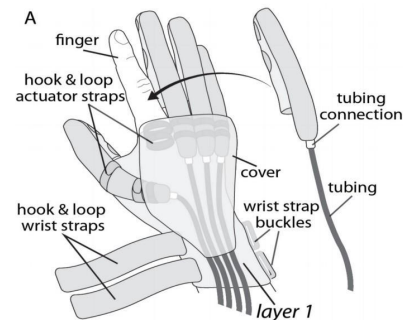


2022 Capstone

Shape Estimation and Data-driven Intelligent Control of Soft Robotic Upper-limb Exoskeletons for In-home Telerehabilitation



Chen Liu, Jiazhi Xu, Xiaojia Pan, Yinuo Zhao

Client - MERIT Lab, Dr.S.Farokh Atashzar
Dr.Jacqueline Libby

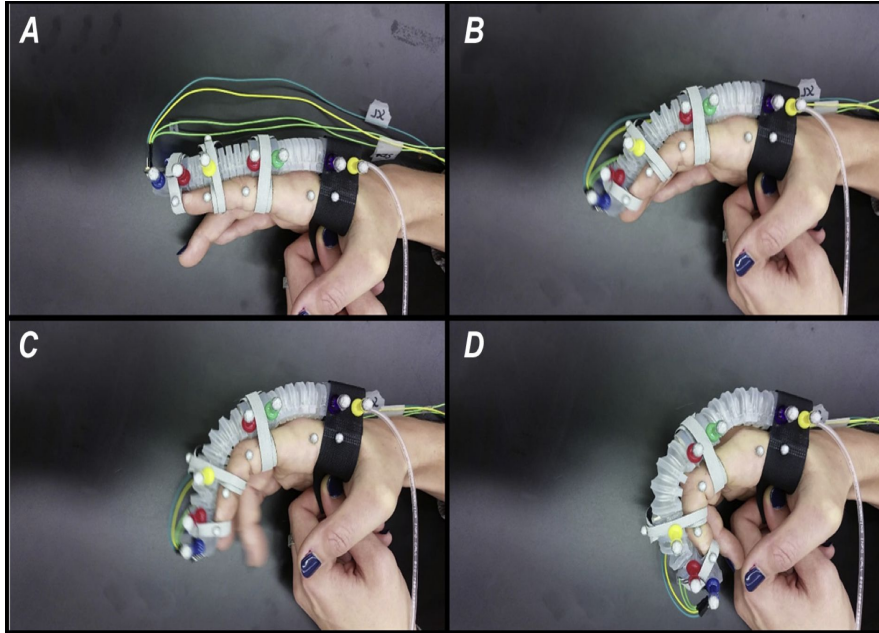
Center for Urban
Science + Progress
Progress Presentation



Meet with the Team



Why Soft Robotics ?



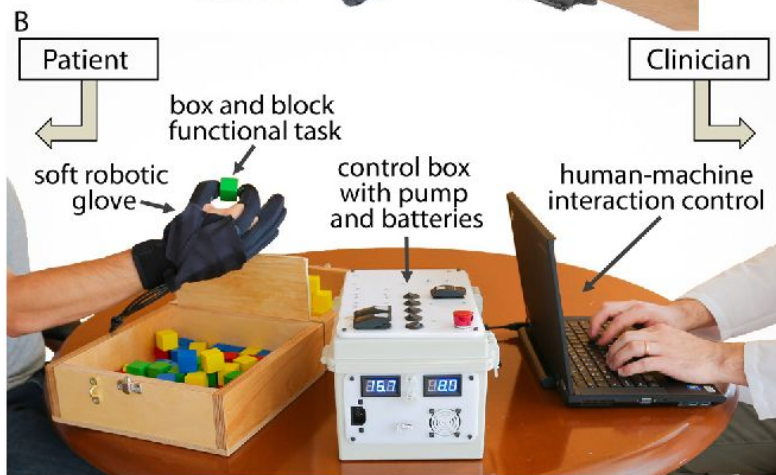
Product Function

Helping patients with limited mobility to maximize their ability to regain self-care in daily life

Advantage

- Light weight
- High wearing comfort
- High adaptability to target shape
- Low contact and collision force with human body

Soft Robotics in Telerehabilitation



Application Scenarios

- In-home Rehabilitation Physical Training
- Develop microtype to physical therapy

Target People

- People with neuromuscular diseases such as Parkinson's disease and stroke
- People suffering from other conditions that limit their mobility

Actionable Policy Insights

Existing Policy

2011 “National Robotics Plan”

Building U.S. leadership in
next-generation robotics
and applications to **help
bring manufacture
industry back**

2013 “US Robotics Technology Plan”

Utilized robotics technology to **improve
society’s quality of life**

2017 “National Robotics Plan 2.0”

