Recognition of Manual Actions Using Vector Quantization and Dynamic Time Warping

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Cognitive Interaction Technology
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ICSI
INTERNATIONAL
COMPUTER SCIENCE
INSTITUTE

Overview

Task

Given recording of hand movements, automatically recognize where known manual actions start and end.

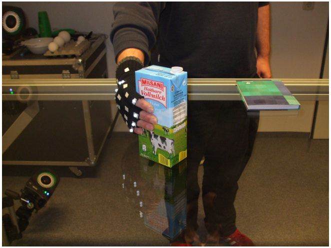
We . . .

- use modified Dynamic Time Warping to locate and classify actions in one step
- use vector quantization to reduce computation time

Pipeline

1. Motion capture
2. Feature computation
3. Modified Dynamic Time Warping
4. Vector quantization

Motion capture setup



- 14 Vicon cameras track 11 reflective markers on one hand
- 20 samples/second
- Vicon software outputs coordinates of each marker

Input for our our algorithm: 33-dimensional time series data

Recordings

Reference manual actions

- Approx. 2.5–5 seconds each
- Move cup to mouth, write in book, pick up cup, . . .

Action sequences

- Concatenation of $\approx$ 10 manual actions ($\approx$ 30 seconds)
- First pick up pen, then write in book, then put down pen, then . . .

Euclidean coordinates cannot be used directly

Requirement

Same motion made at different locations or towards different directions must be recognized as same

Some suitable features

- Inclination of the hand: angle between the table and the axis through the index finger knuckle and baby finger knuckle
- Distance between the thumb tip and the index finger tip
- Velocity of the z-coordinate of the barycenter (center of mass)
- Average distance of five finger tips to barycenter

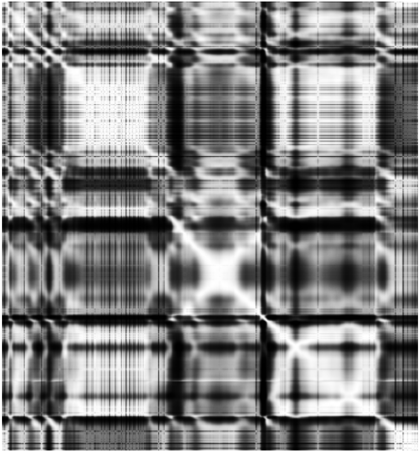
Modifying Dynamic Time Warping to locate actions

First:

Regular Dynamic Time Warping (DTW)

- Compares two recorded signals from start to end, allowing distortions on time axis
- Outputs a distance

DTW example



Shown here

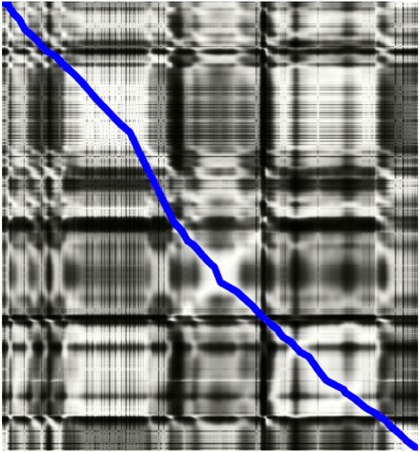
Comparison of all vectors of one sequence to all of other sequence.

White pixels: Low euclidean distance (vector norm)

DTW example

action sequence 1

action sequence 2



Shown here

Comparison of all vectors of one sequence to all of other sequence.

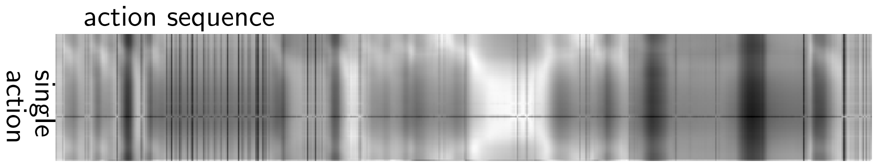
White pixels: Low euclidean distance (vector norm)

Blue: Path with lowest sum of distances (DTW distance)

