SURGICAL ROBOTICS BEYOND ENHANCED DEXTERITY INSTRUMENTATION

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Group 3: Realtime Feedback Tool for Nasal Surgery
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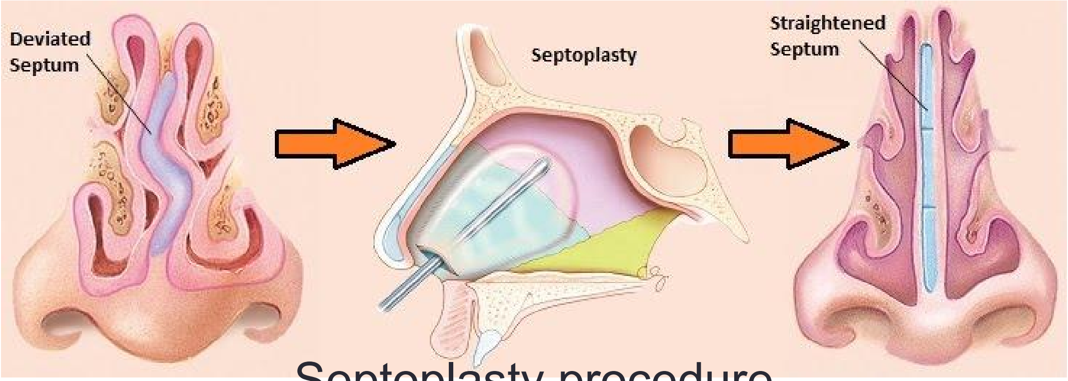
Quick Review

- Septoplasty is a surgical procedure that aims to correct deviated septum, a condition which may cause breathing difficulty.
- Our project aims to provide visualization feedback to help residents train in this procedure.



Septoplasty procedure

https://sites.google.com/site/dranhtruong/bellevue-septoplasty

Paper Selection

Kassahun, Yohannes, et al. "Surgical robotics beyond enhanced dexterity instrumentation: a survey of machine learning techniques and their role in intelligent and autonomous surgical actions." *International journal of computer assisted radiology and surgery* (2015): 1-16.

Relevance to our project

- There are 3 main components for computer based surgical training: activity/gesture recognition, skill assessment, and feedback.
- We are developing visual feedback tool for one of the component in septoplasty surgical training that have capability to show how the cutting should be done, assuming we already have a database of correct way of doing this procedure.
- Computerized feedback for resident surgical training is useful because it is objective, could give targeted feedback, and removes the dependency on availability of faculty member.

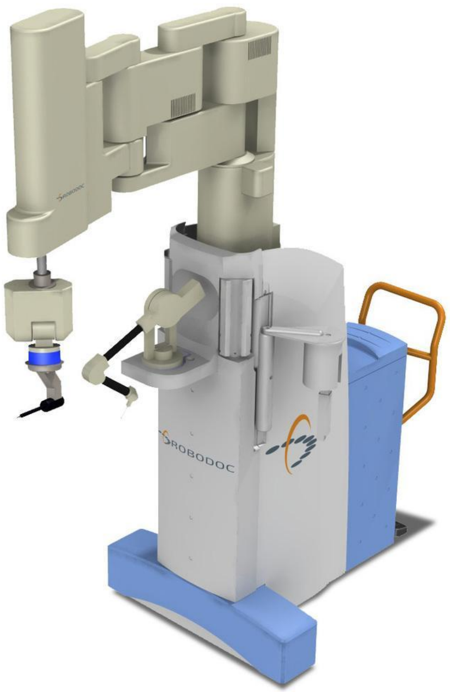
Activity Recognition → Skill Assessment → Feedback

Paper Content

- Motivation for machine learning in surgical robotics
- Introduction to Machine Learning
- Machine learning empowered instrumentation for assisted surgery
- Toward autonomous robotic surgery

Motivation for machine learning in surgical robotics

- Surgical robots allow surgeon to focus on more complex parts of surgery by taking over simpler parts of the tasks.
- Increasing workload for expert surgeon pushed the development of computerized assistant and automation of certain surgery intervention.
- Example of computerized assistance: ROBODOC



