Optimizing Physical Hand Training Effectiveness Using Deep Learning and Unsupervised Learning

Names: Peter Asbæk Skøt (S185185) and Jacob Asbæk Wolf (S236897)
Course: Applied Machine Learning and Big Data
Course ID: 62T22
Date: May 30, 2025

Agenda

- 1 min   Motivation
- 1 min   Problem and Use Case
- 2 min   CNN Model
- 2 min   K-Means Model
- 2 min   Software Demo (Live Inference)
- 2 min   Conclusion and Perspectives

Public

Technical University of Denmark   Optimizing Physical Hand Training Effectiveness Using Deep Learning and Unsupervised Learning   **2**

Motivation

The situation

- Imagine being 19 with CP and cognitive disabilities.
- Hand therapy can improve your quality of life, but it is demotivating.
- Jacob's son had CP after a serious meningitis as a baby.

Our reflection

- Could machine learning motivate and support training at home?

Our solution

- A simple software solution providing live motivational feedback.
- We will now show you what we built…

Public

Technical University of Denmark   Optimizing Physical Hand Training Effectiveness Using Deep Learning and Unsupervised Learning   **3**
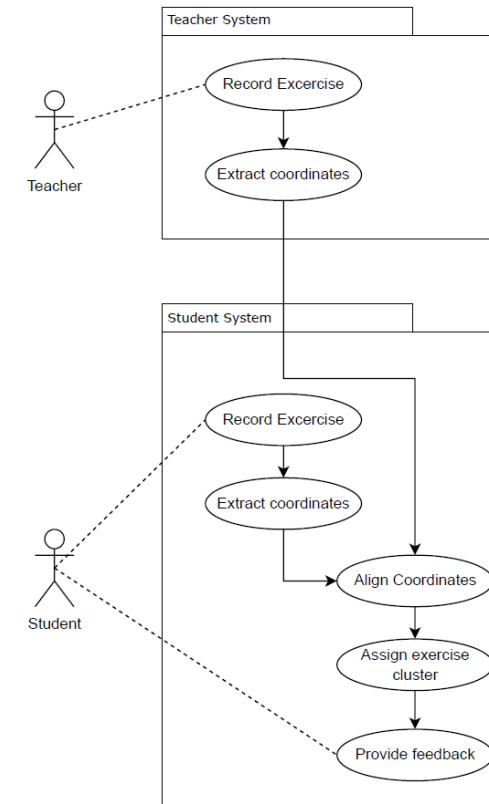
Problem and Use Case

Problem

Hand exercise training targeted for patients with hand mobility issues with the goal of making the training more effective and the patient more motivated.

Hereunder:

1. Track hand positions.

2. Rate the students hand positions against the teacher's hand positions.

3. Apply supervised and unsupervised machine learning to a live stream

Use Case

Public

Technical University of Denmark   Optimizing Physical Hand Training Effectiveness Using Deep Learning and Unsupervised Learning   **4**

CNN Model

Purpose:

- Extract 3D landmarks from an image input.

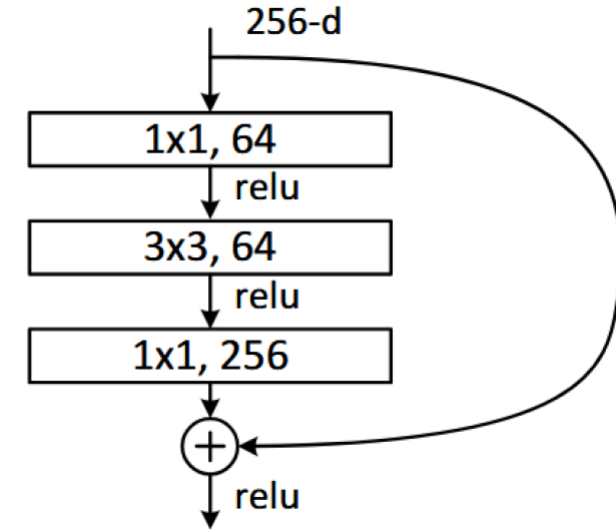**Model data**

Data source: HanCo

Input data: 224x224 RGB images of hands

Output data: 21 normalised 3D coordinates of landmarks.