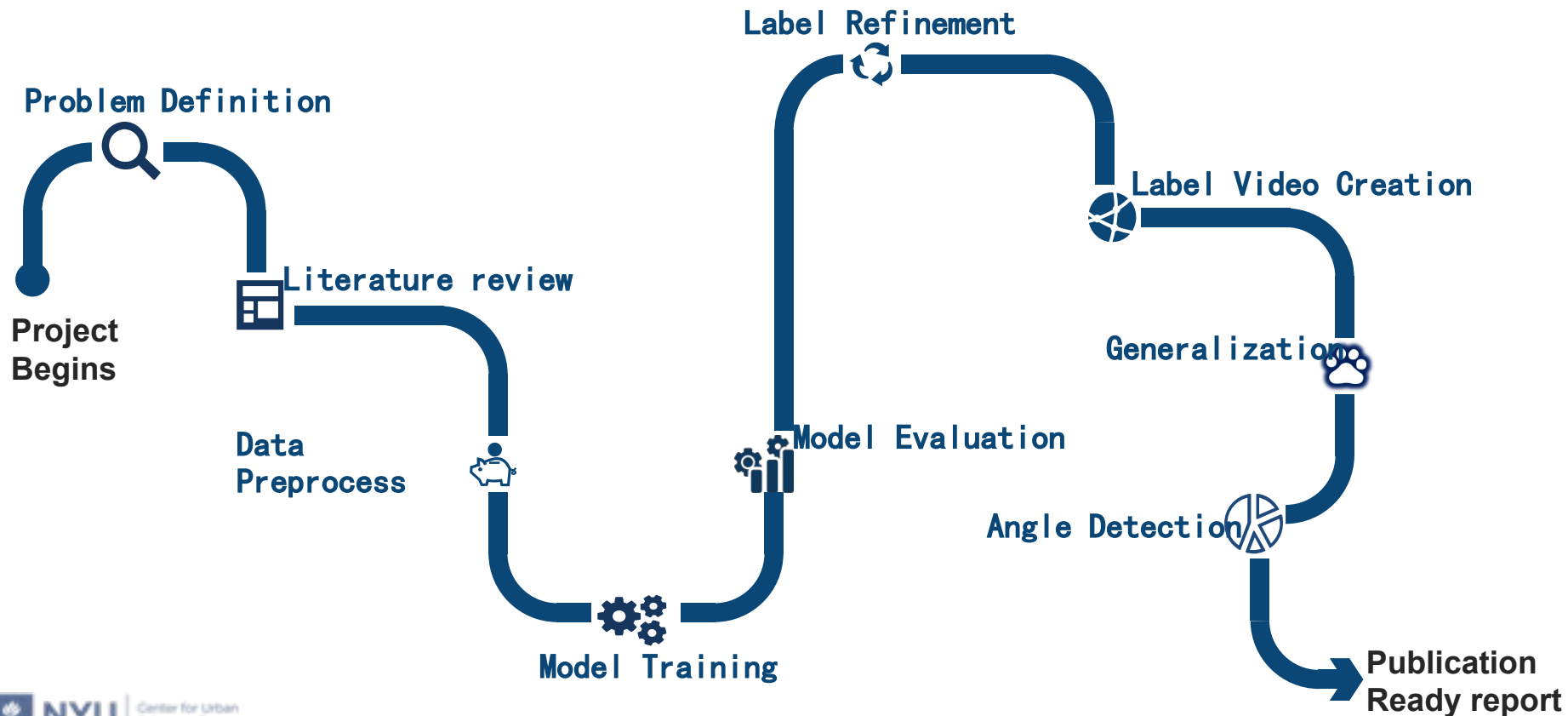
Support basic robotics research
and accelerate the development
and practical application of
collaborative robots



Potential Future Plan

- Address the self-care issues of an **aging society**.
- Let robotics be more **affordable & safe & accessible**.
- Allow **affordable rehabilitation** to everyone.
- Develop **microtype robotics** to physical therapy.
- Propose **Medicare reimbursement** for physical therapy products for post-war wounded service members.

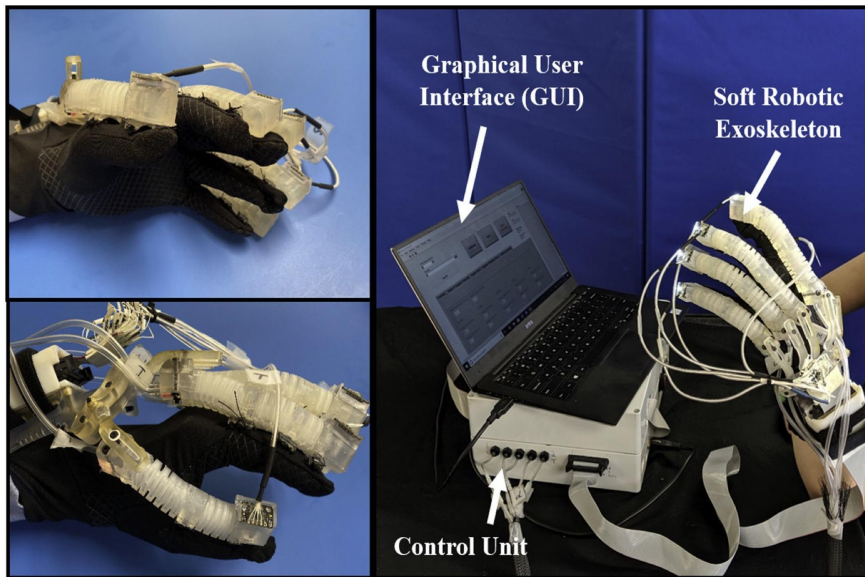
Overall Workflow



Overall Contribution

- **Process seven raw videos and creates relative datasets** for multi-segmentation shape estimation.
- Implement and modified **eleven models** for different Lab actuators.
- Classify **12-21 actuator features** and **track the skeleton movement** by detecting a set of features.
- Evaluate out **the optimal neural network** for the actuators.
- Produce **interactive likelihood graph** for frame refinement.
- Create **function** for angle detection based on model result.

