A Holistic Data Acquisition Framework for Robotic Surgical Skill Assessment
601.446 Computer Integrated Surgery II, Spring 2018

Project Proposal

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Mentors: Dr. Jeremy Brown, Dr. Anand Malpani, Dr. Gina Adrales (Clinical)

Goal:

The goal of this project is to develop an intelligent system that can objectively assess surgical skill using performance data about how surgeons move their hands, connected instruments, and how the instruments interact with the surgical workspace.

Clinical Motivation:

Robot-assisted minimally invasive surgery (RAMIS) is quickly becoming the prescribed method of treatment for many different routine and non-routine surgical procedures. There is a need to ensure that all robotic surgeons have a minimal level of skill proficiency before they operate on patients. (Pradarelli, et al.) Current methods of skill assessment rely almost exclusively on structured human grading which can be subjective, tedious, time consuming, cost ineffective as raters are practicing physicians. (Curry M, Malpani A, Li R, et al.)

There exists some previous work investigating the relationship between robot dynamics and operator skill. Integrating force sensors and accelerometers into surgical skill assessments, such as peg transfer and similar tasks, allows categorization of surgical skill with reasonable accuracy. By analyzing time-series data of contact forces between surgical tools and workspace, as well as high-frequency vibration patterns, it is possible to extract statistical measures that can be used in both regression and classification machine learning algorithms. This approach has been shown the ability to accurately predict Global Evaluative Assessment of Robotic Skills (G.E.A.R.S.) ratings with high interrater correlation scores. (Brown et al) Having these outputs to agree with the (G.E.A.R.S) metrics is desirable, as this metric is considered clinically relevant. (Goh, Goldfarb, et al.) In a similar vein, work has also been done using the kinematics of robot end effectors to predict robotic surgical skill. (Malpani, et al) By integrating these two data modalities of kinematic and force data, we hope to work towards creating a system capable of automated, objective, and time-effective surgical skill assessment.

Technical Approach:

The first phase of the project will involve the development of a hardware + software platform using ROS (Python) that collects synchronous streams of motion and physical interaction data (forces and vibrations). This will combine the two previously developed surgical skill assessment platforms created by Dr. Brown and Dr. Malpani. The hardware will consist of a PC obtained from Dr. Malpani, a smart task board with three axis force sensor inside, and high bandwidth 3 axis accelerometer clips for the da Vinci arms and endoscope.

Our system will interface directly with the da Vinci via ethernet connection and collect kinematic data of both the end effectors and manipulators, as well as discrete time-stamped event data using Intuitive Surgical's API. Simultaneously, the computer will receive serial data from the smart task board microcontroller, describing the forces exerted on the environment during the skill task. Our ROS platform will need to combine the two sources of data, accounting for the different frequencies of output. The visual portion of our code will also grab video frames from the da Vinci camera and synchronize this footage to the time-series data collection. This video collection will not only allow us to get a G.E.A.R.S. assessment retroactively (providing ground truth classification labels for algorithm training), but also to help validate the synchronization of data collection.

