Gait recognition via deep learning of the center-of-pressure trajectory: A proof-of-concept study for biometric applications

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Background

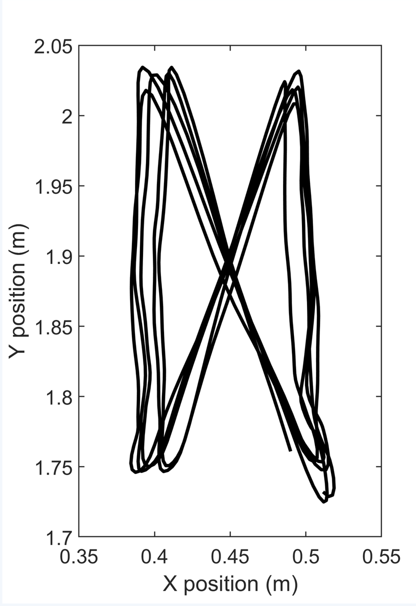
- Biometrics refers to verifying or identifying a person according to his/her biological or behavioral characteristics
- Gait is the coordinated, cyclic combination of movements that result in human locomotion.
- Gait recognition means authenticating a person by his/her manner of walking

Research gap

It is possible to record foot trace on the ground through pressure sensors embedded in the floor.

While walking, the center-of pressure trajectory has a typical butterfly-like shape [2]. The "wings" of the butterfly correspond to the stance on a single foot, while the central crossing corresponds to the double-support phase when the body weight passes from one foot to the other.

To date, no study harnessed this typical trace for identification purposes.



Objective

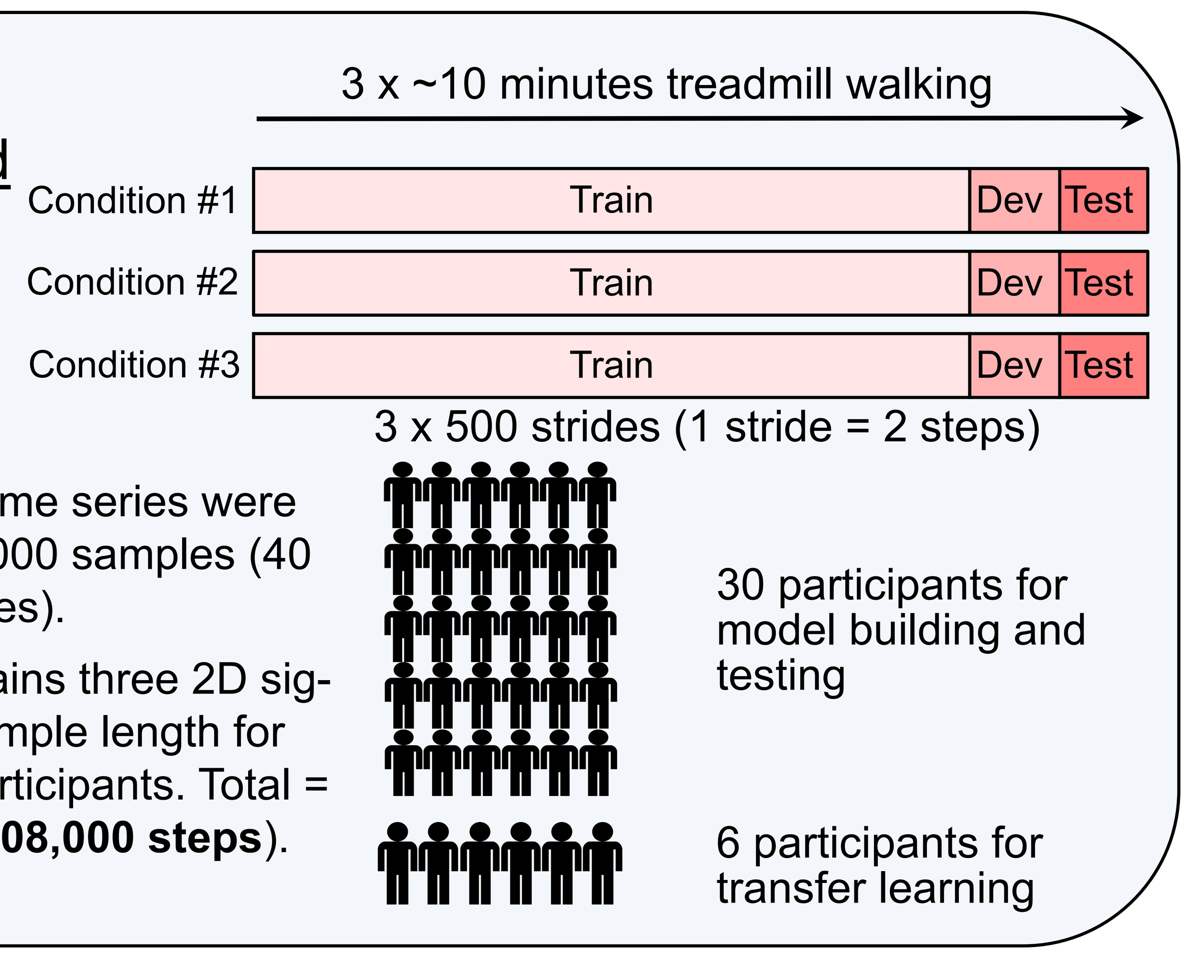
The objective was to bring a proof-of-concept that measuring foot pressure on the floor can be employed for biometry purposes.

