ETH zürich

ICT for Green: High Frequency Sensing and Analysis of Residential Power Consumption

Ubiquitous Computing Seminar

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Importance of context information in households

- Reduce the power consumption
  - Residential sector accounts for 30% of electricity
  - Sensing & analysis of residential power consumption
- Collecting data
  - Location & activity of people
- Home automation


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Load Monitoring

- Intrusive Load Monitoring ILM
  - Distributed sensors
  - Very costly
  - Privacy issues
- Non-Intrusive Load Monitoring NILM
  - Single point sensing

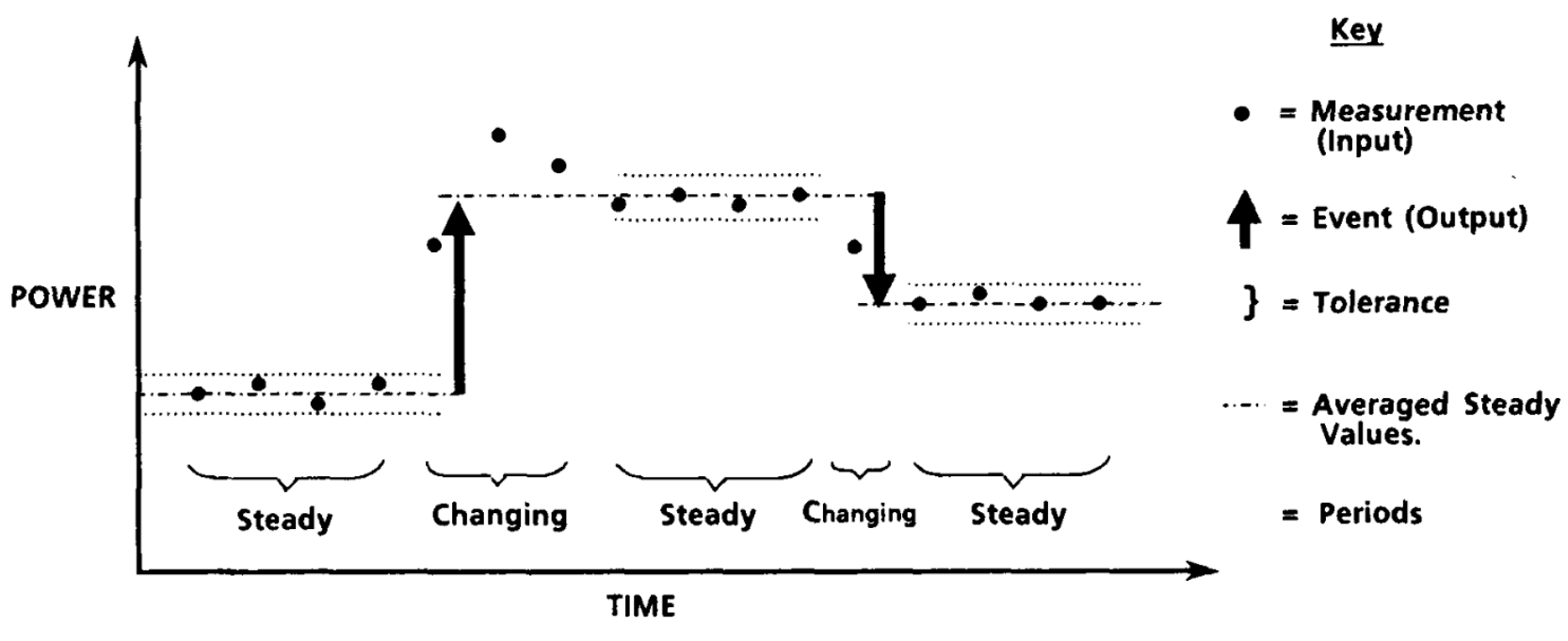
Agenda

- Motivation
- NILM Approaches
  - NILM by Hart [1]
  - Patel *et al.* [2]
  - ElectriSense [3]
- Summary & Outlook

