Path signatures for non-intrusive load monitoring

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Introduction

Non-intrusive load monitoring (NILM) is the analysis of electricity loads at a single supply wire allowing a user to see which appliances are switched on. Path signatures provide a powerful method of feature generation for multivariate, time-ordered data. Here we show how path signature features for NILM give results as accurate as engineered features.

Electricity load monitoring

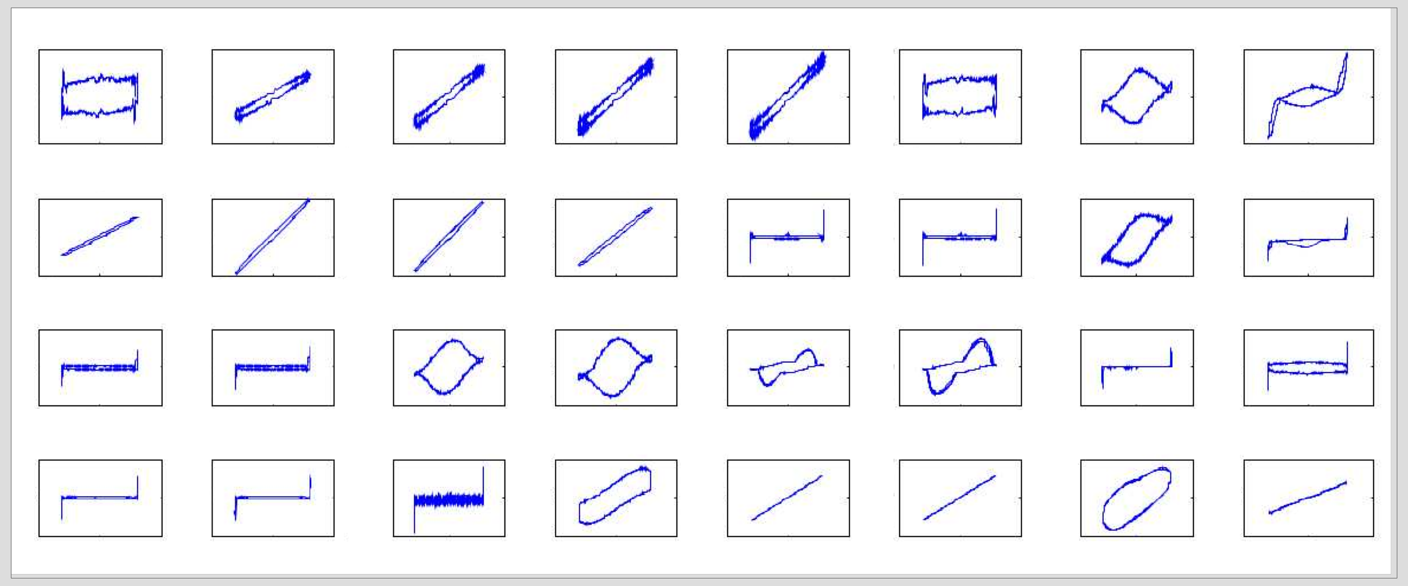

Fig1. Current plotted against voltage for different electrical appliances. Straight lines are from resistive loads such as fan heaters while in other appliances the current is not proportional to the voltage. The task is to identify the appliance from the I-V trajectory.

The use of I-V trajectories for classifying electric appliances was first suggested in 2005 [Ting]. Over the next two decades 'shape features' of the trajectory were developed as quantitative features for machine learning.