Model Architecture

Backbone: ResNet50 + custom model head

Pretrained weights: ImageNet

Layer	Dimensionality
FC + ReLU	2048 x 2048
FC + ReLU	2048 x 2048
FC	2048 x 63

Table 1: Model head architecture with dimensionality of each layer.

Public

Technical University of Denmark　　Optimizing Physical Hand Training Effectiveness Using Deep Learning and Unsupervised Learning　　5

CNN Results

- Strong within-dataset generalisation
  - R^2 of 0.982 on test set
  - Healthy loss curve with small train/val gap.
  - High variance explainability across all landmarks

Dataset	MSE Loss	R^2
Train	0.00172	0.985
Val	0.00272	0.982
Test	0.00271	0.982
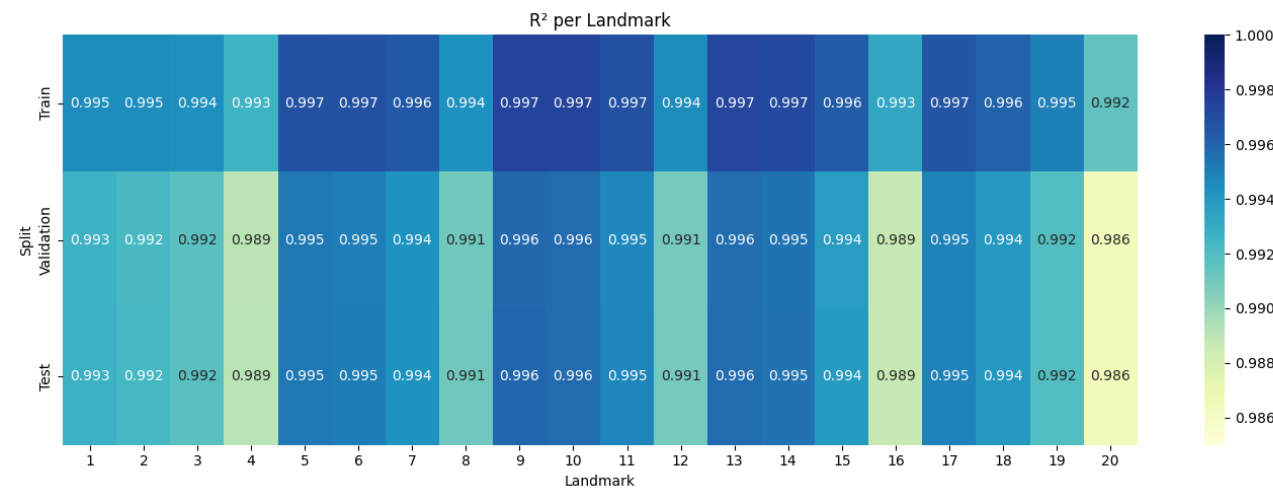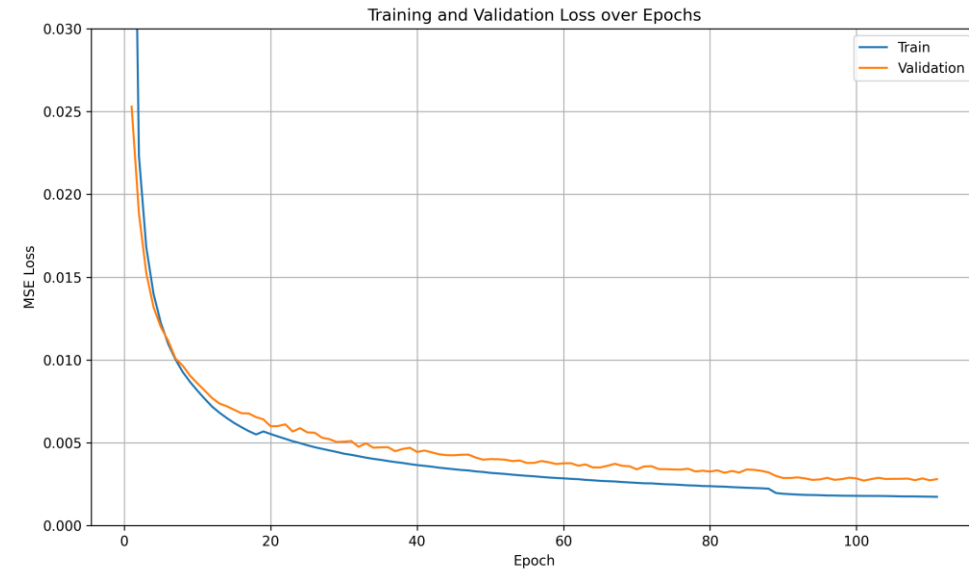
K-Means Model