Pioneer Work: NILM by Hart (1992)

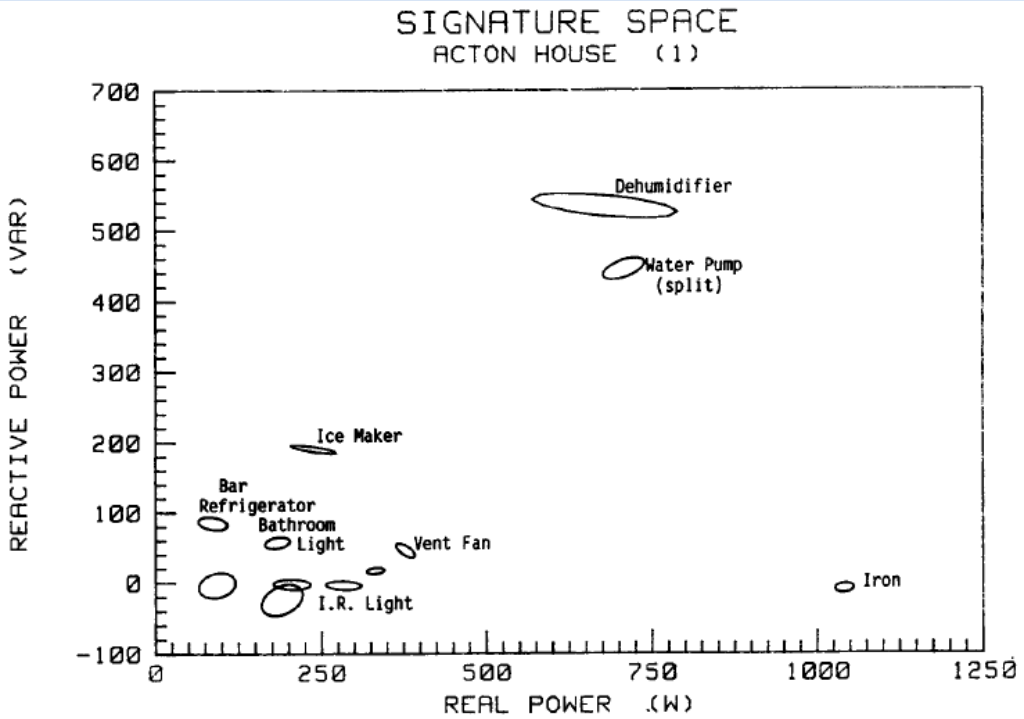
Goal: Identify appliances by inspecting the overall load profile

1. Identify changes in power draw level
   - Low frequency sampling (e.g. 1Hz)



Pioneer Work: NILM by Hart (1992)

