Gait Recognition Using Encodings With Flexible Similarity Measures

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New Opportunities in User Identification Inspired by the Internet of Things

- IoT provides unique opportunities: **volume** and **diversity** of personal sensor data
- These sensors can passively and continuous extract information useful for **identifying** users
  - This could represent an improvement over traditional approaches for identification and authentication
- Biometrics such as face and fingerprints are promising approaches

Smart Phones

Project Tango

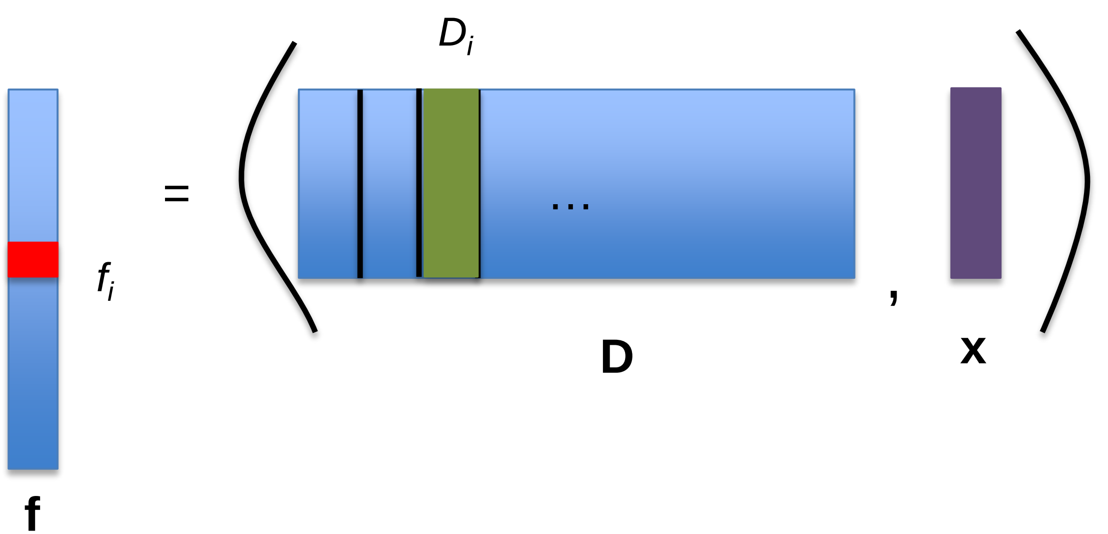
Gait Recognition – An Ideal Biometric for IoT-based Authentication

- Gait is an action that people do naturally, every day that is also characteristic to each individual
- Furthermore, gait signals can be can be measured using a variety of sensors with many advantages:
  - Measurements can be taken **passively** on **ubiquitous** devices
  - Difficult to **mimic**
  - Gait is **cyclic** and measurements are **small** – this allows for efficient classification of user gait signals

Feature Space Encoding for Improved Separability

- Use a dictionary, **D**, of examples (atoms) – $\mathbf{D}_i$
  - The feature space representation for a candidate, **x**, is the measure between it and each atom in the dictionary:
- Feature encoding provides robustness to expected variations within classes

$$\mathbf{f}_i = Similarity(\mathbf{D}_i, \mathbf{x})$$



Convolution Similarity for Sequence Alignment

- A discrete convolution between two signals, *f* and *g* as:

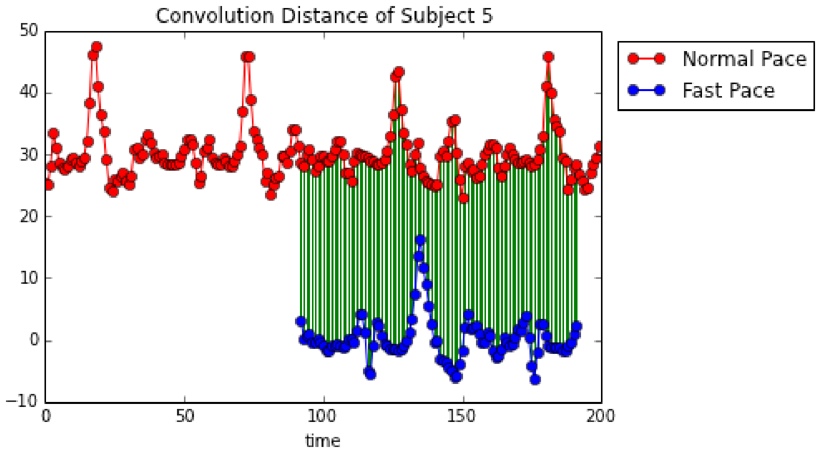
$$(f \star g)[n] \stackrel{\mathrm{def}}{=} \sum_{m=-\infty}^{\infty} f^*[m]\ g[m+n].$$

Convolution similarity is:

$$\arg\max_n (f \star g)[n]$$

- Reduces the necessity of finding every step within gait signal by determining the best alignment of segments

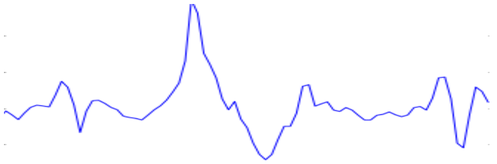
This does not handle stretching and local shifting (but still useful!)



Data Augmentation for Improving Convolution Similarity

One way to improve convolution measure is to **augment** dictionary atoms with stretched and compressed versions

- This is a simple but brute force way of providing additional invariance for the feature encoding