A deep convolutional network was used to extract the features of pressure trajectories and to classify the gaits of 36 individuals.

Instrument

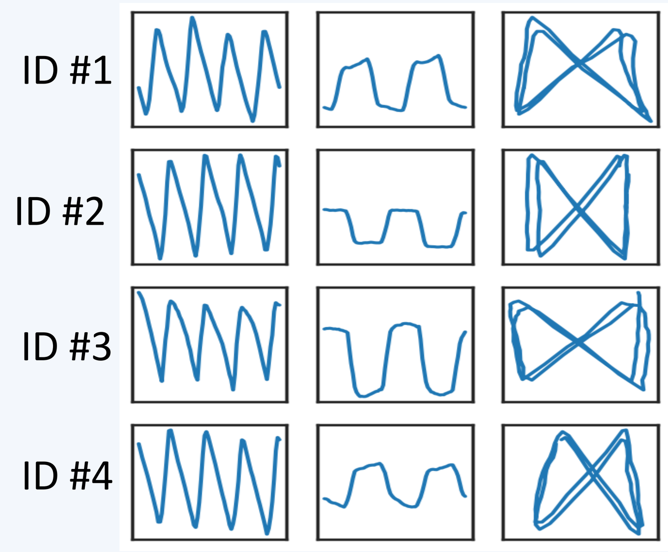
- Instrumented treadmill (300 x 70 cm)
- Vertical force and pressure trajectory recorded at 50Hz
- Participants walked at preferred walking speed [1]
- Three conditions: no cueing, auditory cueing, visual cueing

Procedure and data processing



- The 500-strides time series were resampled to 20,000 samples (40 samples per strides).
- The dataset contains three 2D signals of 20,000 sample length for each of the 36 participants. Total = **54,000 strides** (**108,000 steps**).

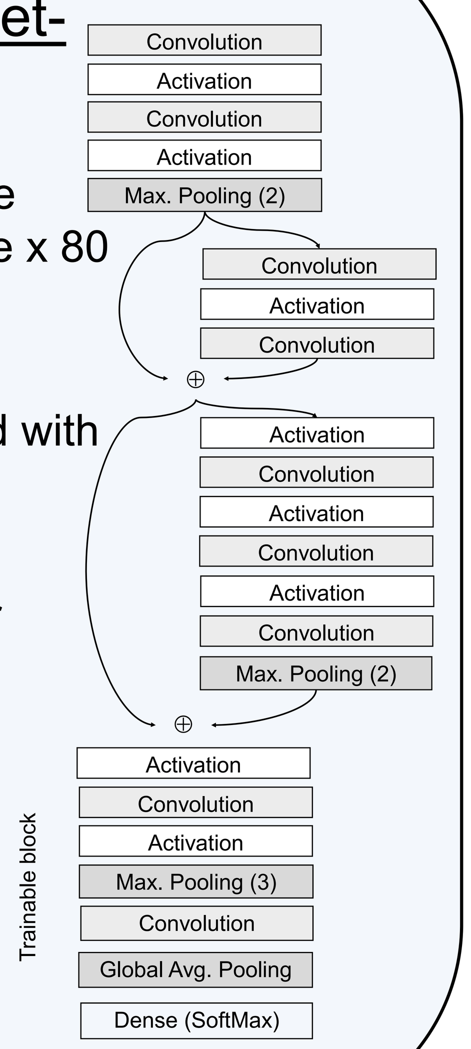
Data segmentation



2D signals were sliced into 80-sample length segments (2 strides, or 4 steps), labelled with participants' ID.