1. Identify changes in power draw level
2. Locate these changes in signature space
3. Combine ON/OFF Events



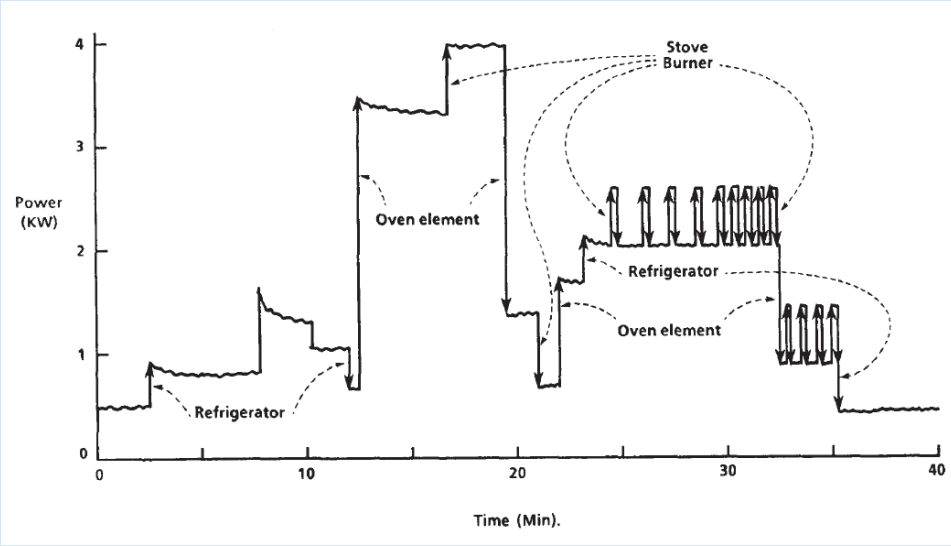
NILM by Hart (1992) – Analysis

Advantages

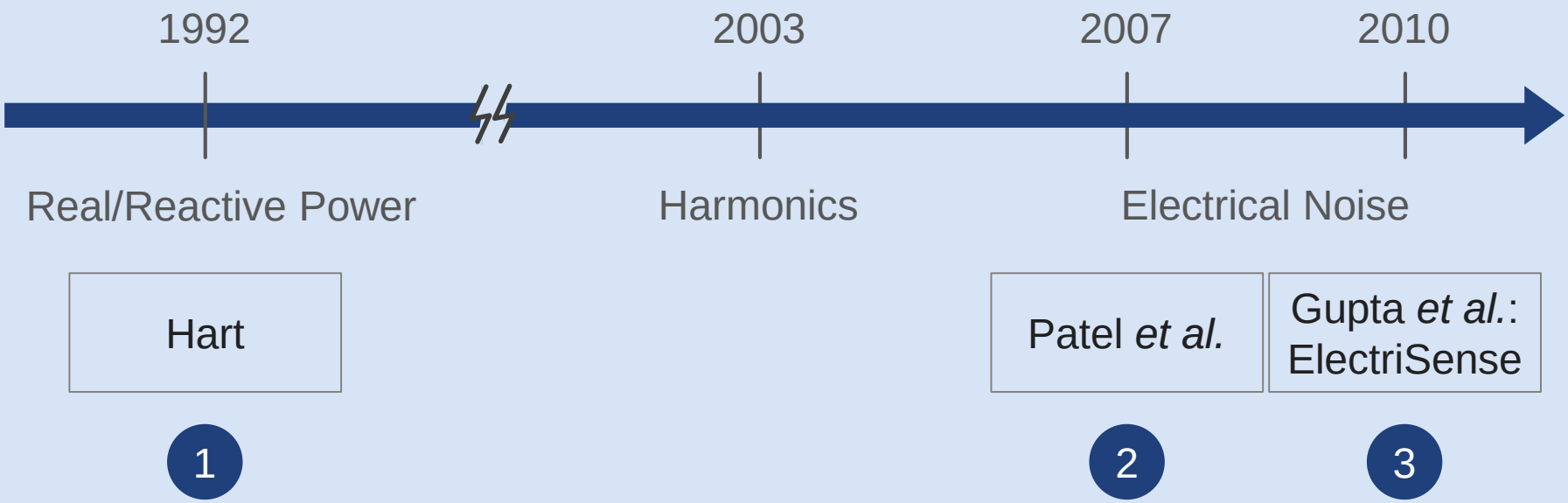
+ Easy to detect and track some On-Off appliances

Drawbacks

- Can not separate:
  - Similar appliances
  - Synchronous appliances
  - Variable-load appliances



High Frequency Sensing



Electrical Noise

- Electrical noise on power line
  - Transient noise (Patel *et al.*)
  - Continuous noise (ElectriSense)
- Created by fast switching of high currents
  - High in energy
- Devices have unique noise signatures
  - Stable over time