Problem Definition



Major Challenge

Perform smooth and correct shape estimation on banding angle

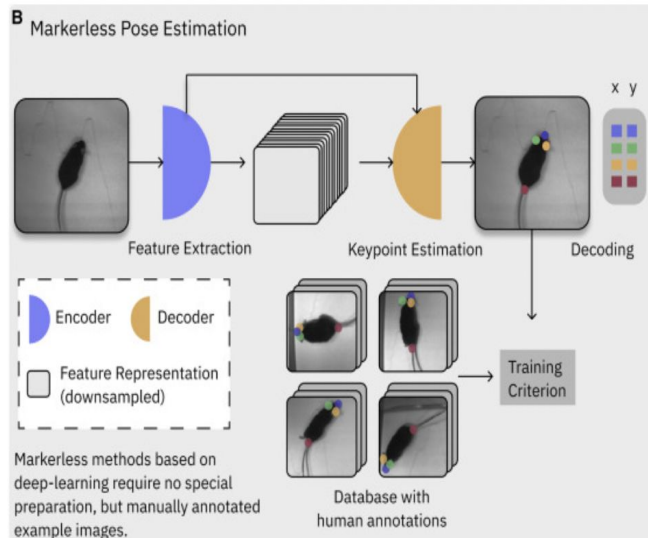
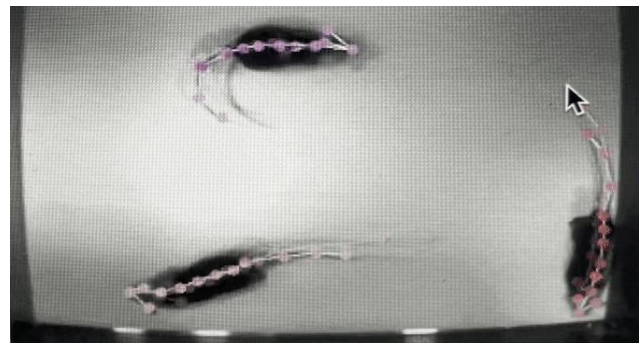
Priority Mission

- Build and train ML model via DeepLabCut
- Find the optimal pre-trained model
- Improve shape estimation for soft robotic




Literature Discovery

Shape estimation

- Tradition methods
- Markeless shape estimation
- Machine Learning (ML) methods
- ML methods:
 - Supervised learning
 - Semi-Supervised learning
 - Unsupervised learning
 - **Transfer learning**
 - reinforcement learning



A Traditional Methods

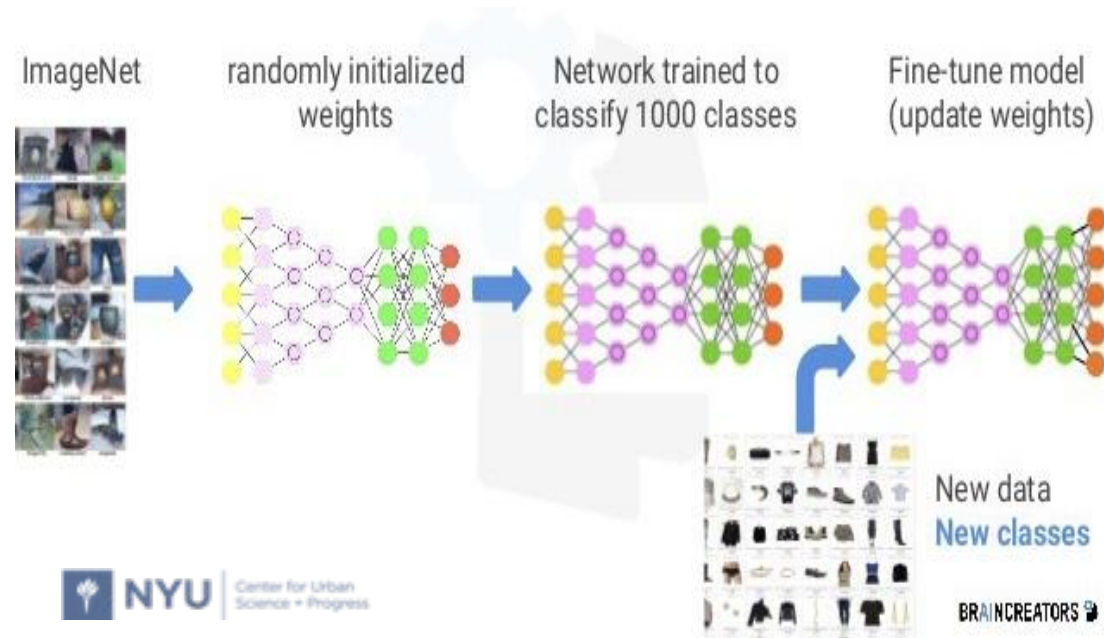
-  Lighthouse Tracking
-  IMU-based Tracking
-  Color-based Tracking

Traditional methods work *ad-hoc*: subjects need to be prepared, but no annotation is needed.

Literature Discovery

Transfer Learning: Pre-trained Model Approach

Transfer learning (TL) improve model performance and speed by **leveraging the already existing labeled data** of some related tasks.

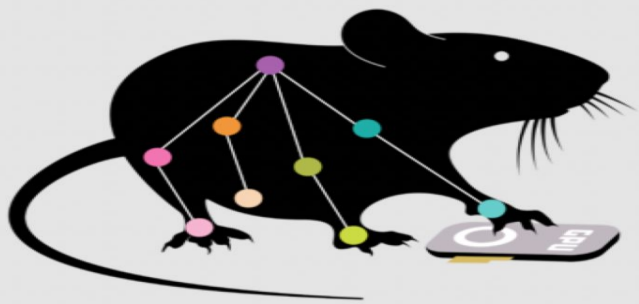


- Pre-Trained Models
- All these model below are pre-trained on **ImageNet**
 - ResNet_50
 - MobileNetV2_1.0
 - MobileNetV2_0.75
 - EfficientNet_B6

Literature Discovery

DeepLabCut (DLC)

- DeepLabCut is a **toolbox** for markerless pose estimation of animals performing various tasks.
- it performs **frame-by-frame prediction** and therefore can also be used for intermittent occlusions.
- It also solve the problem of **detecting body parts in dynamic environments**.



DeepLabCut :
a software package for
animal pose estimation

Data Preprocess Workflow

Actuator Model Creation

- I. Create project in client required naming conventions
- II. Upload actuator videos and copy into target folder
- III. Make sure select the multi-animal option

Please choose an option:

☒ Create new project ☐ Load existing project

Name of the Project:

Name of the experimenter:

Choose Videos:

Optional Attributes

☒ Select the directory where project will be created

☒ Copy the videos

☒ Is it a multi-animal project?