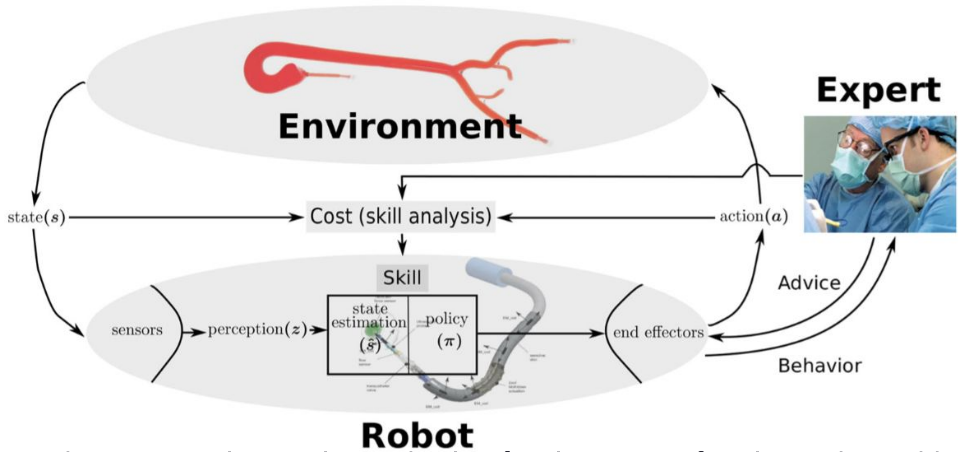
ROBODOC 1.0
http://compassdesign.com/robodoc1/

Motivation for machine learning in surgical robotics

- Majority of surgical system operates under assumption that the environment is invariant to robot movement.
- This assumption limits the number of procedure that can be done by the system, unless it has explicit model for the robot – environment interaction (such as tissue modeling).
- Machine learning approach learns from implicit model from sensor data. This is an advantageous feature, because:
  - It has general applicability
  - It avoids complex physical and biomechanics modeling
  - It is based on data from real case scenarios.

Introduction to Machine Learning

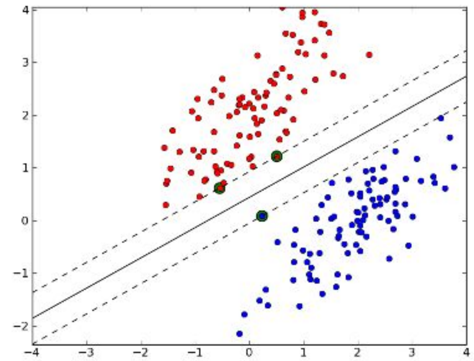
- Machine learning is a multidisciplinary field that provides the computer a way to learn without being explicitly programmed to perform specific task.
- Robot use sensor data to do approximation of its environment state, and do action that minimizes the total cost function based on its current estimated environment.



Overview of learning system in surgical robotics for the case of catheter-based interventions
Kassahun, Yohannes, et.al. “Surgical robotics beyond enhanced dexterity instrumentation”

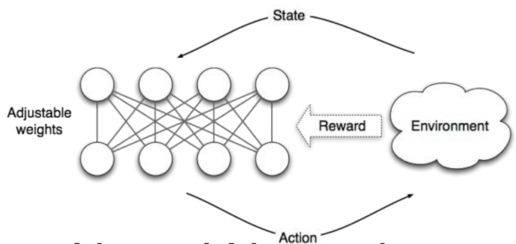
Introduction to Machine Learning

- In surgical robotics, the mapping function between perception from sensor data to action can be considered as surgical skill.
- There are 3 important areas of machine learning:
  - Supervised Learning: Training data are provided externally, and consists of a set of known input vectors along with a set of known corresponding output vectors. Example: Support Vector Machine (SVM)
  - Reinforcement Learning: deals with learning policy, i.e. mapping from states to action, that tries to maximize numerical reward. Example: Neural Network



