Inter- and Intra-Subject Variations in Activity Recognition Using Inertial Sensors and Magnetometers

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Introduction

- human activity recognition through the use of sensor units containing accelerometers, gyros, and magnetometers
- investigate the effect of inter- and intra-personal differences on classification performance
- the acquired data varies nonlinearly from subject to subject in terms of amplitude & speed
- hard to classify activities of a person using another person's data
- lower classification performance in subject-based leave-one-out (L1O) compared to *P*-fold cross validation

Dataset

The dataset for activity recognition [1] is used:

- 8 subjects performing 19 activities, 5 min each
- 5 sensor units containing uncalibrated tri-axial accelerometers, gyros, and magnetometers (9 axes/unit) sampled at 25 Hz

Segmentation and Feature Extraction

- Data is segmented into 5-sec segments:
  - 60 segments per activity of a subject
- A 1,170-element feature vector is calculated from each segment (corresponding to all sensors and units) [1].
- Each signal is made zero-mean.
- Both raw and zero-mean signals, as well as the feature vectors, are used comparatively.

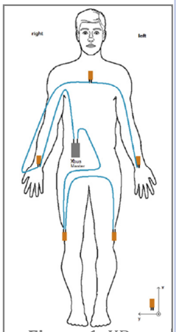

Figure 1: XBus Master and its units.

Distance Measures

3 different distance measures are used to compare the signals $x[n]$ and $y[n]$ ($1 \le n \le N$):

- **absolute distance:**

$$d_{\text{abs}}(x[n], y[n]) = \sum_{n=1}^{N} |x[n] - y[n]|$$

- **Euclidean distance:**

$$d_{\text{Eucl}}(x[n], y[n]) = \sqrt{\sum_{n=1}^{N} (x[n] - y[n])^2}$$

- **Dynamic Time-Warping (DTW) distance:** $d_{\text{DTW}}(x[n], y[n])$

Effect of Bias Error

If $y[n] = x[n] + b$ with b being the bias error, **if $N = 100$ and $b = 0.01$**

$$d_{\text{abs}}(x[n], y[n]) = Nb = 1$$

$$d_{\text{Eucl}}(x[n], y[n]) = \sqrt{N}b = 0.1$$

$$d_{\text{DTW}}(x[n], y[n]) \le Nb \le 1$$

Identifying the "Best" Subjects

- **The "best" subject** is the one whose data are the most similar to other subjects on average
- For each subject, the distances from all signals of that subject to all other subjects are averaged out in terms of the 3 distance measures.
- Both raw and zero-mean time-domain signals, and feature vectors are used in the comparison.

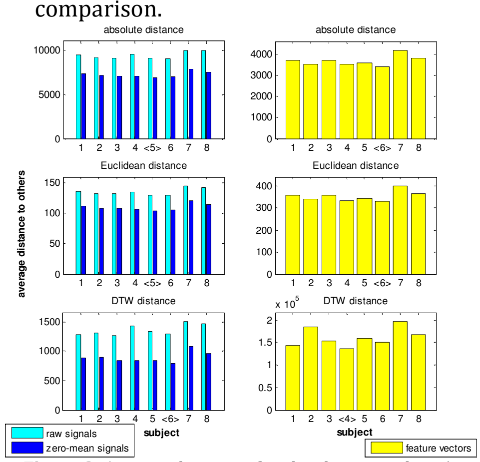

Figure 2: Average distance of each subject to others.*

Average Intra-Subject Distance per Activity

- For each activity, the amount of variation in the data with respect to subjects is calculated.
- Distances between all distinct subject pairs are calculated and averaged out.
- The 3 distance measures are applied to both raw and zero-mean time-domain signals.

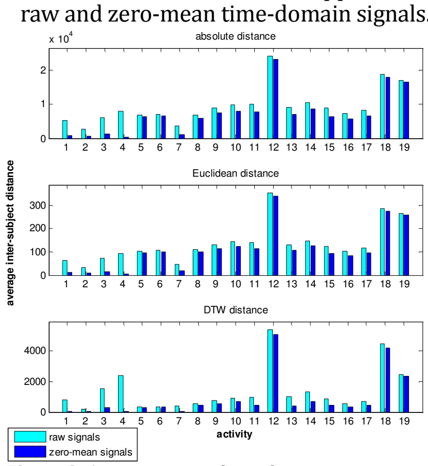

Figure 3: Average intra-subject distance per activity.*

Average Mean and Std. of Inter-Activity Distances

- Distances between time-domain signals (of all the subjects, units, and sensors) belonging to one activity and time-domain signals (of the corresponding subjects, units, and sensors) belonging to another activity are calculated and averaged out for each subject, unit, and sensor separately.
- Only zero-mean signals are used.

Inter-Activity Distances per Subject

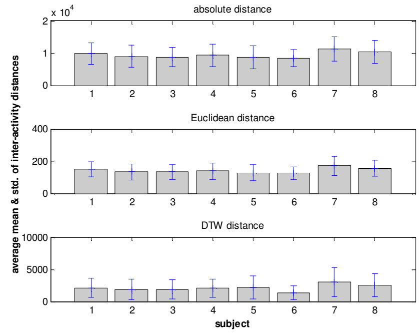

Figure 4: Average inter-activity distance per subject.*

Inter-Activity Distances per Unit Location

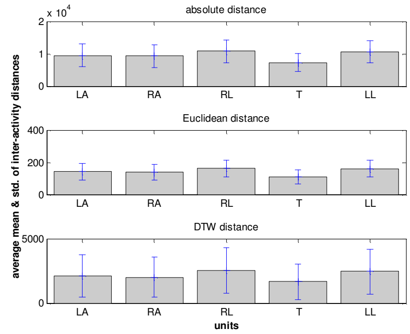

Figure 5: Average inter-activity distance per unit.*

Inter-Activity Distances per Sensor Type

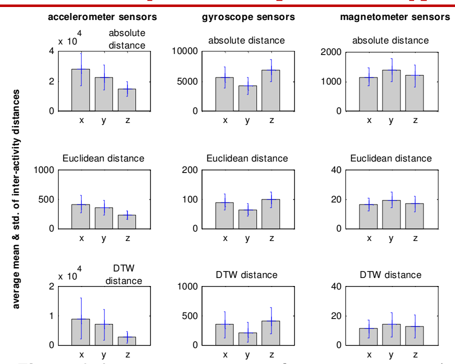

Figure 6: Average inter-activity distance per sensor.*

Conclusion

- The "best" subject may not always be the one performing activities the best.
- Removing mean values highly affects the results due to bias errors.
- Comparison based on time-domain signals can be misleading in "random" activities.

Acknowledgments

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References

[1] K. Altun, B. Barshan, and O. Tunçel, "Comparative study on classifying human activities with miniature and inertial sensors," *Pattern Recognition*, 43(10):3605–3620, Oct. 2010.

* Only 5% of the data is used in the DTW case to speed up the computations. To reduce the data used, all time-domain signals are cropped from the end and only the first 3 feature vectors are used.

ACTIVITIES: sitting (A1), standing (A2), lying down on back and on right side (A3 and A4), ascending and descending stairs (A5 and A6), standing in an elevator still (A7) and moving around in an elevator (A8), walking in a parking lot (A9), walking on a treadmill with a speed of 4 km/hr (in flat and 15° inclined positions) (A10 and A11), running on a treadmill with a speed of 8 km/hr (A12), exercising on a stepper (A13), exercising on a cross trainer (A14), cycling on an exercise bike in horizontal and vertical positions (A15 and A16), rowing (A17), jumping (A18), and playing basketball (A19).