Improving Technical Proficiency in Robot-mediated Surgery Through Counterfactual Inquiry

Computer Integrated Surgery II
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Introduction

- For this project we mainly focus on building a robust system to assist surgeons especially novice surgeons perform at expert-level.
- As we all know, Surgeon skill is among the strongest and most direct predictors for patient outcome.
- With the powerful deep learning(DL) algorithm and some Robot Assisted Surgery datasets, we feel it possible to train a neural network to achieve this.
- However, DL algorithm suffers generalization issues and low interpretability.
- Incorporating causality into DL algorithm is one promising way to address these problems.

The Tasks

- Our ultimate goal is to build a robust system to assist surgeons especially novice surgeons perform at expert-level, which consists of three subgoals:
  - Data: Build a suitable dataset for study
  - Analysis: Explore the difference between novice- and expert- level commands
  - Algorithm: Explore suitable deep learning methods and methods to incorporate causal inference mechanisms into deep learning algorithms

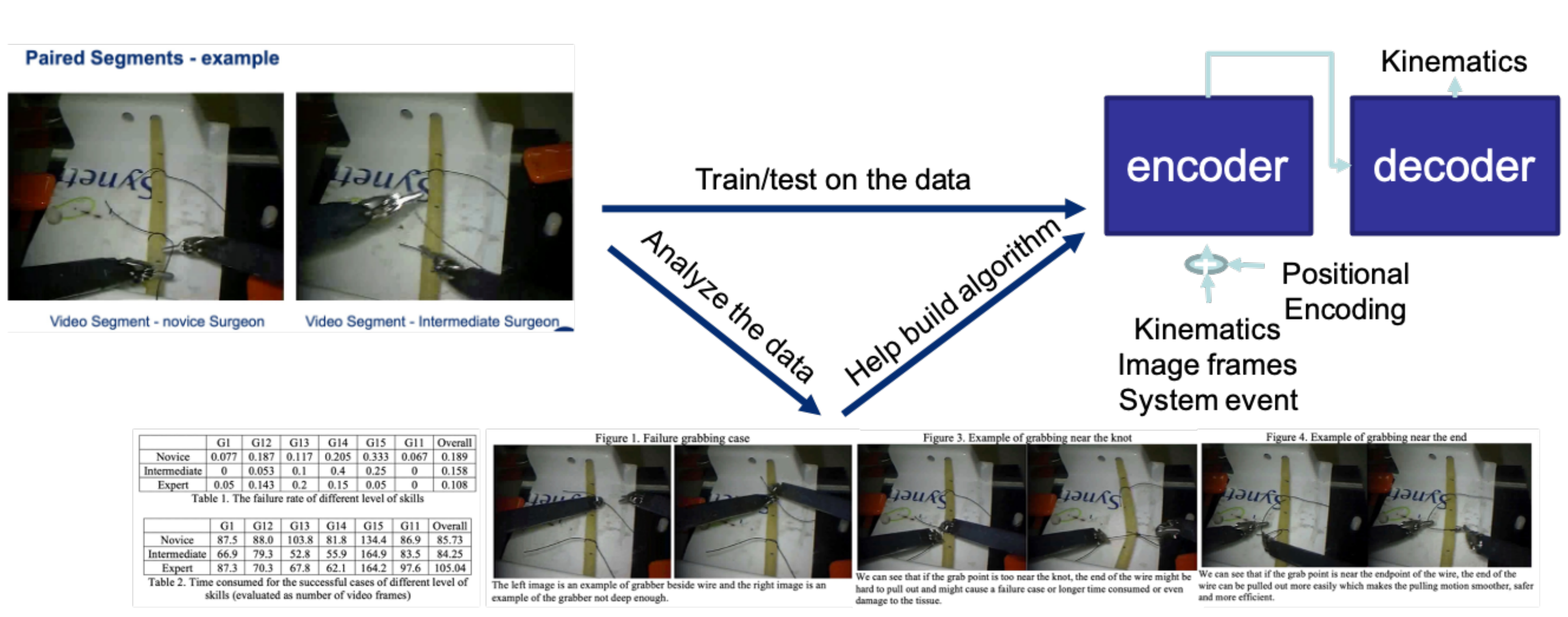
The Solutions

- **Data**:
  - Manually segmenting and paring videos.