SVM

http://www.mblondel.org/images/svm_linear.png

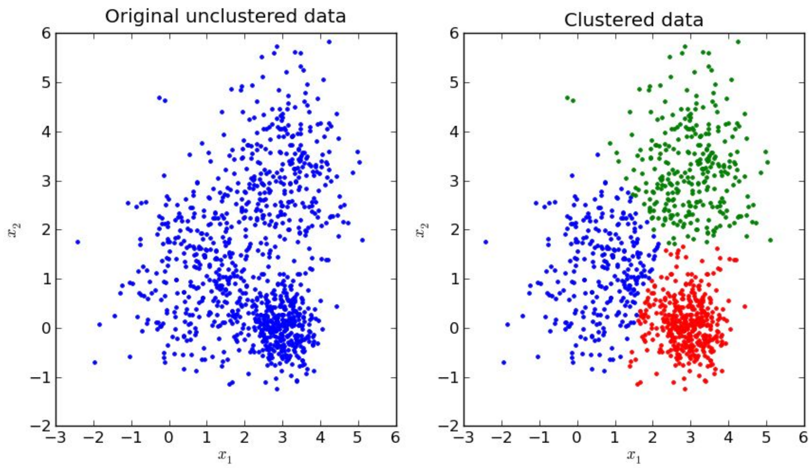


Neural Network

http://homepages.cwi.nl/~rombouts/data/figures/neural_network.png

Introduction to Machine Learning

- There are 3 important areas of machine learning (continued):
  - Unsupervised Learning: the training data consists of a set of input vectors without a corresponding set of target vectors. The purpose of unsupervised learning is to learn the structure and correlation of the data. Example: k-means clustering



K-means clustering

http://i.stack.imgur.com/cIDB3.png

Machine learning empowered instrumentation for assisted surgery

- Surgical skill learning from expert
  - Prior knowledge used for machine learning data is supplied by experienced surgeon.
  - The robot (agent) observes the state transitions of surgeon's (mentor) action, and used these observation to update its own states and action.
- Skill analysis in robotics surgery
  - There are several metrics that could be used to assess skill, such as time completion, instrument speed, instrument trajectory, etc.
  - There are several forms of skill analysis, such as:
    - Explicit skill assessment: using form of cost function defined by expert surgeon.
    - Checklist and rating scales: uses rating scale graded by expert. Needs a lot of expert time

Machine learning empowered instrumentation for assisted surgery

- Skill analysis in robotics surgery (continued)
  - Structured assessment: uses rated checklist on phantom bench-top model. This assessment technique aims to quantifying medical skill evaluation without relying on expert evaluator.
  - Outcome-based analysis: uses metric such as number of complication, morbidity, mortality rates. This technique suffers from the fact that the patient outcome are also strongly dependent on patient characteristic.
  - Motion analysis: surgeon's hand or tool motion are recorded and analyzed. Provides good assessment of dexterity and technical skill level.
  - Time action analysis: surgical procedure broken down into several steps, and the time to complete each one is measured. Time consuming, and do not report how well the particular surgical action is performed
  - Virtual reality: potentially offers a vast amount of valuable information for assessment and analysis of surgical technique. Depends on how well the model correspond to real environment.

Machine learning empowered instrumentation for assisted surgery

- Skill analysis in robotics surgery (continued):
  - Error analysis: number of error made during certain part of the procedure is scored.
  - Implicit skill analysis: uses metric learned by an machine learning approach from a surgeon or group of surgeon.
  - Classification of surgical skill levels: By recording various data, such as tool velocity, from surgeons with various skill levels, it is possible to use unstructured learning to cluster and classify skill level.

Machine learning empowered instrumentation for assisted surgery

- Surgical workflow analysis and episode segmentation
  - Surgical procedure is a combination of surgical acts, which when pertaining to the same specific surgical goal can be grouped into surgical subtasks.
  - Workflow analysis can be conducted to identify surgical subtasks that belong to a surgical intervention, the order of which subtasks can follow each other and possible termination conditions that mark transients between distinct subtasks.
  - The analysis of the surgical workflow is essential to assist surgical navigation and enable design of cognitive surgical system that can adapt and operate in highly dynamic environments.

