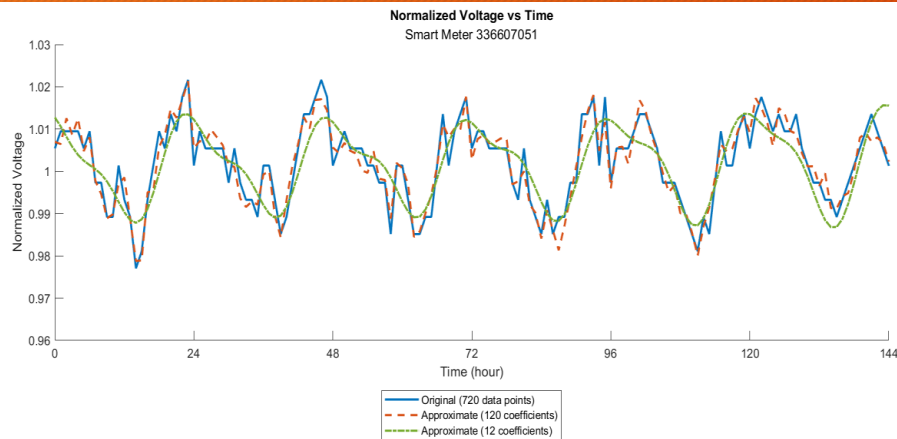


Phase Identification of Smart Meters Using a Fourier Series Compression and a Statistical Clustering Algorithm



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SMARTWORKS

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Overview

- Motivating Fourier series through regression
- Fourier Series on voltage time series
- Phase identification through clustering
- Future work

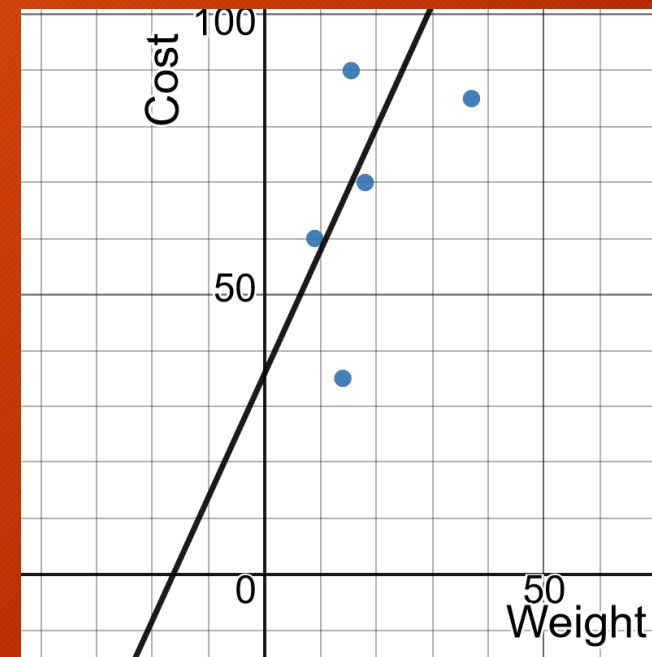
Lines of Best Fit - Monthly Dog Food Bill

Given the following monthly food bills, estimate the cost to feed a 20lb dog.

- Coby the Pomeranian -- \$60, 9lb
- Benji the mutt -- \$35, 14lb
- Tofu the Malti-Poo -- \$90, 15.5lb
- Berkley the Mini Eskimo -- \$70, 18lb
- Noodle the Doodle -- \$85, 37lb