Parameter Adjustment

- I. Edit the config file
- II. Set up label quantity
- III. Set up individual skeleton

```
config.yaml

# Project definitions (do not edit)
Task: PkSsEnetYu02
scorer: Yuna
date: Jun24
multianimalproject: true
identity: false

# Project path (change when moving around)
project_path: /Users/yinuozhao/PkSsEnetYu01-Yuna-2022-06-24-main

# Annotation data set configuration (and individual video cropping parameters)
video_sets:
  /Users/yinuozhao/PkSsEnetYu02-Yuna-2022-06-24/videos/pink02-train-2022-02-21-20.05.09.mp4:
    crop: 0, 1080, 0, 1920
  /Users/yinuozhao/PkSsEnetYu01-Yuna-2022-06-24-main/videos/pink02-train-2022-02-21-20.05.09.mp4:
    crop: 0, 1080, 0, 1920
individuals:
  - individual1
uniquebodyparts: []
multianimalbodyparts:
  - bodypart1
  - bodypart2
  - bodypart3
  - bodypart4
  - bodypart5
  - bodypart6
  - bodypart7
  - bodypart8
  - bodypart9
  - bodypart10
```

Time to get the frames ! !

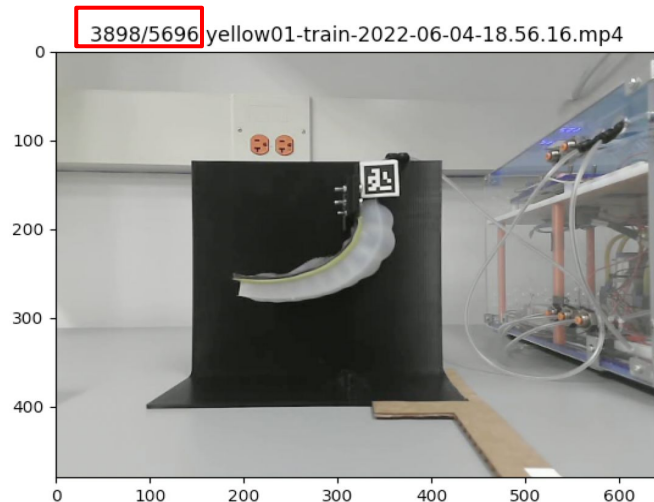
Data Preprocess Workflow

Data Extraction from videos

Based on Client's Requests :

- I. Manually grab frames from videos
- II. Normally grab 3% ~ 5% frames per video
- III. Extract more bulging parts frames than straight ones

DeepLabCut2.0 - Manual Frame Extraction



Select the config file

Optional Attributes

Choose the extraction method

☐ automatic

☒ manual

Want to crop the frames?

☐ False

☐ True (read from config file)

☐ GUI

Need us

Grab Frames

0

3898

5696

Start Frame Index
Range of frames

1

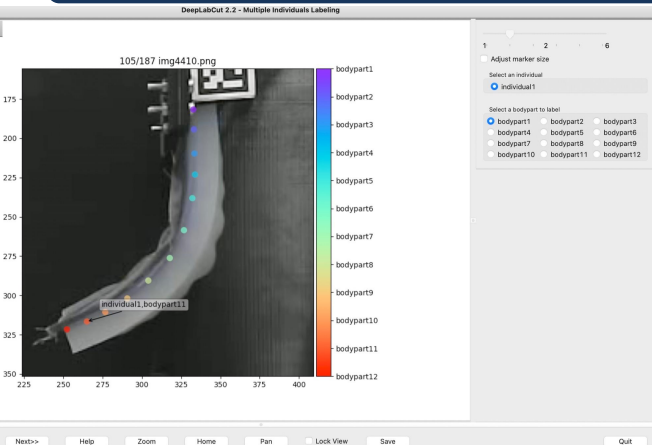
Number of Frames
Update

Time to make the dataset ! ! !

Data Preprocess Workflow

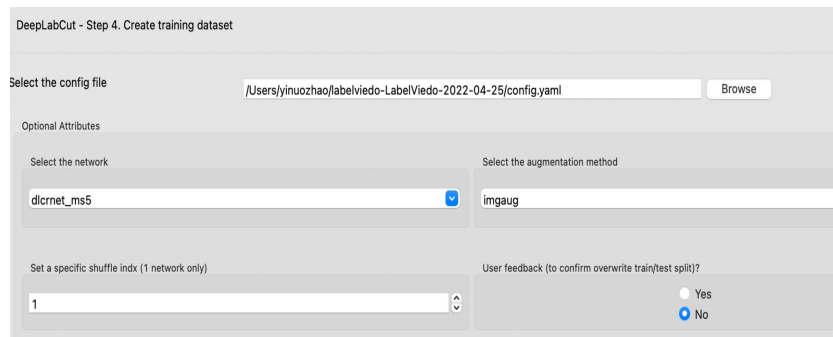
Label Dataset Creation

- I. Manually label the extracted frames
- II. Create the key points dataset of labels
- III. Check if the labels and skeleton correct



Training Dataset Creation

- I. Set training parameters
- II. Choose pre-trained network
- III. Create dataset for model training



Ready For Model Training !!!