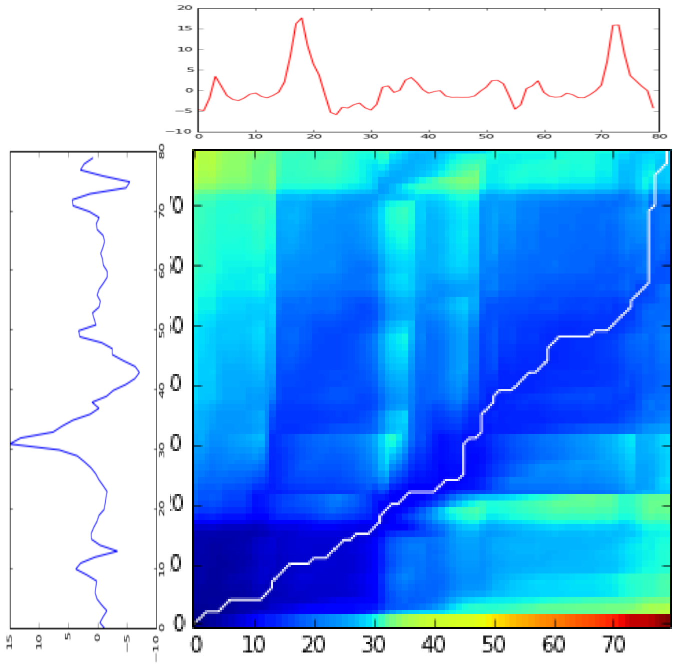


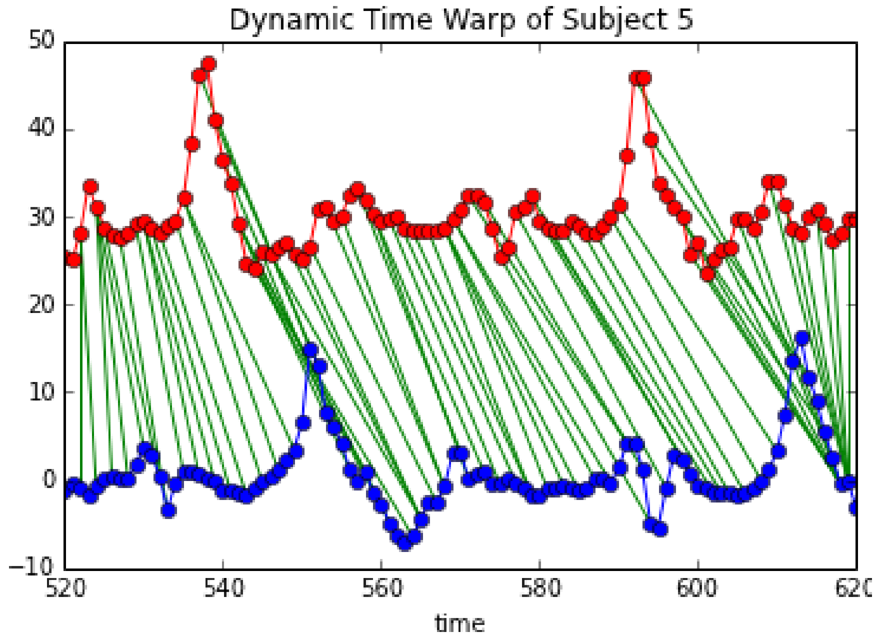
Original

Stretched

Compressed

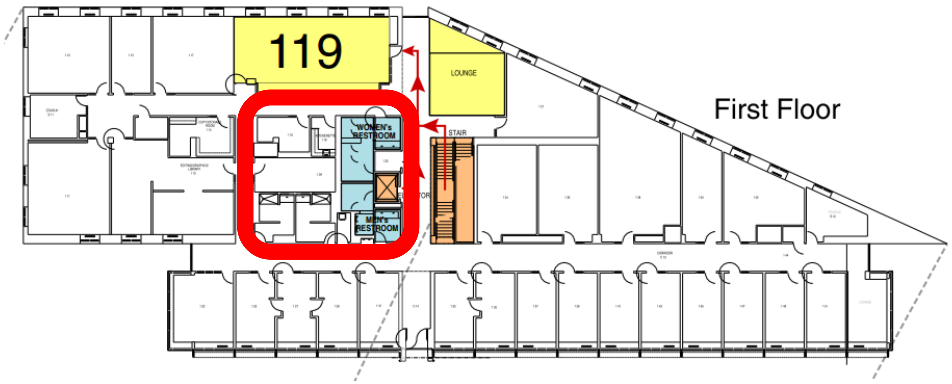
Dynamic Time Warping (DTW): A More Robust Similarity Measure





- Dynamic Time Warping is a more robust similarity measure for comparing two time-series sequences
  - Finds a non-linear warping between two signals using a dynamic program
  - Allows for the signals to be stretched/compressed for best alignment between significant features