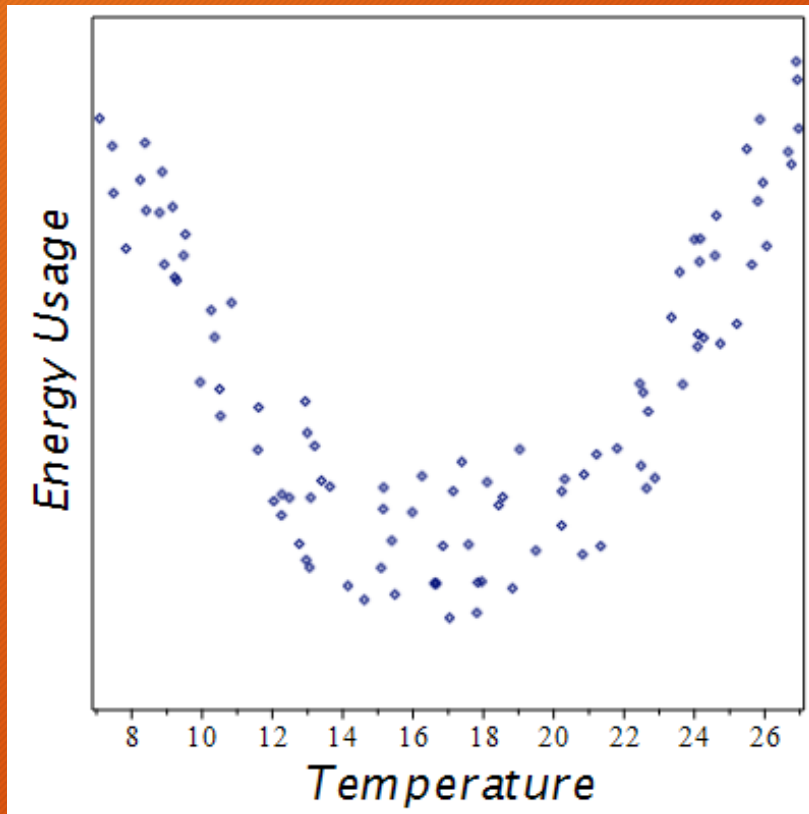


Lines of Best Fit - Monthly Dog Food Bill



$$C = a_1 W + a_0$$

Lines of Best Fit - Energy vs Temperature

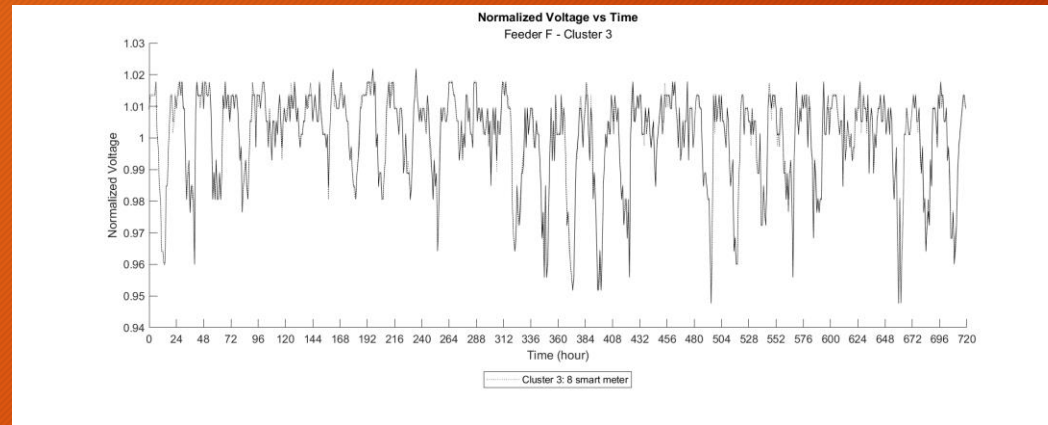


$$E = a_0 + a_1T + a_2T^2$$

More generally,

$$f(t) = a_0 + a_1t + a_2t^2 + a_3t^3 + \dots$$

Lines of Best Fit <- Sines of Best Fit



The (grossly over-simplified) **Fourier series** of a function $f(t)$ is

$$f(t) = a_0 + a_1 \sin\left(\frac{2\pi}{P}t\right) + a_2 \sin\left(\frac{2\pi}{P}2t\right) + a_3 \sin\left(\frac{2\pi}{P}3t\right) + \dots$$

Fourier Series - Definition and Forms

Consider a periodic function $f(t)$ with period P .

The **sine-cosine form** is

$$f(t) = \frac{a_0}{2} + \sum_{n=1}^N \left(a_n \cos\left(\frac{2\pi}{P}nt\right) + b_n \sin\left(\frac{2\pi}{P}nt\right) \right)$$