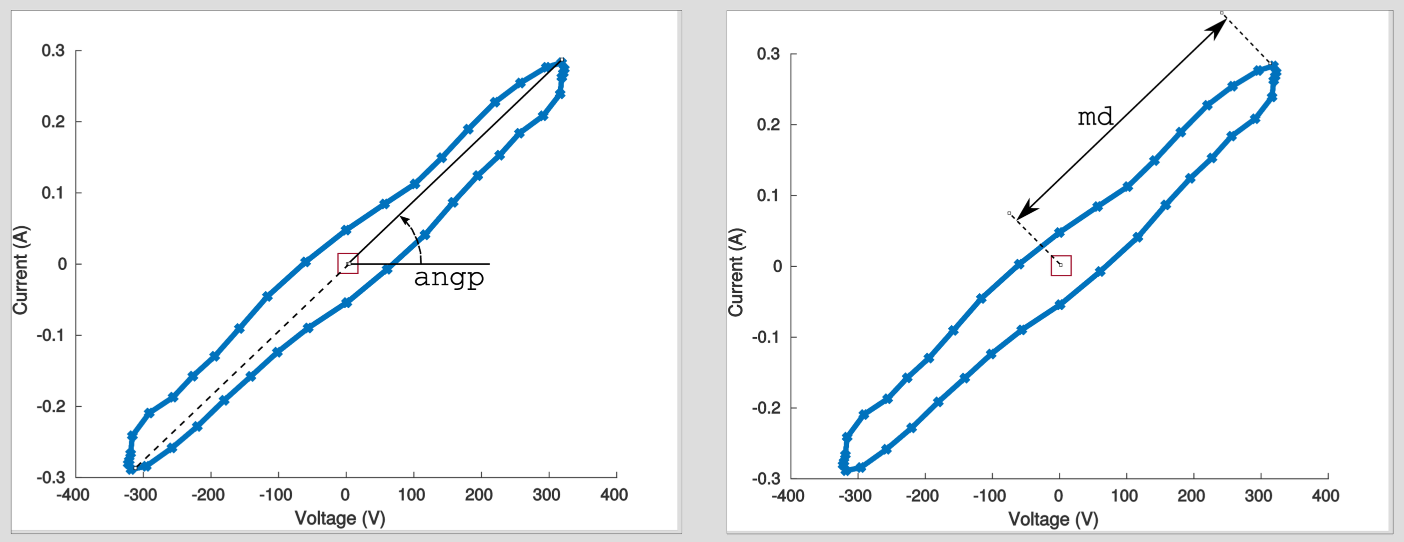

Fig 2. Two shape features from the I-V trajectory; **left**: angle of the maximum-minimum line; **right**: distance from the centroid to the maximum point.

The path signature

The path signature characterizes a path with a sequence of numbers. It is a systematic equivalent of the shape features, where instead the simple quantities are increments and areas. It is now used for many applications in machine learning [Chevyrev].

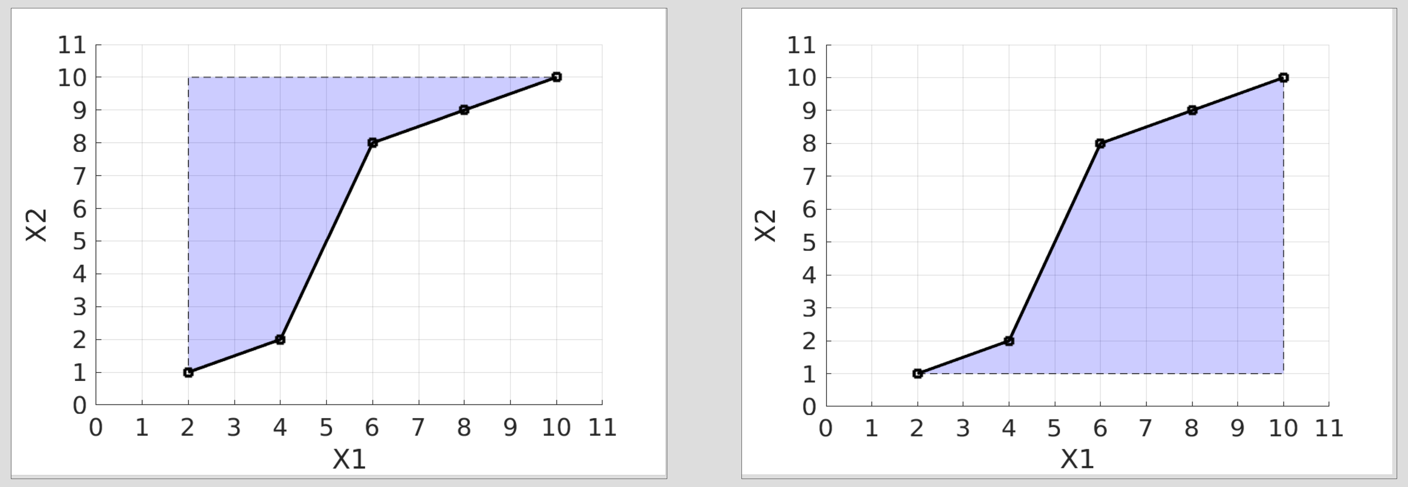

Fig 3. Two area terms from the signature of a path through variables X1 and X2; **left** $S^{(1,2)}$ with value 31; **right** $S^{(2,1)}$ with value 41. The path signature is formalized in degree 2 as S = {1, S^1, S^2, $S^{(1,1)}$, $S^{(1,2)}$, $S^{(2,1)}$, $S^{(2,2)}$}; Terms $S^{(1)}$ and $S^{(2)}$ are increments of X1 and X2 respectively. The degree is the highest order of the iterated integrals forming S. The degree 2 signature of this path is {1, 8, 9, 32, 31, 41, 40.5}.