Data Preprocess

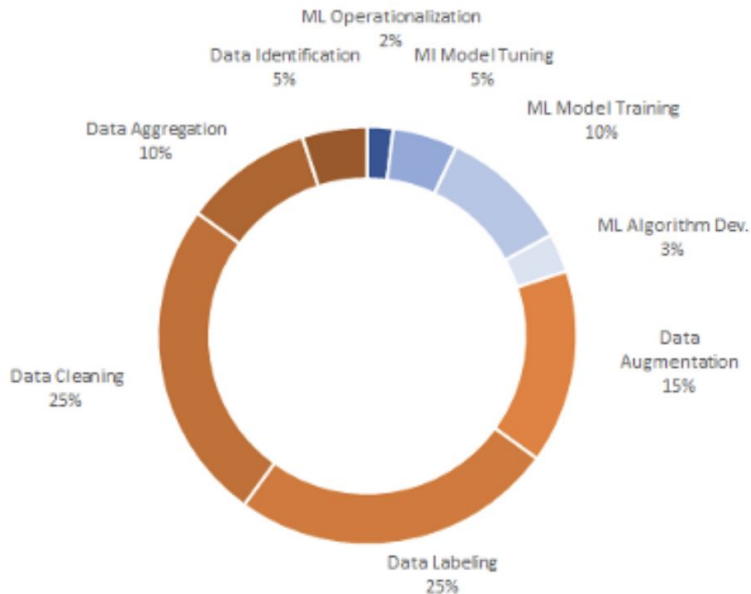
80% of time spent for Machine Learning Projects is allocated to Data related tasks

Business Value created

Based on 2022 On-Demand label price formula

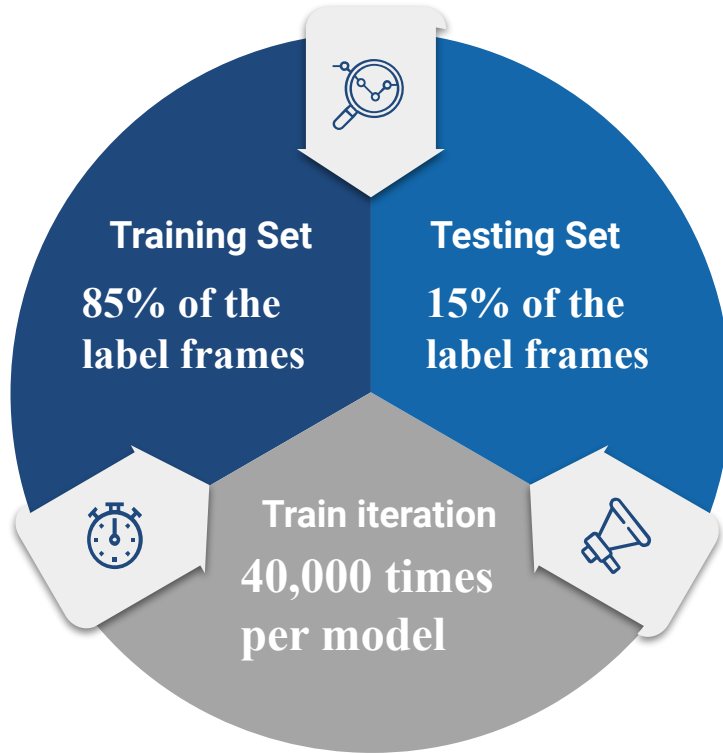
➤ Point-annotation :

\$0.08/image frame + 0.04/point



| Actuator label type | Total Image frame | Labeled Frame | Frame Refine | Point per frame | Label times | Cost |
|---------------------|-------------------|---------------|--------------|-----------------|-------------|--------|
| Pink Sealing 02 | 697 | 80 | 30 | 12 | 9 | 530.96 |
| Pink Vally 01 | 1162 | 40 | 56 | 11 | 4 | 261.92 |
| Pink Vally 02 | 697 | 35 | 36 | 11 | 6 | 243.2 |
| Pink Peak 01 | 1162 | 30 | 60 | 12 | 6 | 352.16 |
| Pink Peak 02 | 697 | 20 | 52 | 12 | 6 | 263.12 |
| Pink Peak&Vally 01 | 1162 | 40 | 57 | 21 | 2 | 255.92 |
| Pink Peak&Vally 02 | 672 | 24 | 50 | 21 | 6 | 426.72 |
| Blue Seling | 5134 | 60 | 45 | 12 | 7 | 763.52 |
| Yellow Seling | 5696 | 75 | 30 | 12 | 2 | 556.48 |
| Orange Seling | 5211 | 67 | 50 | 12 | 4 | 641.52 |
| Green Seling | 4466 | 65 | 80 | 12 | 2 | 496.48 |
| | | | | | Total cost | 4792 |