The **exponential form** is

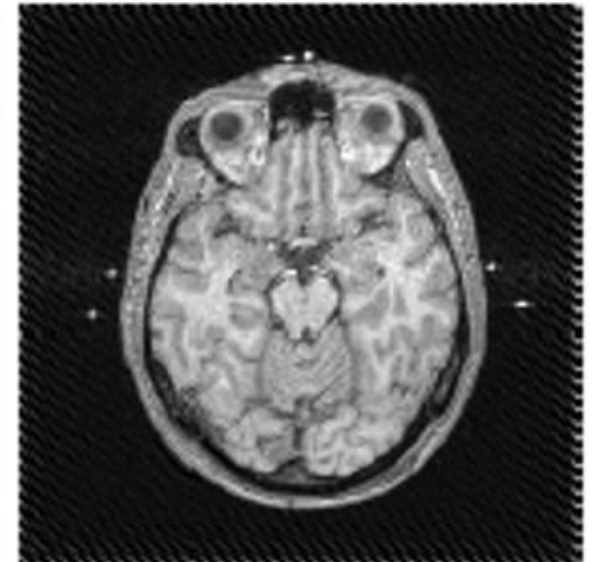
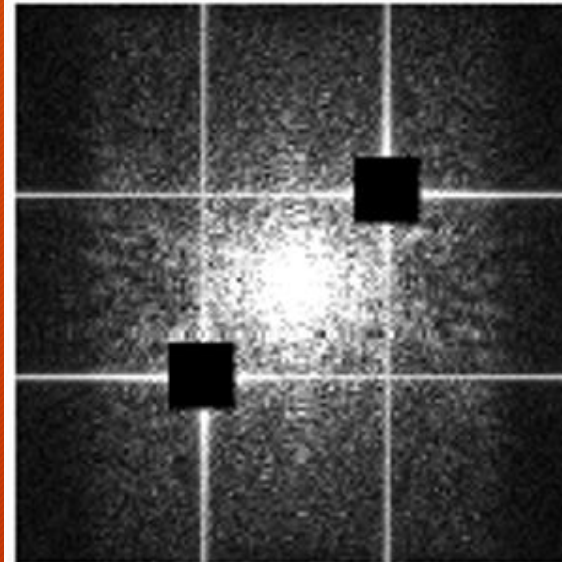
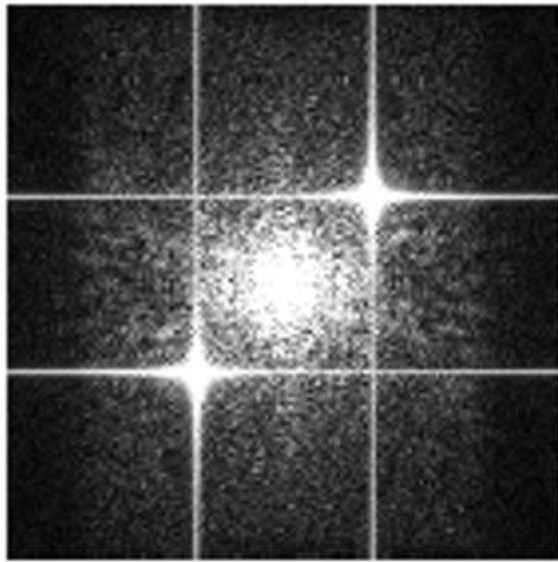
$$f(t) = \sum_{n=-N}^N c_n e^{i2\pi nt/P}$$

The **amplitude-phase form** is

$$f(t) = \frac{a_0}{2} + \sum_{n=1}^N a_n \cos\left(\frac{2\pi}{P}nt - \phi_n\right)$$

■ a_i, b_i, ϕ_i real; c_i complex

Noisy Brain Example

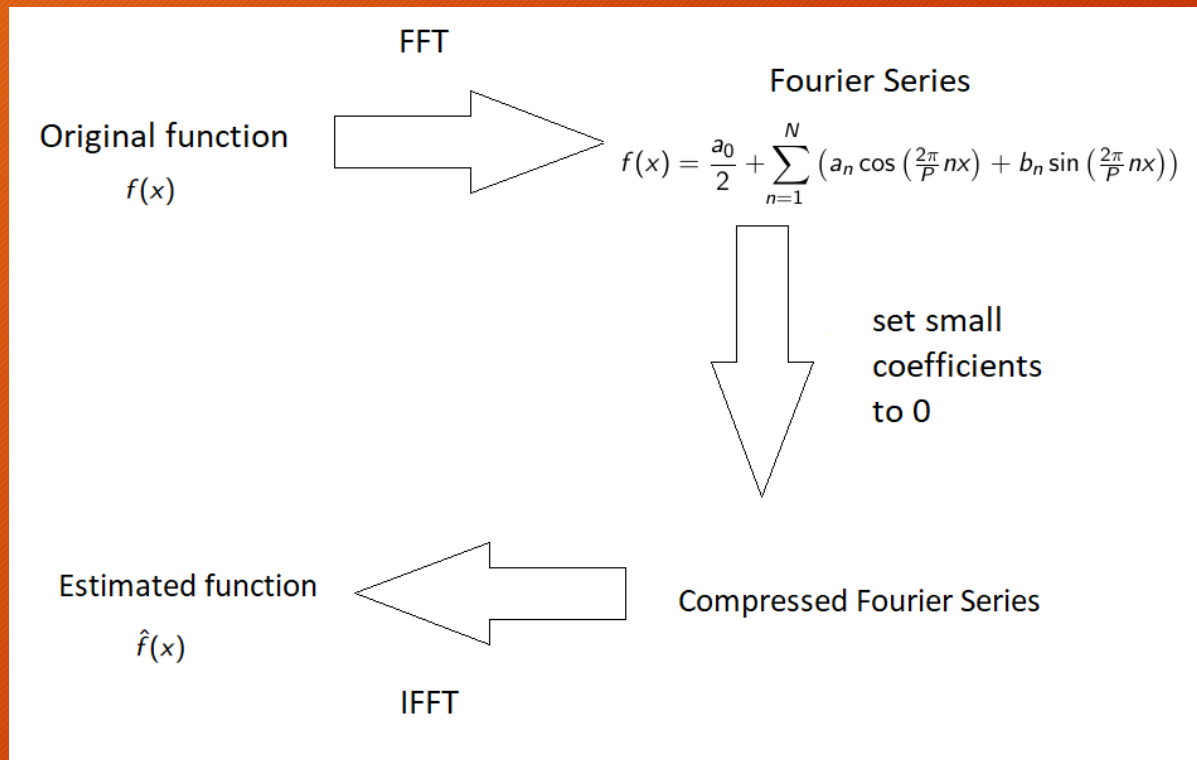


Maintz, Twan. "Digital and medical image processing." *Universiteit Utrecht* (2005), Lecture Notes.