Deep convolutional neural network (CNN)

- The CNN is directly feeded with the segments of dimension: [batch size x 80 x 2]
- 700,000 parameters
- 1D convolutional layers interleaved with Max Pooling layers
- Batch normalization
- Activation: sigmoid weighted linear unit (trainable Swish)
- Residual shortcuts (ResNet)
- Regularized via L2 weight decay
- Loss function: categorical cross-entropy
- Mini-batch optimizer for gradient descent: Adam



Hyperparmeter tuning and accuracy results

Training set	Development set
18,000 segments	2,250 seg.

Tuned hyperparameters:

Number of layers | Number of filters in layers | Filter size | Regularization strength | Activation algorithm | Initial learning rate

Training + dev sets	Test set
20,250 segments	2,250 seg.

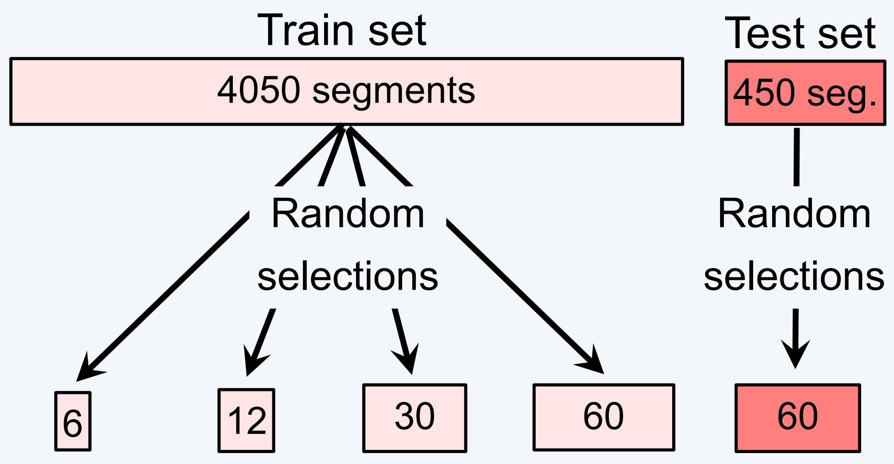
Overall classification accuracy on the test set:

10 repetitions of learning / assessment. Try to correctly classify the segments belonging to each of the 30 participants.

$$\frac{\text{2,246 correct classifications}}{\text{2,250 total number of examples}} = 99.8\%$$

Transfer learning: method

- Most CNN parameters were frozen,
- Only the weights of the last two convolutional layers were further fine-tuned
- The output (softmax) layer was replaced with a new layer with six neurons to match the new classification task.