Purpose

Cluster landmarks into different exercise states

Model Data

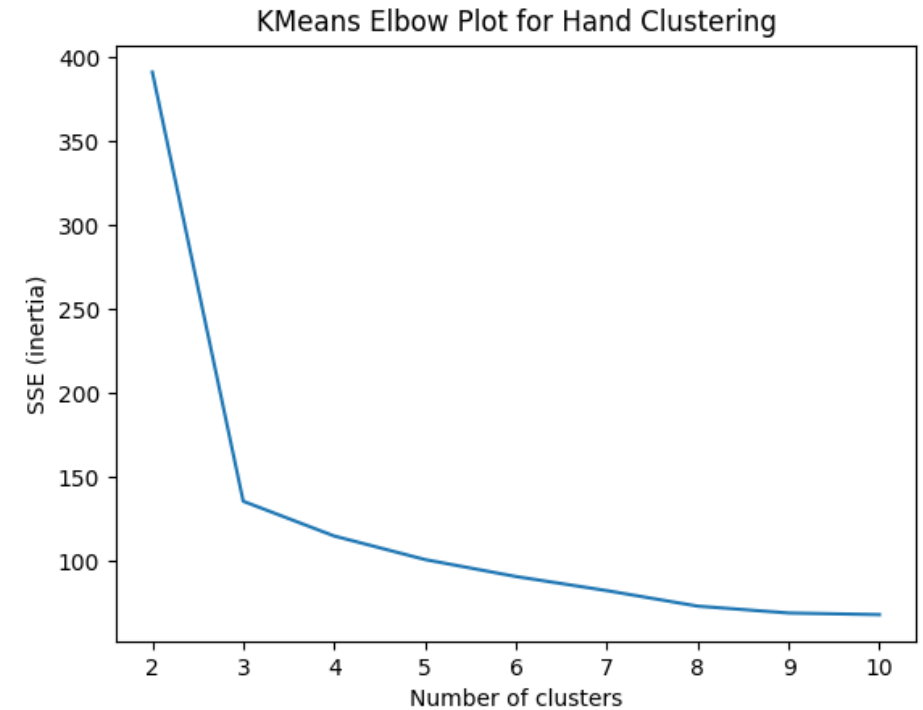Data Source: CNN prediction on self collected images (1174)

Input Data:

- 21 normalised 3D coordinates of landmarks
- 3 (1 good and 2 wrong) positions recorded (~400 each)
- Aligned to canonical coordinate system

Output Data: 63 dimensional centroid for each cluster.