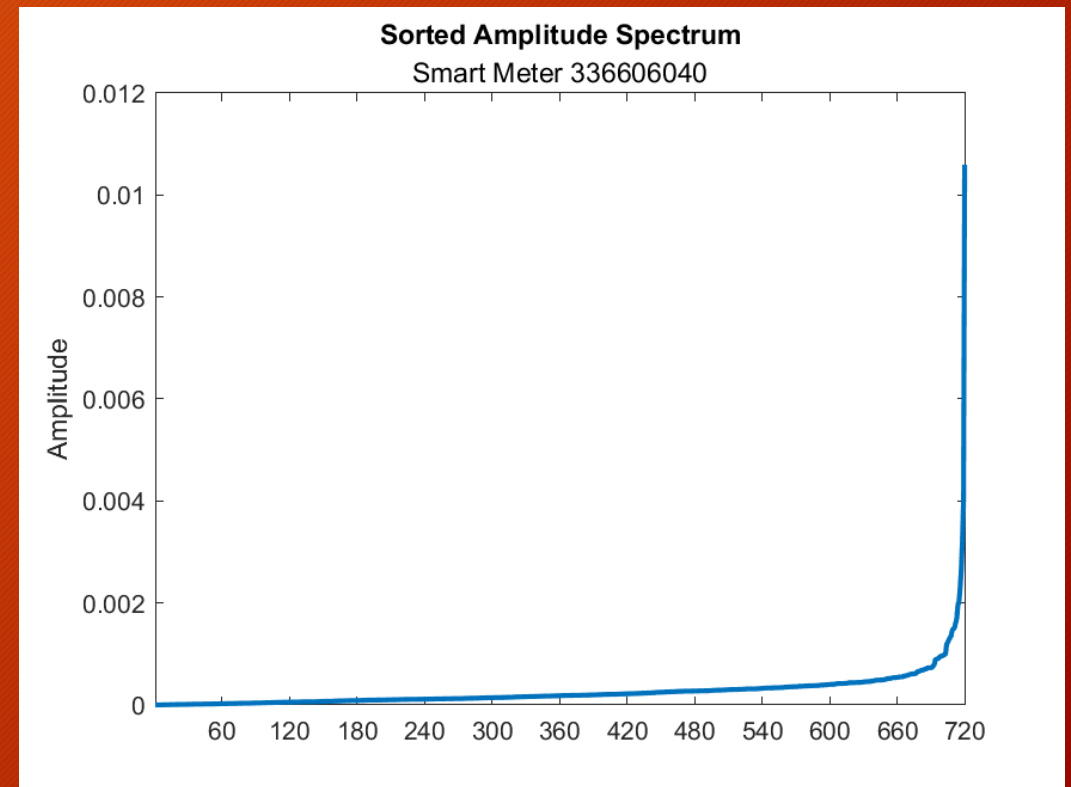
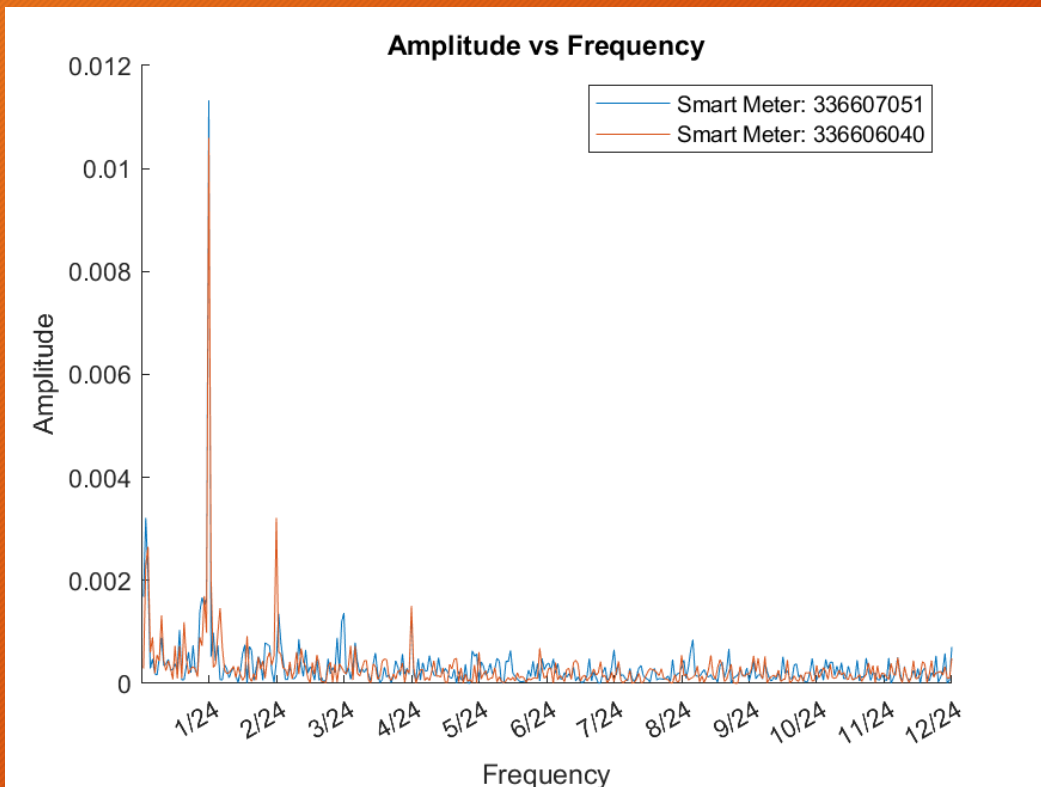
Voltage Data Set