Training Parameters



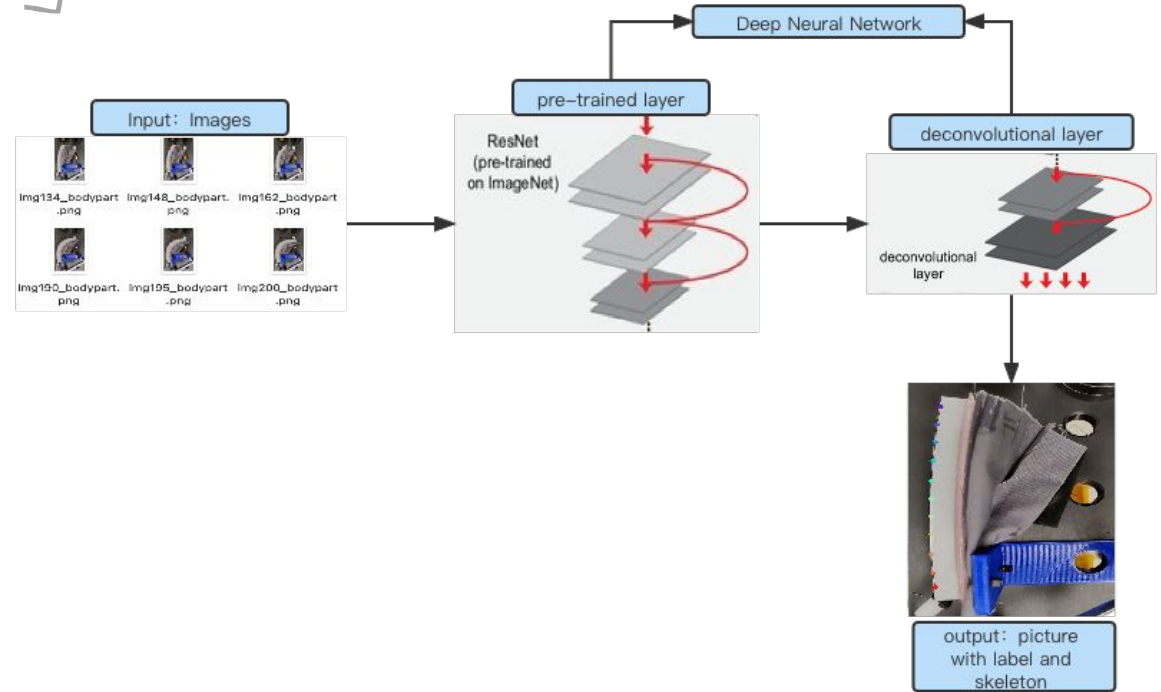
- The part of the model that is **learned from historical training data.**
- **Iterations** is the number of batches needed to complete one epoch
- **Data Augmentation** : Use imgaug for our image augmentation
- Crop frame into suitable size could improve model performance

Methodology



Feature Extraction

- Deep Neural Network
- Input: images
- Output: images with label and skeleton



Methodology



HPC Training

- **High-performance computing (HPC)**
- Use **supercomputers** and **computer clusters** to solve advanced computation problems
- **Improve Training Speed**



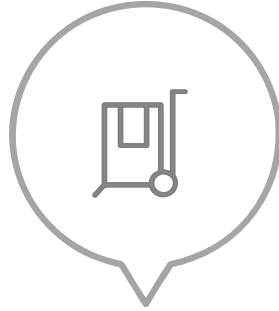
Angle Detection

- **Clockwise Angle Calculation** with coordinate
- Help to prove model accuracy
-

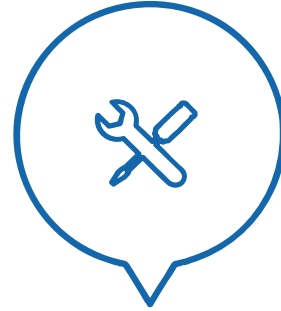
Risk Identification



1st
Manual label
result in bad
labels



2nd
Model is too easy
to re-write



3rd
Can't decide
which frame
to refine

Alternative Approach



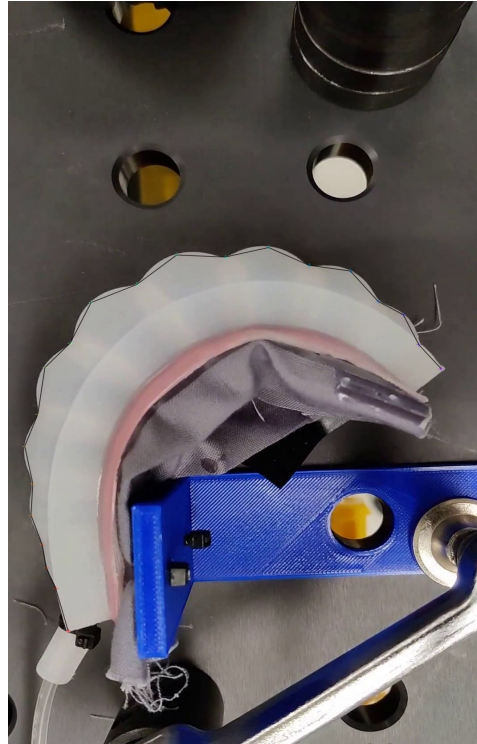
**Label
Problem**

check label
skeleton



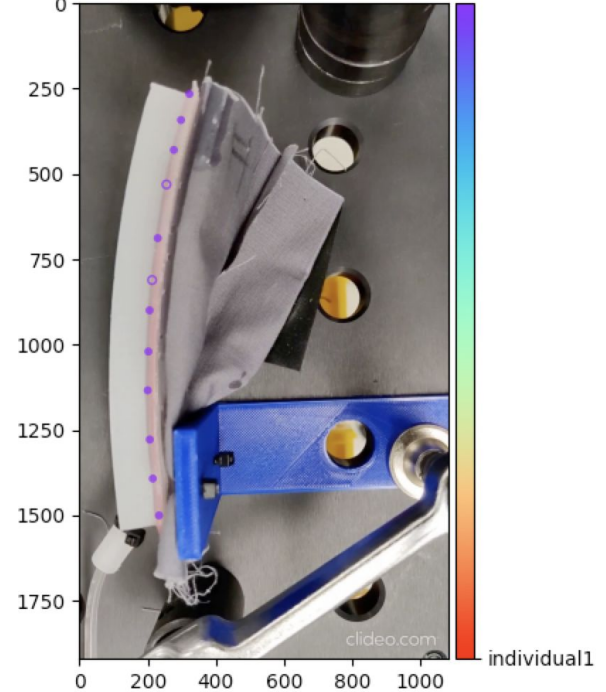
**Label
Problem**

label
refinement



Overall checking

0/12 img126 Threshold chosen is: 1.00



**Individual point checking
based on likelihood**

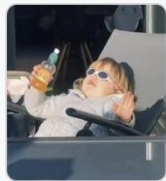
Alternative Approach

Model rewrite

Set Github Organization

Model rewrite

Google drive back-up



capstone2022-soft-robot

Overview

Repositories 40

 Projects

Packages

 Teams

People 5

Shared with me > SoftRoboticsEstimation ▾

Folders

instructions

 results

data

 presentations

Files

General notes

- Don't create "bad" models - keep more exactly the way it is
- (Although the **stiller** video has better model performance and smaller RMSE)
 - You should manually adjust factors, such as α -means
 - We did not Google's related function to calculate errors, also grouping the unrelated parts after movie
 - It's important to be larger with the original movie, because corresponds other key in the content pipeline

