Hybrid Systems for Modeling, Performing and Teaching the Language of Surgery (CPS 0931805)

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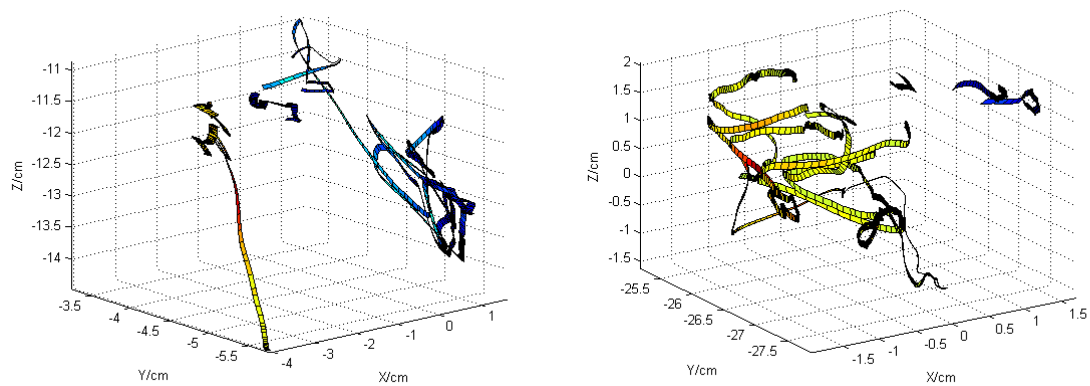
The aim of this project is to investigate methods for modeling human expert surgeons performing robotic minimally invasive surgery, and to understand how to reflect this expertise back upon students in the form of teaching and training. At a fundamental level, we view modeling the surgical "signal" as one of language modeling. We have pursued two approaches to general-purpose low-level modeling. In one path, we are extending traditional HMM-like models with dynamics. We have now advanced that work to a structured model in which each high-dimensional kinematic data vector is viewed as the linear transformation of a low-dimensional gesture-dependent motion vector plus a gesture-independent nuisance (noise) vector. We then introduced temporal dynamics into these two underlying vectors. Finally, we made the parameters of the temporal dynamics state-dependent. We call this the structured switching vector autoregressive (SS-VAR) model. At the same time, we have looked at global optimization methods for classification of data on multiple manifolds based on structured sparse representation. Our most recent work treats the training data as a self-expressive dictionary where the data in each class are organized into several blocks of the dictionary where each block corresponds to a low-dimensional subspace of a high-dimensional ambient space. We cast the classification as finding a block-sparse representation of a test example in the dictionary of the training data. While this is an NP-hard problem, we propose two classes of convex relaxations and prove that under broad conditions, the convex programs can successfully perform the classification task. In the challenging case of having a small number of training data for each class, the proposed algorithms improve the state-of-the-art classification algorithms by 10%.

We have used these modeling tools to recognize and create contextual feedback to users. In particular, we have explored methods for automated collaborative (traded control) execution of robot motions. The overall execution of a task can be viewed as a state transition system, where each state may be performed by the human operator or automatically. The states are recognized using the previously describe discrete models, and the motion is a learned representation from training data.

Finally, we have continued to push forward in using our results in surgical assessment. In new work, we have begun to compute (longitudinal) learning curves for our trainees based on expert assessed and automatically computer metrics, and explore correlation between automated assessment and expert assessment. Recently, we have extended these results for use in curricular training for robotic otolaryngology, and to simulation based training for robotic surgery. This is also the first work to utilize motion data from identical training tasks in physical and simulated training tasks for robotic surgery training as illustrated below.



This figure shows the surfaces swept out by a surgical needle operated with a robotic instrument as a subject performs a dry-lab (left) and simulation-based (right) robotic surgery training task.