- Voltage data set provided by *Harris SmartWorks*, an American utility company
- Used Feeder F (26 meters) and Feeder D (55 meters)
- Each meter is one of three (unknown) phases
- Hourly voltage data, so one meter in June has $24 \times 30 = 720$ entries
- Normalized each time series by dividing by its mean

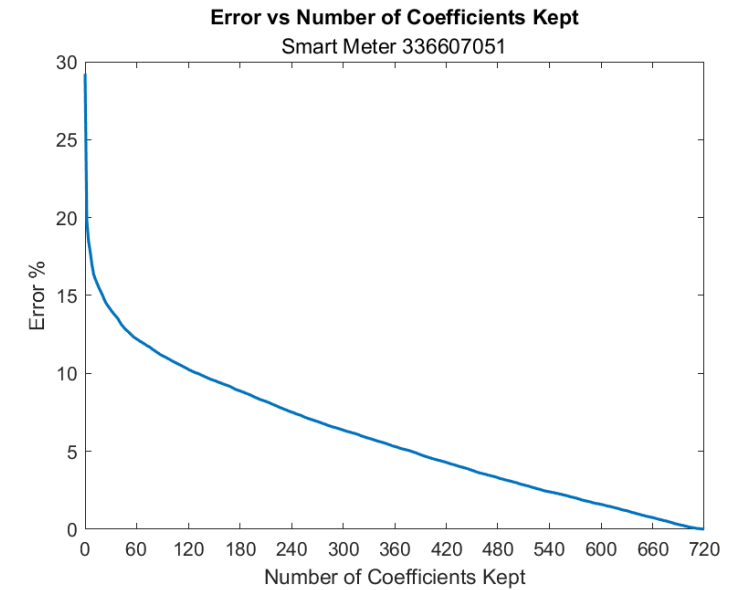
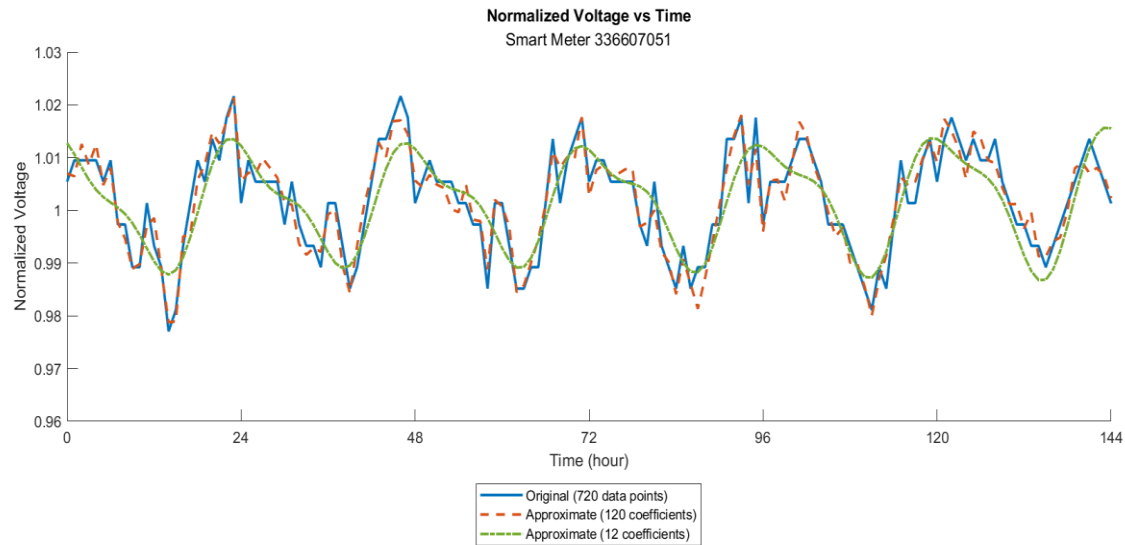
Overview of Fourier Compression