Cluster Selection

- Elbow method used
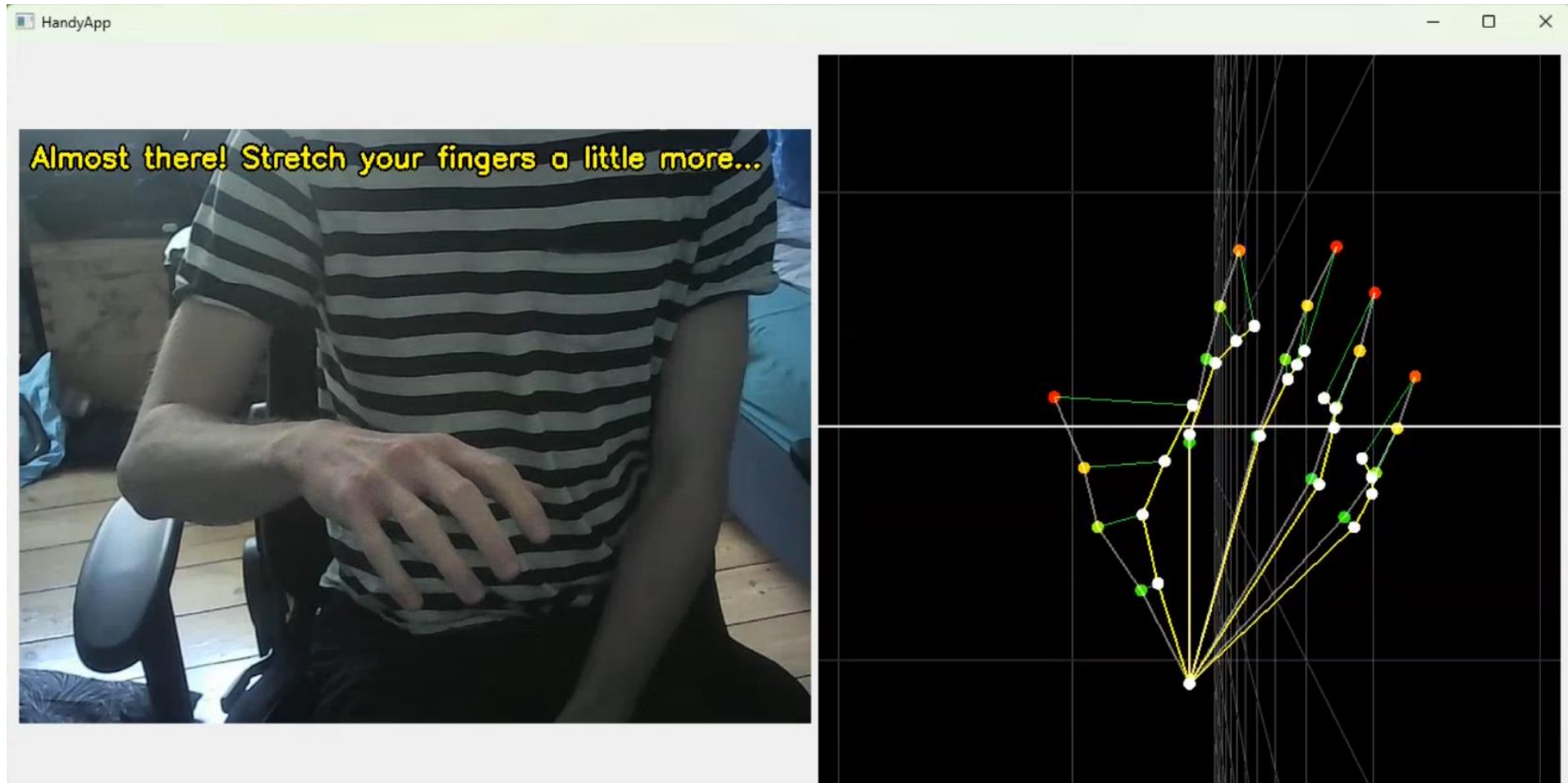- Matches the expected 3 positions

K-Means Results

Centroids match the exercise's three positions well.

- Wrist-landmark distances in each cluster matches our expectations from the three recorded image scenarios.
- The datapoints distribute close to their centroids
- PVE shows good explainability for landmarks further from the wrist (exluding the thumb).