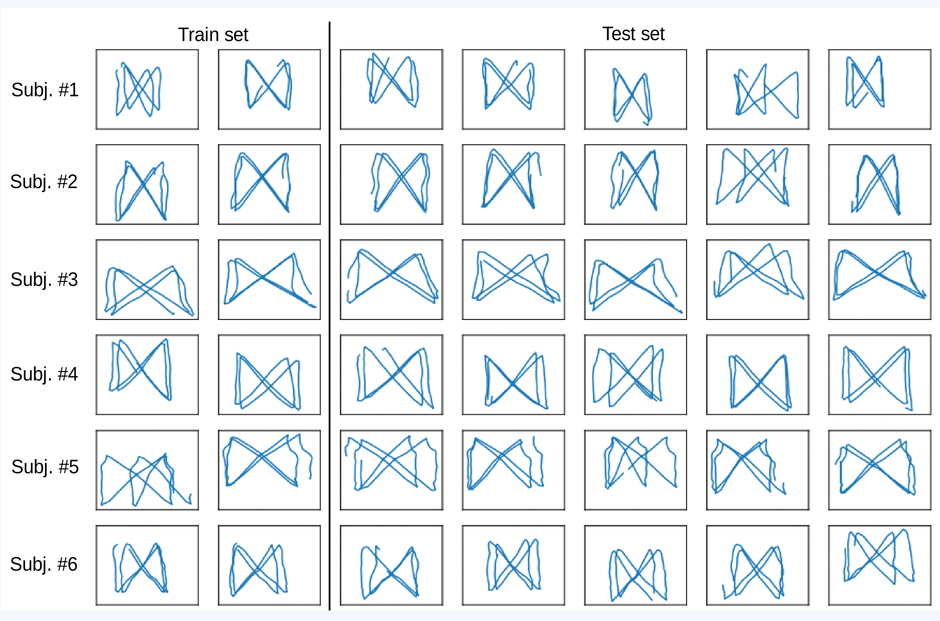


- 4x50 repetitions with different number of segments in the training set, from 1 per subject, to 10 per subject

Transfer learning: results

Example:

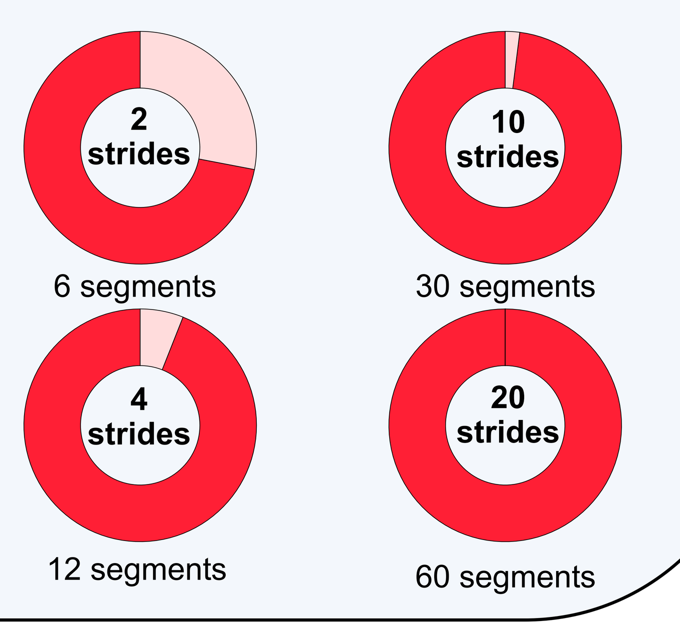
The pre-trained CNN was able to correctly learn and then classify unseen gaits from 6 participants



Over the 200 random trials, the pre-trained CNN was able to reach 100% accuracy in 182 trials.

With only 1 segment (2 strides) per subject in the training set, the CNN was already able to reach 100% accuracy in 36 over 50 trials.

Proportion of trials with 100% accuracy



Discussion

Previous studies have demonstrated that floors sensitive to foot pressure of walking individuals can be used for identification purposes [3].

Butterfly-like traces corresponding to the center-of-pressure trajectory can be collected from pressure sensitive floors by subtracting the average speed vector from position data.

Here, I show that these traces are unique for each individual, and can be easily learned by a deep convolutional neural network.

Future studies are needed to extend the finding of the present laboratory study to less controlled environments.

In particular, the long term variability of foot pressures and the influence of footwear should be further investigated.

Take Home message

- **The center-of-pressure trajectory of a walking person has a unique butterfly-like shape**
- **A deep CNN can learn from these unique shapes to recognize people with a high confidence**
- **A pre-trained CNN can further learn new gaits from previously unseen individuals by being trained with only 2-4 strides.**

References

[1] P. Terrier, "Fractal Fluctuations in Human Walking: Comparison Between Auditory and Visually Guided Stepping," *Ann Biomed Eng*, vol. 44, n° 9, p. 2785–2793, 2016.

[2] A. Kalron and L. Frid, "The 'butterfly diagram': A gait marker for neurological and cerebellar impairment in people with multiple sclerosis," *J. Neurol. Sci.*, vol. 358, no. 1–2, pp. 92–100, Nov. 2015.

[3] J. Suutala and J. Röning, "Methods for person identification on a pressure-sensitive floor: Experiments with multiple classifiers and reject option," *Information Fusion*, vol. 9, no. 1, pp. 21–40, Jan. 2008.