- `add(wd301, Kaaps 1777-82 DE)` (for the modern text)
- `add(wd301, Kaaps 1777-82 DE eng)` (for the older orthography)
- `add(wd301, Kaaps 1777-82 DE engproj)` (for the older orthography)

- `color=Focus-Midlet.gc+Label+MidletForm+Color+FFFF0000`
- Color
 - `rgb, r, g, b` green blue orange black white
 - `0x, 01, 02, 03, 04, 05, 06, 07, 08, 09, 0A, 0B, 0C, 0D, 0E, 0F`
- Font

- actionItems

[illegible]

Selected Papers

Alternative Approach

Frame Specification

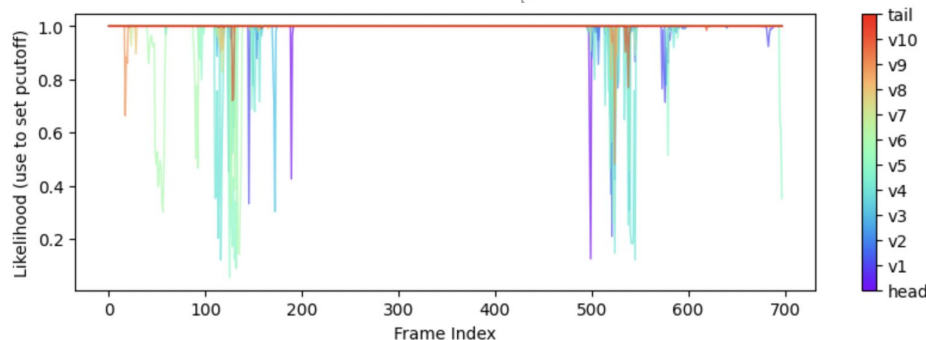
Extract outliers in command line

Frame Specification

Likelihood Graph

Command method

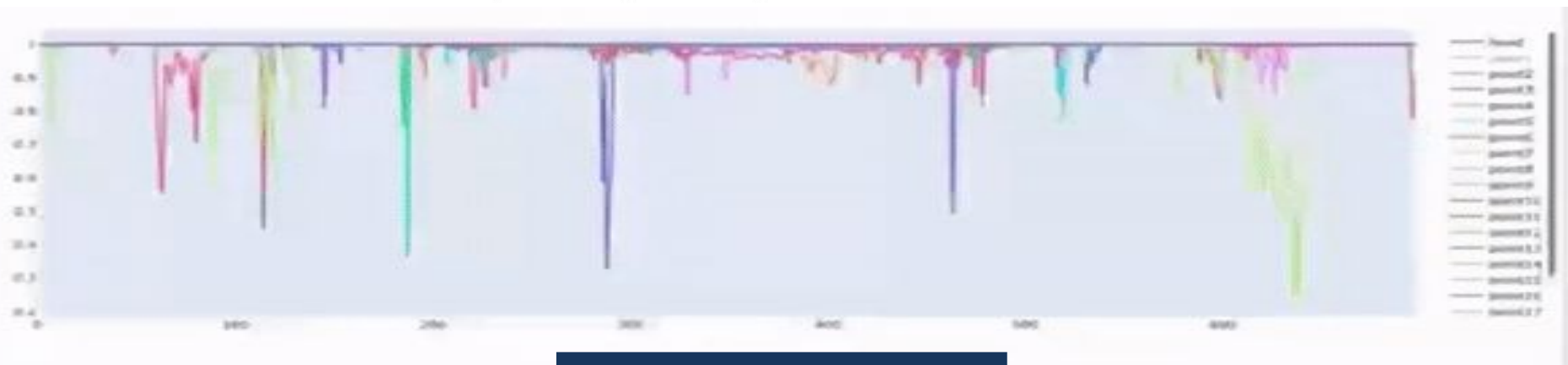
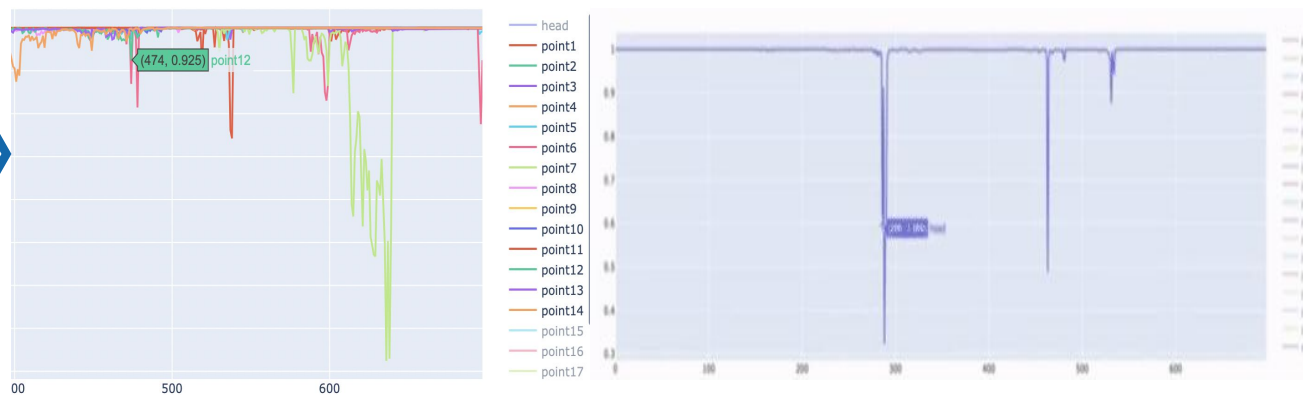
```
"""
>>> config = '/Users/yinuozhao/Downloads/PkSsEnetYu03-main/config.yaml'
>>> video = '/Users/yinuozhao/Downloads/PkSsEnetYu03-main/videos/pink02-train-2022-02-21-20.05.09.mp4'
>>> deeplabcut.extract_outlier_frames(config, video, outlieralgorithm='uncertain',
p_bound=0.95, shuffle=0)
Method uncertain found 15 putative outlier frames.
Do you want to proceed with extracting 50 of those?
If this list is very large, perhaps consider changing the parameters (start, stop, p_bound, comparisonbodyparts) or use a different method.
yes/noyes
Frames from video pink02-train-2022-02-21-20.05.09 already extracted (more will be added)!
Loading video...
Duration of video [s]: 23.266666666666666, recorded @ 30.0 fps!
Overall # of frames: 406 with (cropped) frame dimensions:
Kmeans-quantization based extracting of frames from 4.19 seconds to 17.68 seconds.
Let's select frames indices: [139, 155, 156, 157, 158, 159, 214, 488, 490, 496, 499, 501, 502, 507, 513]
```