Toward autonomous robotic surgery

- The role of machine learning in autonomous robotic surgery

Table 1 Aspects of autonomous robotic surgery (ARS) where ML could play an enabling role

Workflow analysis episode segmentation	Surgical procedure broken down into logical subtasks or episodes
Environment modeling	Rigid and flexible registration, reconstruction of environment, recognition of anatomical features and landmarks, mechanical and physiological modeling
Localization	Localization of instrument/robot w.r.t. environment
Robot control	Low-level modeling and robot control
Skill analysis	Analysis of surgical skill, derivation of performance metrics or cost functions for optimization
Critical event detection	Detection of adverse events
Planning and control	High-level trajectory and interaction planning, error handling

Kassahun, Yohannes, et.al. "Surgical robotics beyond enhanced dexterity instrumentation"

- Examples of machine learning used in surgical robotic research:
  - Autonomous knot tying, superhuman performance of surgical tasks, skill transfer from surgeon teleoperator to flexible robot.

Toward autonomous robotic surgery

- Example of possible application of machine learning in surgical robotics:
  - Automation of the surgical operation, training surgeons, classification and standardization of medical practices, saving best strategies of an experienced surgeon, etc.
- Challenges for further work:
  - High-quality medical/surgical data
  - Modeling challenge: Dynamic and deforming nature of living body restrict the use of preoperatively estimated 3D maps and requires analysis of intraoperative data
  - Learning and defining skill analysis metric: finding metrics that adequately capture the characteristic of best practice
  - Adaptation to unknown or yet observed situations: system need to be able to cope with unpredictable situations and guarantees the safety of the patient
  - Pipeline for training and deploying autonomous surgical action

Conclusion

- There are various machine learning techniques that can be employed to surgical robotics.
- It is possible to extract the needed mapping from perception to action for various surgical tasks and quantitatively analyze learned skills
- Subdividing surgical procedure into individual surgical task through episode segmentation helps management of the learning process.
- By embedding surgical robot with appropriate decision-making mechanism to choose appropriate skill at appropriate time, robot could gain autonomy overtime.

Comments

- Pros
  - It describes various concepts that could be understood by beginners in this field.
  - Covers many applications of machine learning in surgical robot.
- Cons
  - Very small amount of figures that helps understanding various concepts introduced in the paper.

Questions?

GLOBAL RATING SCALE OF OPERATIVE PERFORMANCE

Please circle the number corresponding to the candidate's performance in each category, irrespective of training level

Category	1	2	3	4	5
Respect for Tissue :	Frequently used unnecessary force on tissue or caused damage by inappropriate use of instruments		Careful handling of tissue but occasionally caused inadvertent damage		Consistently handled tissue appropriately with minimal damage
Time and Motion :	Many unnecessary moves		Efficient time/motion but some unneccessary moves		Clear economy of movement and maximum efficiency
Instrument Handling :	Repeatedly makes tentative or awkward moves with instruments by inappropriate use of instruments		Competent use of instruments but occasionally appeard stiff or awkward		Fluid moves with instruments and no awkwardness
Knowledge of Instruments :	Frequently asked for wrong instrument or used inappropriate instrument		Knew names of most instruments and used appropriate instrument		Obviously familiar with the instruments and their names
Flow of Operation :	Frequently stopped operating and seemed unsure of next move		Demonstrated some forward planning with reasonable progression of procedure		Obviously planned course of operation with effortless flow from one move to the next
Use of Assistants :	Consistently placed assistants poorly or failed to use assistants		Appropriate use of assistants most of time		Strategically used assistants to the best advantage at all time
Knowledge of Specific Procedure :	Deficient knowledge. Needed specific instruction at most steps		Knew all important steps of operation		Demonstrated familiarity with all aspects of operation

Structured Assessment

http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3574562/