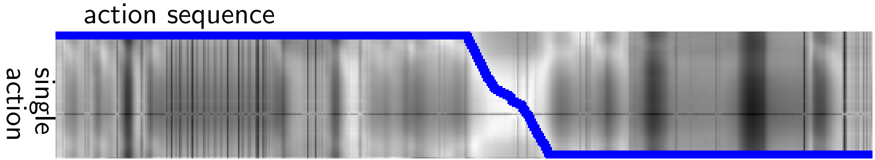
Modification to Dynamic Time Warping

- Inspiration from bioinformatics: They use “semi-global” alignment to find a pattern within text
- Idea: Add (conceptual) “white” row above and below matrix
- $\rightarrow$ sequence 2 may now start and end anywhere within sequence 1
- Output: DTW distance **and** location of searched sequence

Example of modified DTW

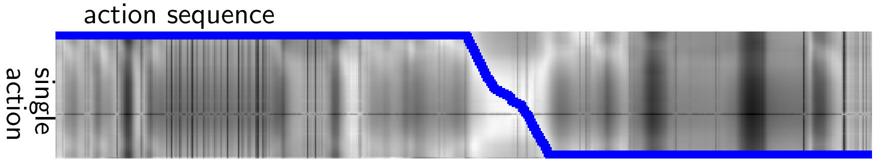


Example of modified DTW



Blue: Path with lowest sum of distances

Example of modified DTW



Blue: Path with lowest sum of distances

Remaining problem

All $n \cdot m$ euclidean distances must be computed

(n: length of action sequence, m: length of reference action)

Speed up computation using symbols

Input data: Sequences of feature vectors from $\mathbb{R}^d$

- Idea: Map each feature vector to a **symbol from a finite set**
- Similar vectors are mapped to the same symbol
- Only work with sequences of symbols (string)

Advantage: Distance computation is **faster**

- Compute distance between two d-dimensional vectors: $\mathcal{O}(d)$
- Compute distance between two symbols (table lookup): $\mathcal{O}(1)$

Vector quantization (VQ)

Our definition

Mapping a large set of vectors to a small set of vectors that are representative for the large set

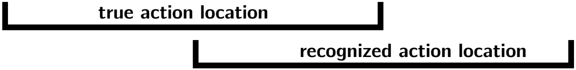
Use an unsupervised learning method, such as k-means, Growing Neural Gas (GNG), self-organizing map (SOM):

1. Train classifier on set of all feature vectors
2. Classify each vector into one of k classes
3. Replace each feature vector with its class label $(1, \ldots, k)$
4. Additionally: Pre-compute distances between all classes

Evaluation

Algorithm:

1. Compute features from input data
2. Train vector quantization algorithm
3. Convert sequences to symbols
4. For each action sequence and for each reference action: Run modified DTW and determine **overlap** of true and predicted intervals.



5. Output average overlap

Results

Test data

14 action sequences containing 132 known actions

Results

	avg. overlap	total runtime [s]	DTW time only [s]
No VQ	**70.4 %**	148.2	133.2
GNG	68.9 %	43.6	**17.5**
SOM	72.2 %	231.0	**16.3**
k-means	70.45 %	41.0	**25.1**

- Almost no decrease of recognition accuracy
- Severe reduction of time spent on DTW

Summary

- There are simple features of hand movements that are rotation and translation invariant
- A modification of Dynamic Time Warping can locate and classify manual actions in one step
- Vector quantization can reduce high-dimensional time series data to sequences of symbols
- Using symbols instead of full $\mathbb{R}^d$ vectors reduces DTW computation time
- Using symbols **does not** decrease recognition accuracy

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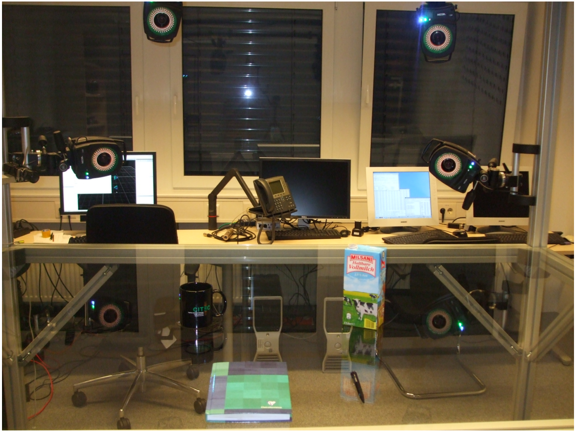
Thank you for your attention

Motion capture setup



Manual action: Pour milk into cup