Predicting appliances

We compare shape features and signatures in predicting appliance labels using a random forest classifier. Fig.4 shows the relative importance of the different features.

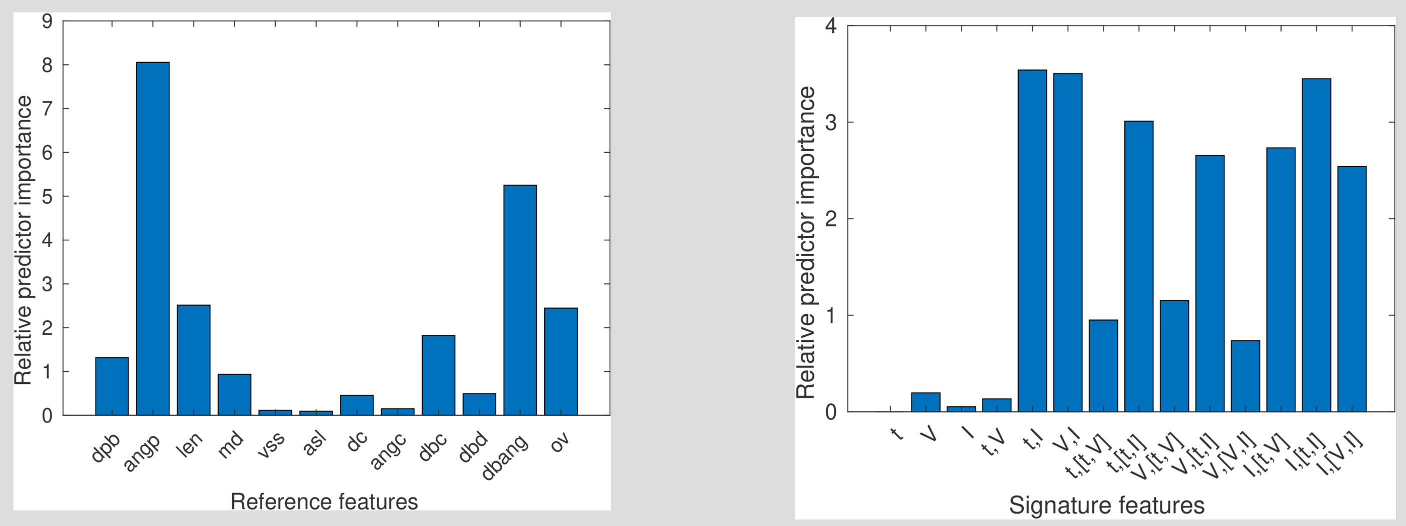

Fig 4. Relative predictor importance used for classifying appliance labels with a random forest; left: shape features; right: path signature for the steady state cycles.

Set	Features	Number	Accuracy(SD)	Test set
Full	Shape	12	97.77 (0.74)	97.62
	Signature	28	98.81 (1.13)	98.81
Selected	Shape	5	98.51 (1.17)	99.40
	Signature	7	99.11 (0.82)	98.81

Table 1. Accuracy of appliance classification comparing shape features with path signature features. Full and selected features sets are shown. The penultimate column is for cross-validation on the training set, and the last column shows a test set accuracy.

Table 1 shows the accuracy of the shape features and path signatures for full and selected feature sets. The shape features were engineered over a period of more than a decade, but we found path signatures gave similar results with just a few days' work. The project repository is at `github.com/Fivetuple/nilm_sig`

Conclusion

The path signature characterizes multivariate ordered date with a sequence of real numbers which can be used for machine learning. In this application It performs as well as engineered features, and it is easier to use. It is applicable in a wide range of applications and has potential for much greater use.

Bibliography

Ting, K. H., et al. "A taxonomy of load signatures for single-phase electric appliances." IEEE PESC (Power Electronics Specialist Conference). 2005.

Chevyrev, Ilya, and Andrey Kormilitzin. "A primer on the signature method in machine learning." arXiv preprint arXiv:1603.03788 (2016).

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