    Reannotate the videos with more detailed gesture & motion division, divide videos into motions and annotate each motion with its purpose and state.
  - Making paired segments into same length

    Algorithm: dynamic time warping

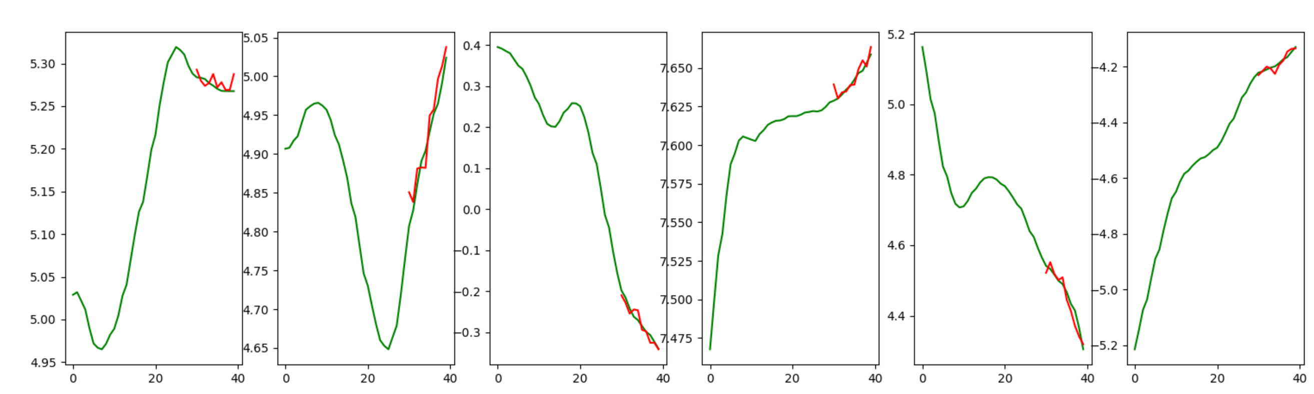
    Distance function: l1 norm between normalized traveled distance
- **Analysis**:
  - Calculate the statistic of the failure rate of motions and time consumed for successful motions for surgeons at different levels.
  - Explore the direct causes of the failure and successful motions.
- **Algorithms**:
  - DL algorithm: build a transformer architecture for the kinematic predictions.
  - Causal Inference: will explore deep structural causal model and adversarial training methods



Overall solutions for each task

Outcomes and Results

- **Data**:
  - Reannotated the Knot-tying subset of the datasets.
  - Divide all videos and kinematics series into segments according to the annotation
  - Implemented the dynamic time warping algorithm and tested on paired segments.
- **Analysis**:
  - Quantitative analysis of the difference of performance of surgeons at different levels.
    - Difference of gesture-wise failure rates
    - Difference of time consumed for successful motions
  - Qualitative analysis for the direct causes
    - Accuracy of perception
    - Motion Choices
  - Proposed some future directions (e.g. Informative datasets, Detailed affordance detections, and Precise real-time 3d space perception) for the exploration of surgery training or automated surgery research.
- **Algorithm**:
  - Build the basic transformer model for kinematics prediction and corresponding dataloader and training pipelines
  - Performed some ablation study for the design choice of the architecture.



Example Output of the kinematics predictor

Future Work

- Try more mechanisms to enhance the transformer.
- Incorporate causal inference methods into the model.
- Build a more detailed annotated datasets for study.

Lessons Learned

- Document the code before implementation. This will help the corporation and the code test.
- Make a well-formed schedule and adjust the schedule accordingly frequently.

Credits

- Hao Ding: solely finish all the tasks.
- Prof. Unberath: : Advised students for all tasks.

Support by and Acknowledgements

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