Original DLC Graph

Frame Specification

Interactive Likelihood Graph



New Interactive Graph

Evaluation Metrics

Result: Model Comparison

Pink Sealing



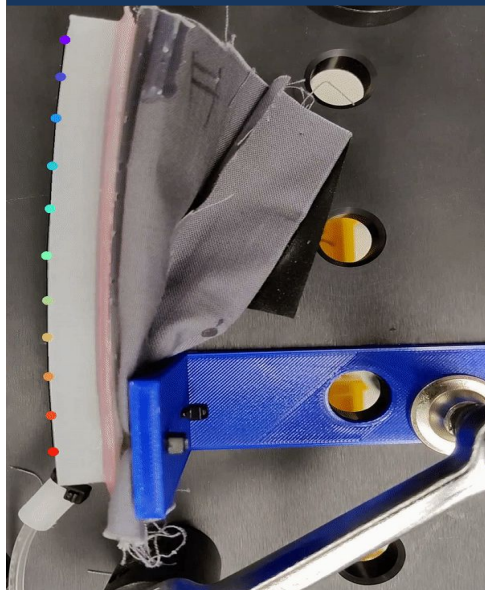
MobileNetV2_0.75

ResNet_50

EfficientNet_B6

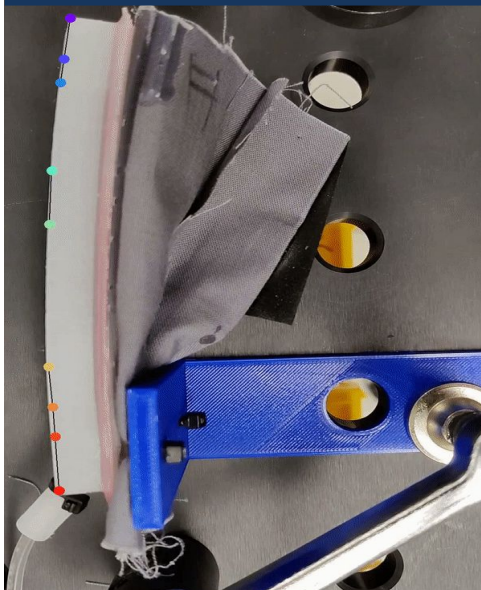
Result: Label Comparison

Bulging Peak



PinkPeak_ResNet_50

Bulging Valley



PinkValley_ResNet_5

PinkPeakVally_ResNet_50

Result: Other Color Actuators

Blue Model

Yellow Model

Orange Model

Green Model

Result: Angle Detection

Reference for the project

- Mathis, A., Mamidanna, P., Cury, K., Abe, T., Murthy, V., Mathis, M. and Bethge, M., 2018. DeepLabCut: markerless pose estimation of user-defined body parts with deep learning. *Nature Neuroscience*, 21(9), pp.1281-1289.
- Mathis, A., Biasi, T., Schneider, S., Yüsekönül, M., Rogers, B., Bethge, M., & Mathis, M. W. (2020, November 12). *Pre-training boosts out-of-domain robustness for pose estimation*. arXiv.org. From <https://arxiv.org/abs/1909.11229>
- Lauer, J., Zhou, M., Ye, S., Menegas, W., Nath, T., Rahman, M. M., Santo, V. D., Soberanes, D., Feng, G., Murthy, V. N., Lauder, G., Dulac, C., Mathis, M. W., & Mathis, A. (2021, January 1). *Multi-animal pose estimation and tracking with deeplabcut*. bioRxiv. From <https://www.biorxiv.org/content/10.1101/2021.04.30.442096v1>
- Raman, S., Maskeliūnas, R., & Damaševičius, R. (2021, December 24). *Markerless dog pose recognition in the wild using resnet deep learning model*. MDPI. From <https://www.mdpi.com/2073-431X/11/1/2>
- Reiter, A., Bajo, A., Iliopoulos, K., & Simaan, N. (2012, April). *Learning-based configuration estimation of a multi-segment Continuum Robot*. IEEE Xplore. From <https://ieeexplore.ieee.org/document/6290702>

Question Time

Any Questions ?



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<xp2027@nyu.edu>
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<yz8461@nyu.edu>

THANKS
for being here

A close-up photograph of a green leaf, likely from a plant. The leaf is a vibrant green color and has a smooth, slightly curved shape. In the lower-left portion of the leaf, there is a faint, hand-drawn smiley face. The face consists of two small, dark dots for eyes and a simple, curved line for a mouth. The background is a soft, out-of-focus blue, suggesting a sky or a wall.