Fourier Spectrum of Time Series



Fourier Time Series Approximation

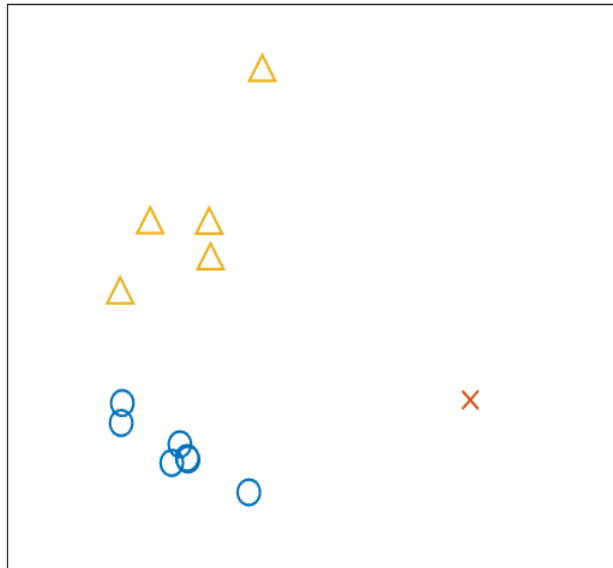


Phase Identification Through Clustering

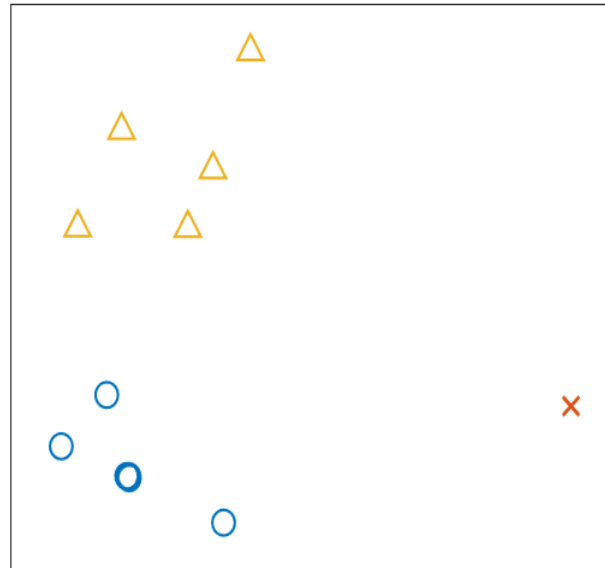
- Clustering Method: Ward D, with dimension-reduced Fourier coefficients and 3 cluster groups
- Kept 12 Fourier coefficients (of the original 720)
- 3 methods to [in]validate clustering results:
 - MDS Visualization
 - Time Stability
 - Same Transformer, Same Cluster

MDS Visualization - Feeder F

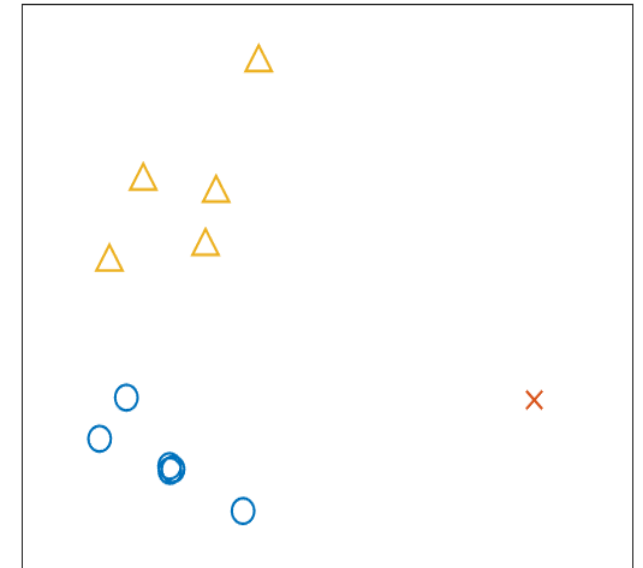
June 2021



July 2021



June & July 2021 Combined



Time Stability - Feeder F

Without compression:

	July				
June		A	B	C	Total
	A	12			12
	B		8		8
	C	1		5	6
	Total	13	8	5	26

With compression:

	July				
June		A	B	C	Total
	A	13			13
	B		8		8
	C			5	5
	Total	13	8	5	26

Same Transformer, Same Cluster ? Almost for Feeder F

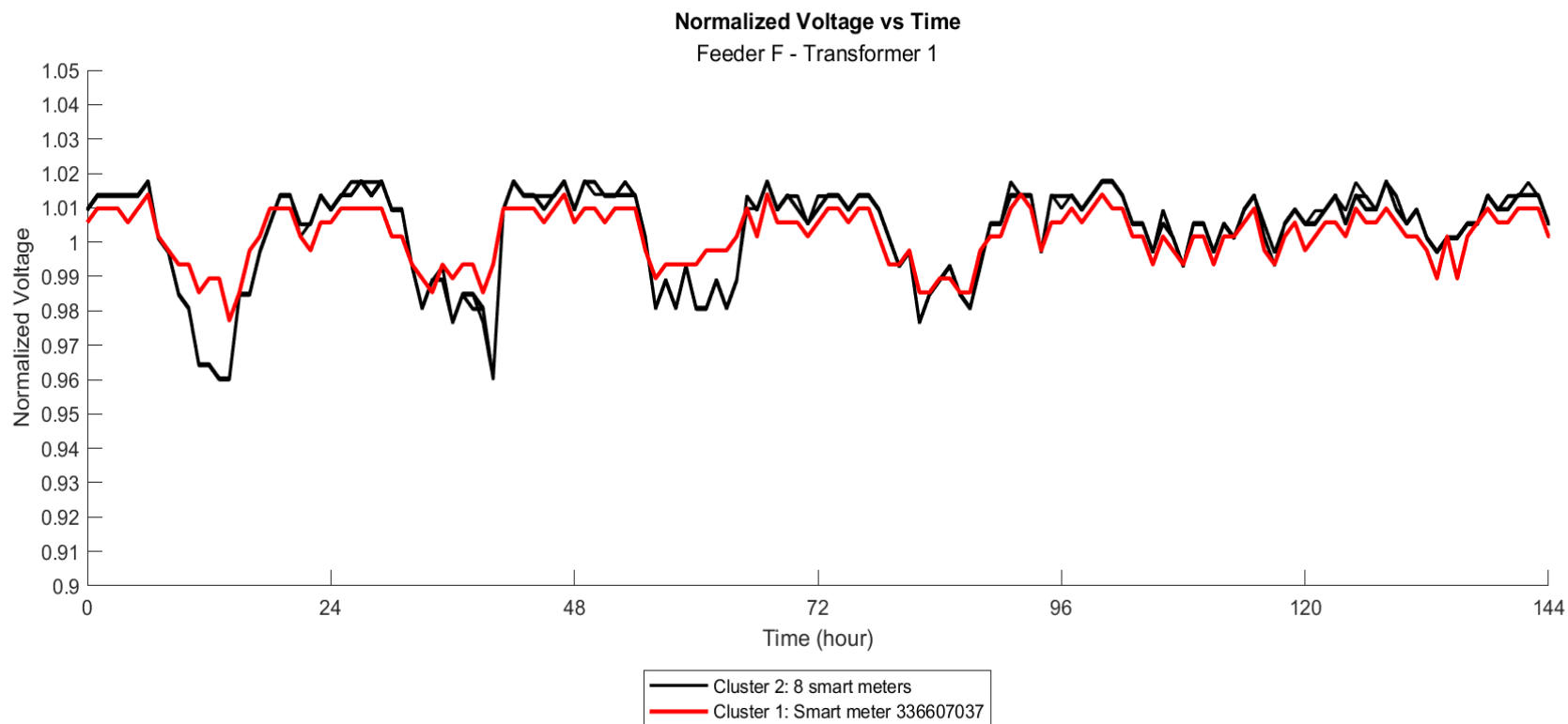
Transformer	June Cluster			Total
	1	2	3	
1	1	8		9
2051	1			1
3840	1			1
3965	1			1
4611			1	1
4702	4			4
4711			1	1
11917			1	1
12187			1	1
12188			1	1
12298	5			5
Feeder F	13	8	5	26

Transformer	July Cluster			Total
	1	2	3	
1	1	8		9
2051	1			1
3840	1			1
3965	1			1
4611			1	1
4702	4			4
4711			1	1
11917			1	1
12187			1	1
12188			1	1
12298	5			5
Feeder F	13	8	5	26

Transformer	June + July Cluster			Total
	1	2	3	
1	1	8		9
2051	1			1
3840	1			1
3965	1			1
4611			1	1
4702	4			4
4711			1	1
11917			1	1
12187			1	1
12188			1	1
12298	5			5
Feeder F	13	8	5	26