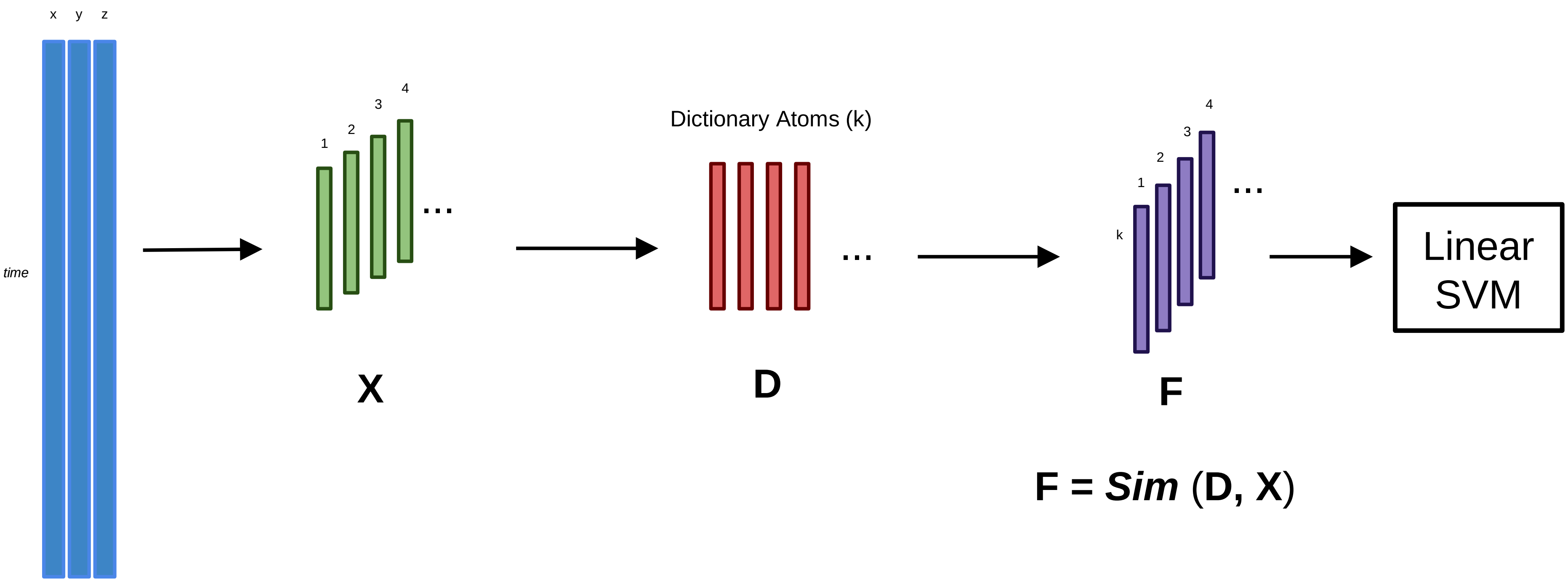
Experimental Setup and Dataset



- Used an HTC Droid DNA (Android phone) with a custom app to capture sensor data
  - Device placed in **front left pocket**, sampled at **50Hz**
    - The human body generally accelerates between -+2 gs, effectively 15-20hz. Nyquist sampling rate for walking with sensor at thigh is roughly 40Hz [1,2]
- The experiment consists of each subject performing 4 separate walks, 2 in each direction of path (roughly 30 seconds in duration)
  - 30+ subjects walked 4 separate times around a predefined route

1 Mathie, Merryn J., et al.
2 Marcus Chang

A Gait Recognition Pipeline



Raw Data

Extract Windows and Dimension Reduction

Construct Dictionary

Feature Encode

Gait Identification Experiments with Under Various Scenarios

- Our experimental design is to create several scenarios in order to test several hypothesized variations:
  - walks on the same day, different days, different paces, different phone orientation

Multi-Class Accuracy Results

setting (# subjects)	$\mathsf{Enc}_{\mathsf{conv}}$	$\mathsf{Enc}_{\mathsf{conv}} + \mathsf{aug}$	$\mathsf{Enc}_{\mathsf{dtw}}$	Best Prior α	Best Prior β
complete training set (31)	.99	.99	.99	.94	.90
different sessions (31)	.88	.88	.99	.90	.88
different orientation (9)	.88	.92	.73	n/a	n/a
different days (9)	.69	.77	.76	.48	.53
different pace (9)	.48	.70	.79	.75	.76

Conclusion

- Gait is a new, useful biometric that can be used to identify many users (30) with high accuracy
  - Training samples are simple to obtain and the number of measurements for classification is small
- Using a simple linear classifier in feature space with no tuning, high accuracy can be achieved
  - Tuning the hyper plane and penalty parameters could be done to improve performance further
- Scaling to larger numbers of users is possible by considering larger numbers gait cycles and increasing the size the dictionary

Future Work

- Sensor Fusion – combining many sources of sensor data can further bolster FAR and FRR
  - Gait is an ideal target because of the simple setup and the regularity at which it occurs for users
- Capturing larger and more challenging datasets
  - Variations between days, pace and other environmental factors need to be explored and at scale (100+ users)
  - Increase type and location of sensors
- Explore how variations between days could be exploited via incremental update of user gait templates for strengthening authentication
  - Changing pattern could make potential attacks more difficult (less predictable, unique for biometrics)

Thank you!

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