquiring psychomotor skills and compare these data to normative databases.

2. Training System Prototype

The system prototype consists of an enclosure with openings for instrument insertion. Tasks are performed within this enclosure using a video feed. Motion sensors mounted on the tip of each instrument gather data in real-time. We use the microBIRD 3D sensing system developed by Ascension Technology Corporation for this purpose (Ascension Technology Co. 2006). The sensing system includes a magnetic field transmitter, two position sensors (1.3mm in diameter) and a PCI interface data processing card. The measurement rate is 68.3 Hz with linear accuracy of ±1.4mm and rotational accuracy of ±0.5 degrees. The transmitter remains fixed to provide a Cartesian frame of reference for position tracking.

We have designed exercises that involve the manipulation of objects within an enclosed space. These are designed to enhance psychomotor skills, depth perception and 3D visualization, camera handling, familiarity with instrument ergonomics and dexterity. A simplified example of such an exercise may be the placement of a rubber band across two hooks as shown in the cross-sectional diagram below. More sophisticated exercises involving the use of synthetic tissues and organ models to perform basic surgical tasks such as suturing, dissection, translocation, etc. have also being developed.

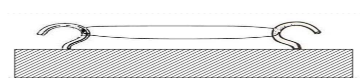

Figure 1: Basic skills exercise

3. Performance Assessment

We employ motion planning methods to determine the optimal path of the instrument from the current position to the desired goal state. Specifically, we use potential field methods to model the work space as a region influenced by an imaginary force field. The field would be attractive (or have lower potential) at the goal states and be repulsive (or have higher potential) at obstacles and pre-defined "no-fly" zones, as shown in figure 2. The tips of the instruments, in our case would be analogous to robots, and would be represented by points in the configuration space (C-space), which is the region within which the robot navigates. We imagine an artificial potential field U, influencing the motion of the instruments around the goals positions in C-space. We compute the artificial force (attractive towards the goal state and repulsive towards forbidden regions of C) given by

Proceedings of the 14th Annual IEEE International Conference and Workshops on the Engineering of Computer-Based Systems (ECBS'07)
0-7695-2772-8/07 $20.00 © 2007 IEEE

$$\vec{F}(q) = -\nabla U(q) \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where

$$U(q) = U_{attractive}(q) + U_{repulsive}(q) \ldots\ldots..(2)$$

and

$$\nabla U(q) = \begin{bmatrix} \dfrac{\partial U}{\partial x} \\ \dfrac{\partial U}{\partial y} \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Performance assessment will be based against the "steepest descent" path. Movement towards the steepest descent path will earn credit and movement towards obstacles will impose penalties. An overall score will be computed upon completion of the procedure. The score will also be affected by the time taken to complete the procedure successfully and the number of collisions with obstacles or other instruments and for intrusions outside the C-space region.

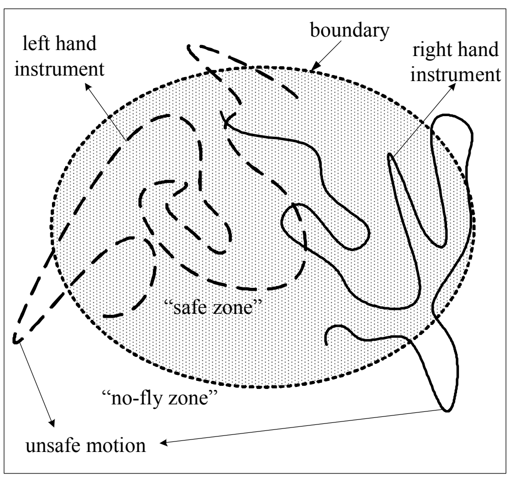

Figure 2: Motion tracks

4. Experiment

We discuss the potential field for the example in figure 1 above. Each instrument is modeled as a separate robot maneuvering in the given C-Space and a separate potential field defined for each instrument. We will focus on the potential field for the right instrument. The left hook will be an obstacle for the right instrument, with the right hook being the goal state in this exercise. The potential field is as represented in figure 3 below.

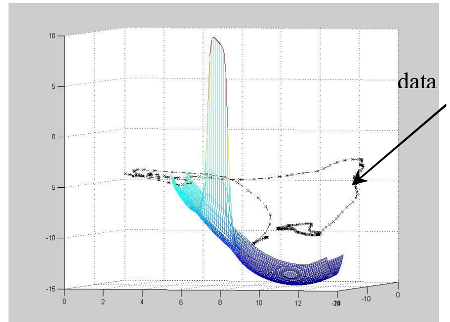

Figure 3: Potential field

5. Results

The collected data was plotted and is shown by the series of points in figure 3. The visual representation of the results of this preliminary experiment demonstrates the principle behind our approach. The collected data is compared against the force exerted by the potential field with respect to current and next positions. For any given current position, an ideal next position is dictated by the potential field. When a trainee moves in the direction of the potential field positive points are awarded and points taken away for movement in a different direction. This paper presents a work in progress and the results are preliminary proofs of concept. The poster version of this paper will contain the results and conclusions drawn from currently ongoing trials.

6. Conclusion and Future Work

The above experiment demonstrates the principles behind our approach. Future work will focus on expanding on the initial idea by refining the development of potential fields, using organ and tissue models for more complex exercises involving suturing, and dissection and exploring the feasibility of incorporating MRI images to define the configuration space.

References

[1] Shortliffe, E. H. 1976. "Computer-Based Medical Consultations: MYCIN" American Elsevier Publishing Co., Inc.,

[2] Ledley, R. S. 1969. "Practical Problems in the Use of Computers in Medical Diagnosis" Proceedings of the IEEE, Vol. 57, No. 11, 1900-1918

[3] Finlay, P.A. and Ornstein M.H.1995 "Controlling the Movement of a Surgical Laparoscope" IEEE Engineering in Medicine and Biology, 289-291