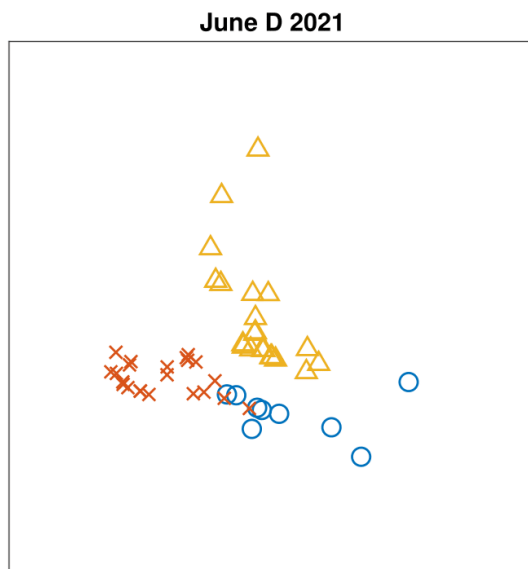
The smart meter is
336607037

Transformer 1: Smart Meter 336607037

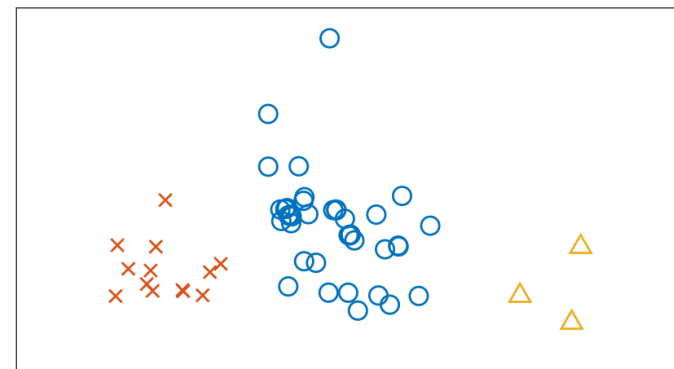


MDS Visualization - Feeder D

Without compression:



With compression:



Time Stability - Feeder D

Without compression:

	July				
June		A	B	C	Total
	A	9	10	17	36
	B		12		12
	C			7	7
	Total	9	22	24	55

With compression:

	July				
June		A	B	C	Total
	A	39			39
	B		13		13
	C			3	5
	Total	39	13	5	55

Same Transformer, Same Cluster ?

Yes for Feeder D

Transformer	June Cluster			Total
	1	2	3	
58	1			1
59	1			1
60	1			1
61	1			1
77	2			2
92	1			1
117			1	1
154	1			1
261	1			1
277	4			4
315	1			1
324			1	1
457			1	1
490	1			1
504		1		1
651	1			1
928	2			2
980	1			1
982	1			1
1033		1		1
1374		1		1
1390		3		3
1392		1		1
1409		2		2
1863	2			2
1893		1		1
12454	1			1
12565	1			1
12788		1		1
12894	1			1
13195	2			2
13197	1			1
13597	4			4
13714	1			1
13718	1			1
13799		1		1
14281	2			2
14614	3			3
15109		1		1
Feeder D	39	13	3	55

Transformer	July Cluster			Total
	1	2	3	
58	1			1
59	1			1
60	1			1
61	1			1
77	2			2
92	1			1
117			1	1
154	1			1
261	1			1
277	4			4
315	1			1
324			1	1
457			1	1
490	1			1
504		1		1
651	1			1
928	2			2
980	1			1
982	1			1
1033		1		1
1374		1		1
1390		3		3
1392		1		1
1409		2		2
1863	2			2
1893		1		1
12454	1			1
12565	1			1
12788		1		1
12894	1			1
13195	2			2
13197	1			1
13597	4			4
13714	1			1
13718	1			1
13799		1		1
14281	2			2
14614	3			3
15109		1		1
Feeder D	39	13	3	55

Transformer	June + July Cluster			Total
	1	2	3	
58	1			1
59	1			1
60	1			1
61	1			1
77	2			2
92	1			1
117			1	1
154	1			1
261	1			1
277	4			4
315	1			1
324			1	1
457			1	1
490	1			1
504		1		1
651	1			1
928	2			2
980	1			1
982	1			1
1033		1		1
1374		1		1
1390		3		3
1392		1		1
1409		2		2
1863	2			2
1893		1		1
12454	1			1
12565	1			1
12788		1		1
12894	1			1
13195	2			2
13197	1			1
13597	4			4
13714	1			1
13718	1			1
13799		1		1
14281	2			2
14614	3			3
15109		1		1
Feeder D	39	13	3	55

Future Work

- More clustering!
 - Additional feeders
 - Additional time periods
 - Different Fourier compressions
- Automate selection of Fourier coefficients over time
- Cluster with derivative of time series

Acknowledgements

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- IEEE
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 - Work on Campus program
 - Applied Research Centre

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Questions?