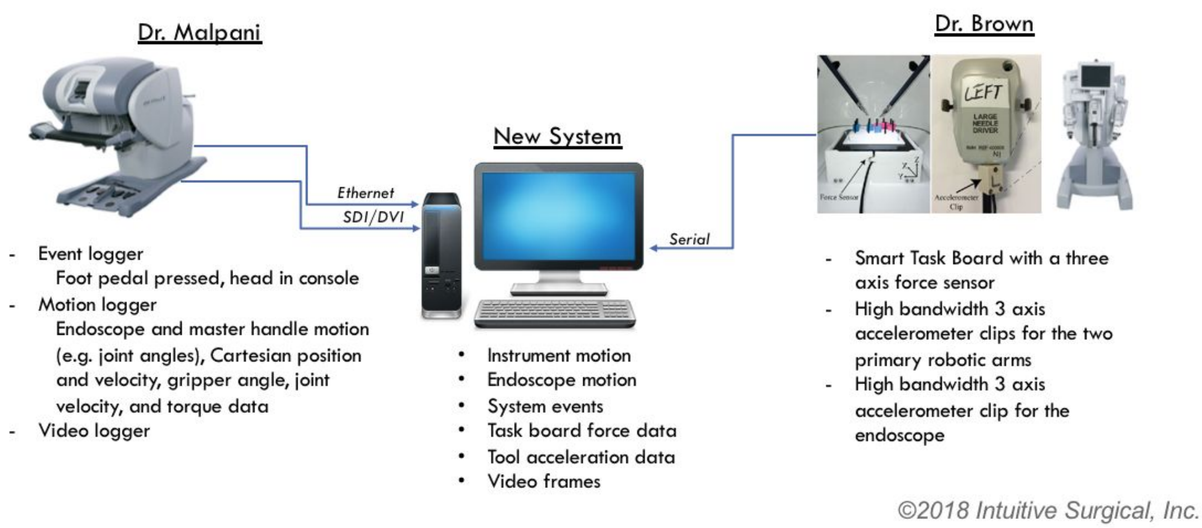

Figure 1: High level system overview

Once the system has been validated, pilot data collection can begin. This will include members of the LCSR group and some clinicians including our clinical mentor Dr. Gina Adrales. This will provide a baseline for skilled and unskilled data. It will then be necessary to analyze the data using machine learning techniques. Previous work has shown that discrete features can be generated from the time series signals to be used for classification or regression based machine learning. These include mean, standard deviation, minimum, maximum, range, RMS, TSS, and time integral. (J. D. Brown et al.) As skill cannot be directly measured, skill labels will be generated using various proxies. These include number of robotic surgeries performed, surgical appointment (eg. engineering, medical student, resident, fellow, attending) and G.E.A.R.S. rating. If this method of pattern recognition does not perform as well as it has been shown to work previously, other machine learning methods will be explored. These may include neural nets that use the full time series signals or Hidden Markov Models.

The final phase of this project consists of the start of a large-scale data collection. This beings by submitting an IRB proposal. This will detail experimental protocol such as how consent will be obtained, how participants will be recruited, reimbursement, what the participants will be doing exactly, and what information we will be collecting. If the proposal is approved data collection can begin. If not, the appropriate changes will be made to receive approval.

The ultimate goal of this endeavor is to transport our system, comprising of the PC, smart task board, and clip-on sensors to the JHU Minimally Invasive Surgical Teaching Innovation Center, interface with the da Vinci system and monitor setup there to collect data on a large scale from many clinicians of varying skill levels. With this larger set of data, we will be able to more exhaustively evaluate our system's ability to objectively classify surgical skill.

Deliverables:

- Minimum Deliverables:
    - Design plan and documentation (3/11/18)
    - Dr. Brown system set up and verified (3/18/18)
    - Dr. Malpani system set up and verified (3/18/18
    - Integrated system set up and verified (4/15/18)
    - Portable container for transporting system to MISTIC (3/11/18)
- Expected Deliverables:
    - Pilot data collected (5/6/18)
    - Feature based machine learning method implemented (4/29/18)
- Maximum Deliverables:
    - IRB proposal written and submitted (5/6/18)
    - Clinical data collected at MISTIC (5/18/18)

Management Plan:

- Weekly meetings with Dr. Brown and Dr. Malpani
- Weekly meetings of student group to go over progress made on individual responsibilities and continue work as a group
- Source control via separate LCSR git repository due to private code for da Vinci API
- Design and documentation of system (interface specifications, code, etc.) will be maintained through google doc between group members

Scott	**Giacomo**
Hardware setup	Installation of programming environment
Project documentation	ROS program for combining systems
Verification of Dr. Brown subsystem	Verification of Dr. Malpani subsystem

CAD design, and creation of portable container for Dr. Brown system	Machine learning implementation
Oversee pilot data collection	
Data verification	
IRB writing	

Figure 2: Work Division

Dependencies:

Dependency	Proposed Solution	Status	Contingency Plan
Access to mock OR	Appropriate forms submitted to LCSR office	Complete	N/a
da Vinci training	Training session with Dr. Malpani	Scheduled meeting for 2/27	*Need resolved by* (3/18/18). *If not resolved will* continue to write code for integrated system until training is complete and verification of subsystems can start.
Access to Dr. Brown code	Granted access to git repository	Complete	N/a
Access to Dr. Malpani code	Access to Dr. Malpani's git repository given after signing of NDA	Complete	N/a
Access to ROS wrapper for interfacing Intuitive API	NDA signed, request for access sent to lcsr-it@jhu.edu	Request sent	*Need resolved by* (3/11/18). *If not resolved will* continue to write ROS code for interfacing with Dr. Brown system until access is given
Smart task board/ Accelerometer	Malfunctioning motherboard, new board is ordered, expected delivered by Monday (2/26/18), installation expected to be complete by Friday (3/2/18)	Expected resolved by 3/2/18	*Need resolved by* (3/4/18). *If not resolved will* continue to work on Dr. Malpani system until board is installed.
PC to handle data acquisition	PC given by Dr. Malpani, required software installed	Complete	N/a

Figure 3: Dependencies

Timeline:

Our timeline is being tracked online through tomsplanner.com. The timeline is password protected and can be easily be shared with our mentors and others through the link:

https://www.tomsplanner.com/public/skpgztcis The timeline can updated as we make progress, make changes to the design of the system, and encounter obstacles. The timeline can be seen in full below:

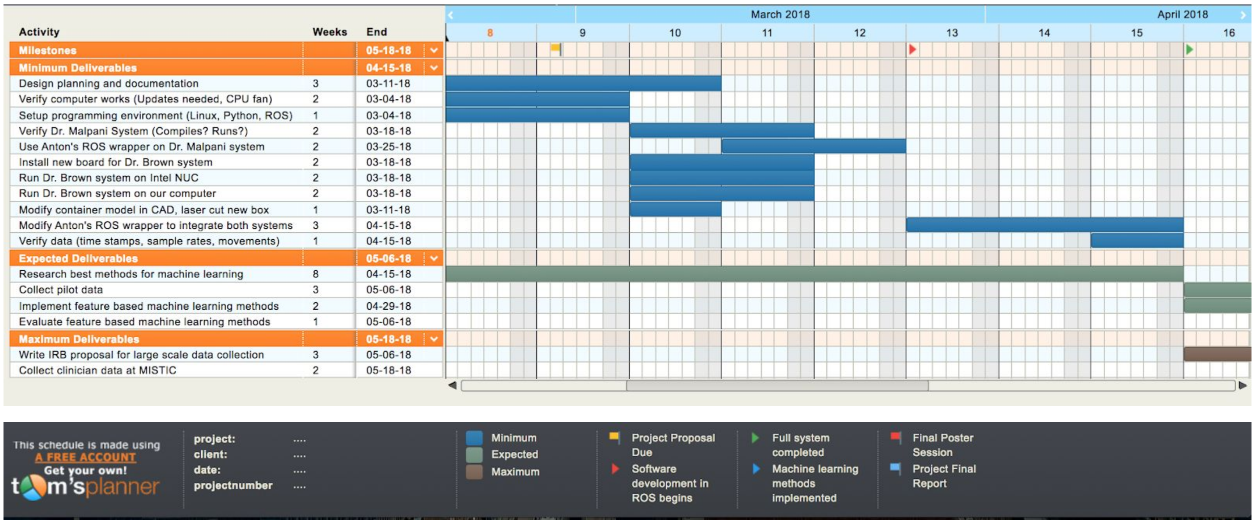

Figure 4: Weeks 1-9

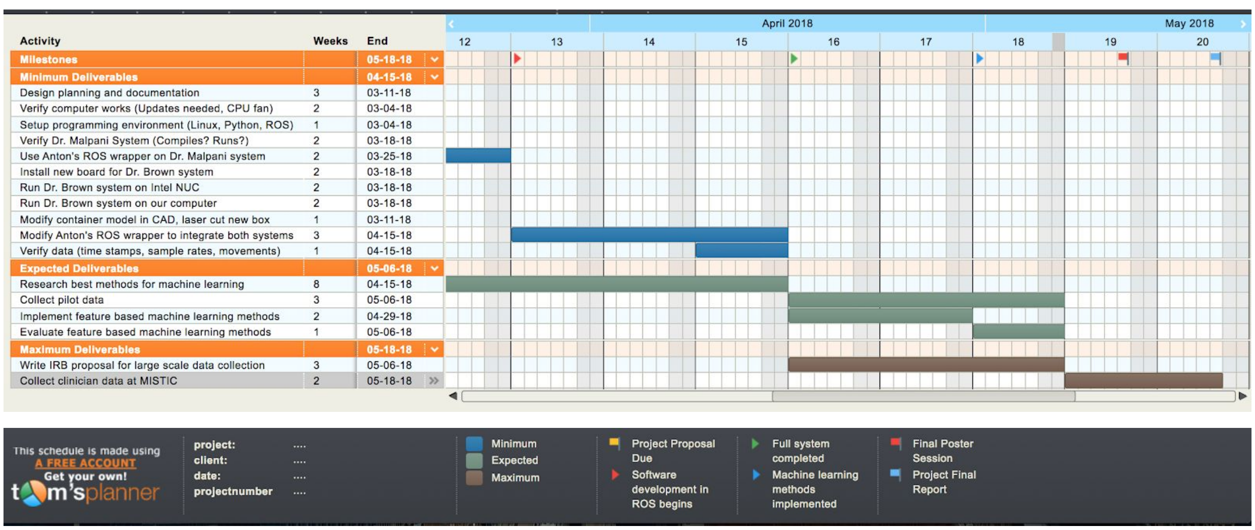

Figure 5: Weeks 5-13

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