Distance from Wrist to Landmarks 1–20 by Cluster

PVE Heatmap (Cluster × Distance)
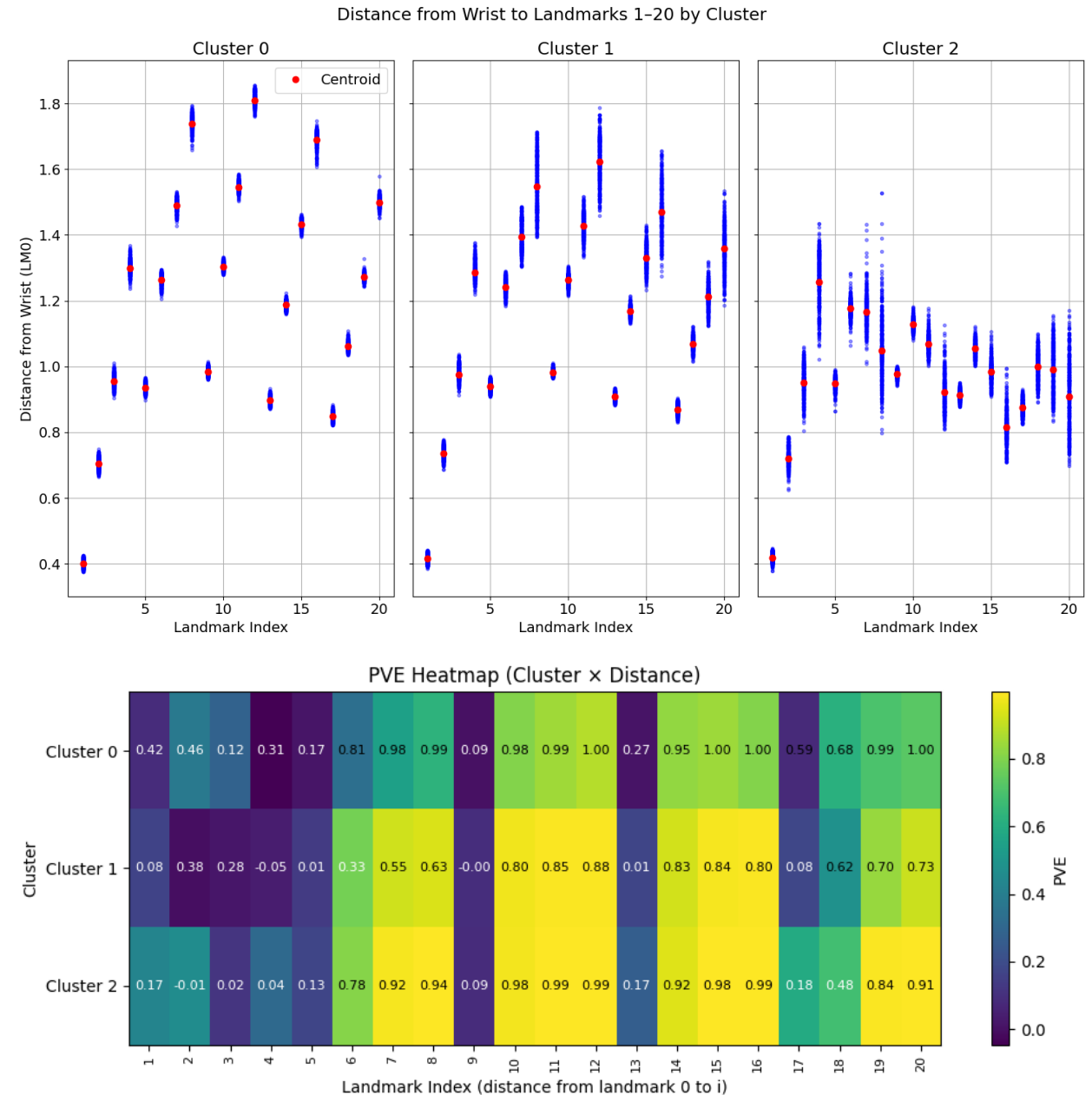
Software Demo (Live Inference)

Software Demo (Live Inference)

Public
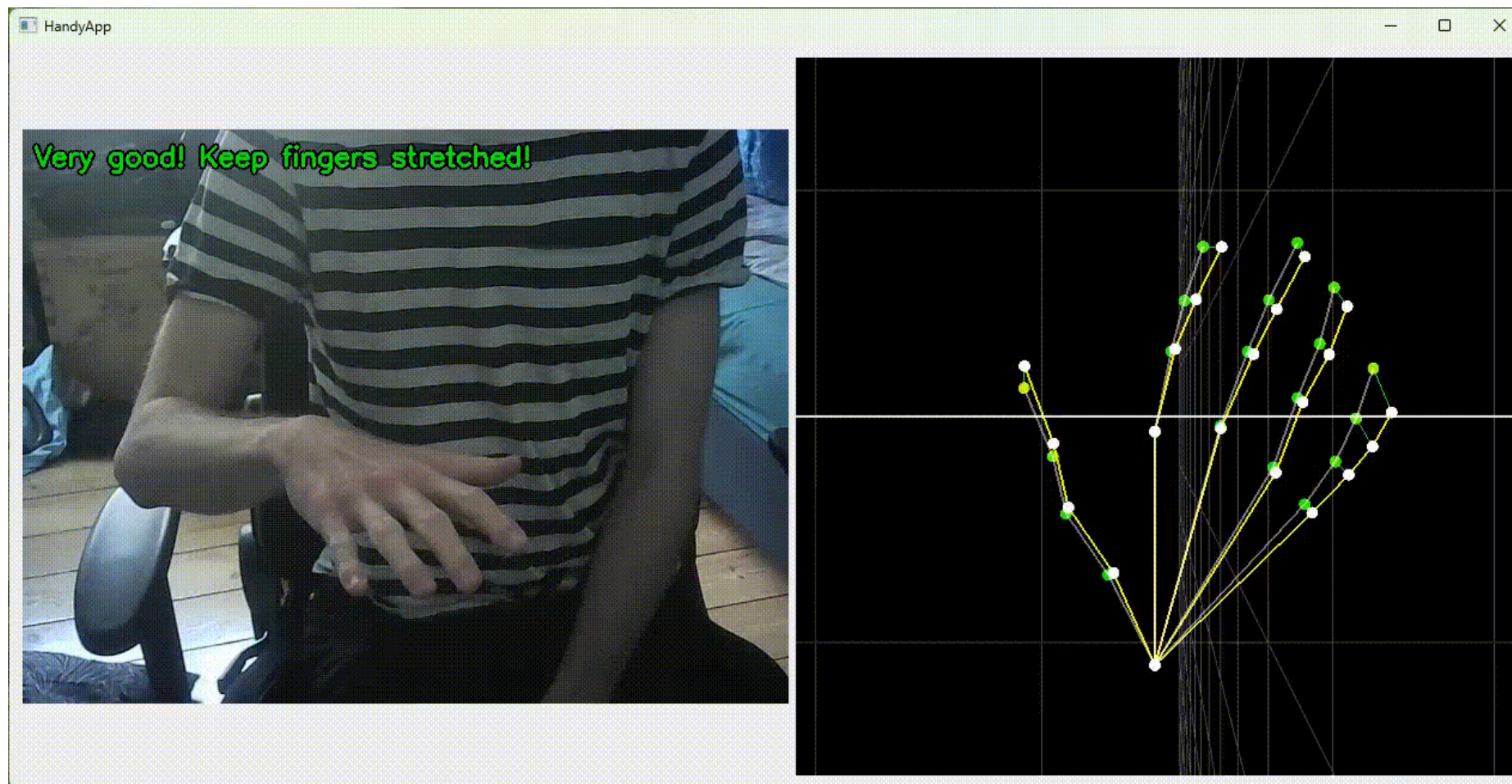
Conclusion

- Good CNN performance/generalisation with $R^2 = 0.982$
- Well performing K-means clustering matching our 3 scenarios
- Well perfoming live-inference software capable of guiding the patient

Perspectives

| Dataset expansion/ Fine tuning | More exercises | Data collection | Regulatory compliance |

| Faster detection/ Mobile devices | Telemedicine |

Public

Technical University of Denmark Optimizing Physical Hand Training Effectiveness Using Deep Learning and Unsupervised Learning **11**