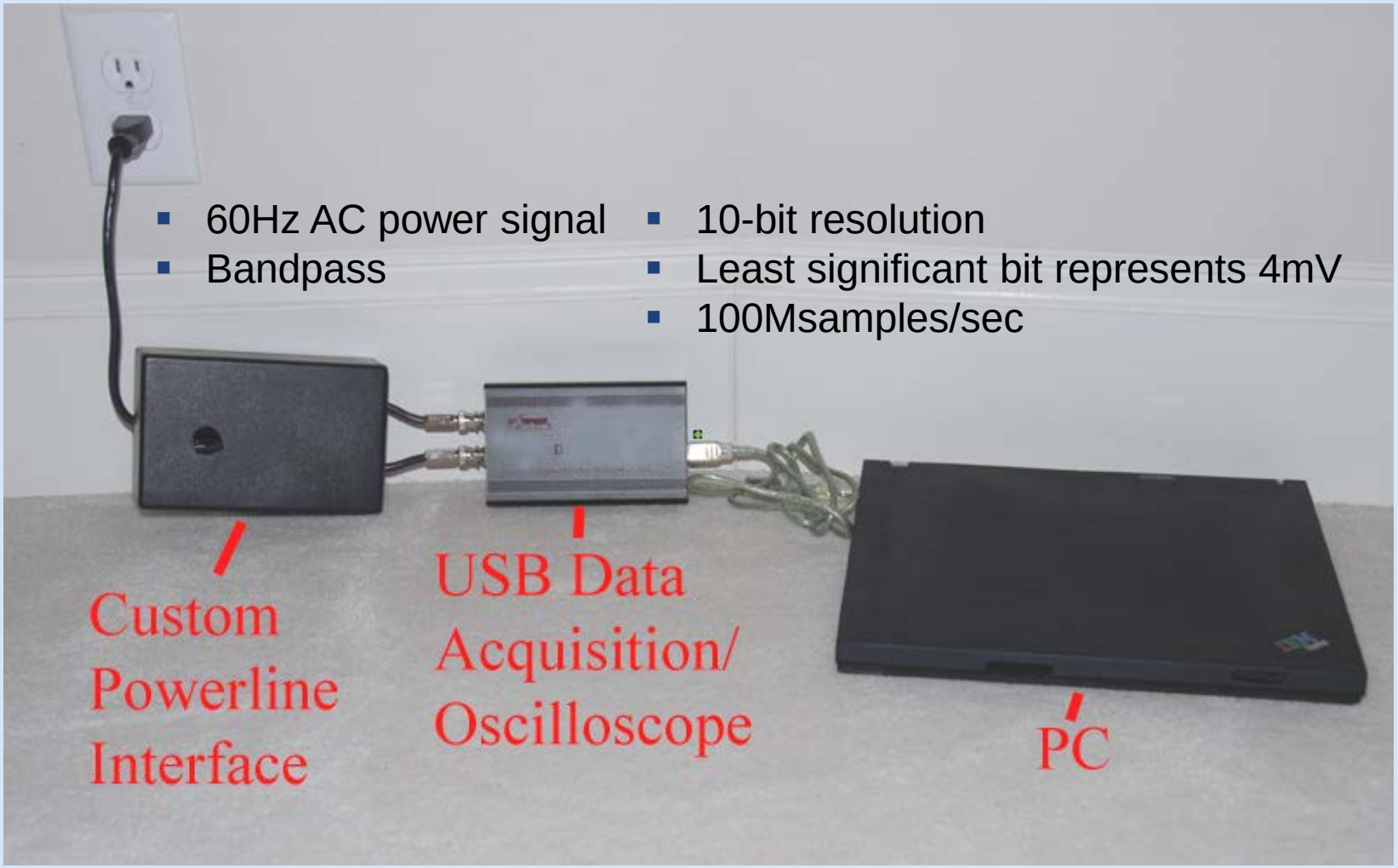
Noise Sources

- Resistive loads
  - No noise in operation
  - Transient noise in mechanical switch

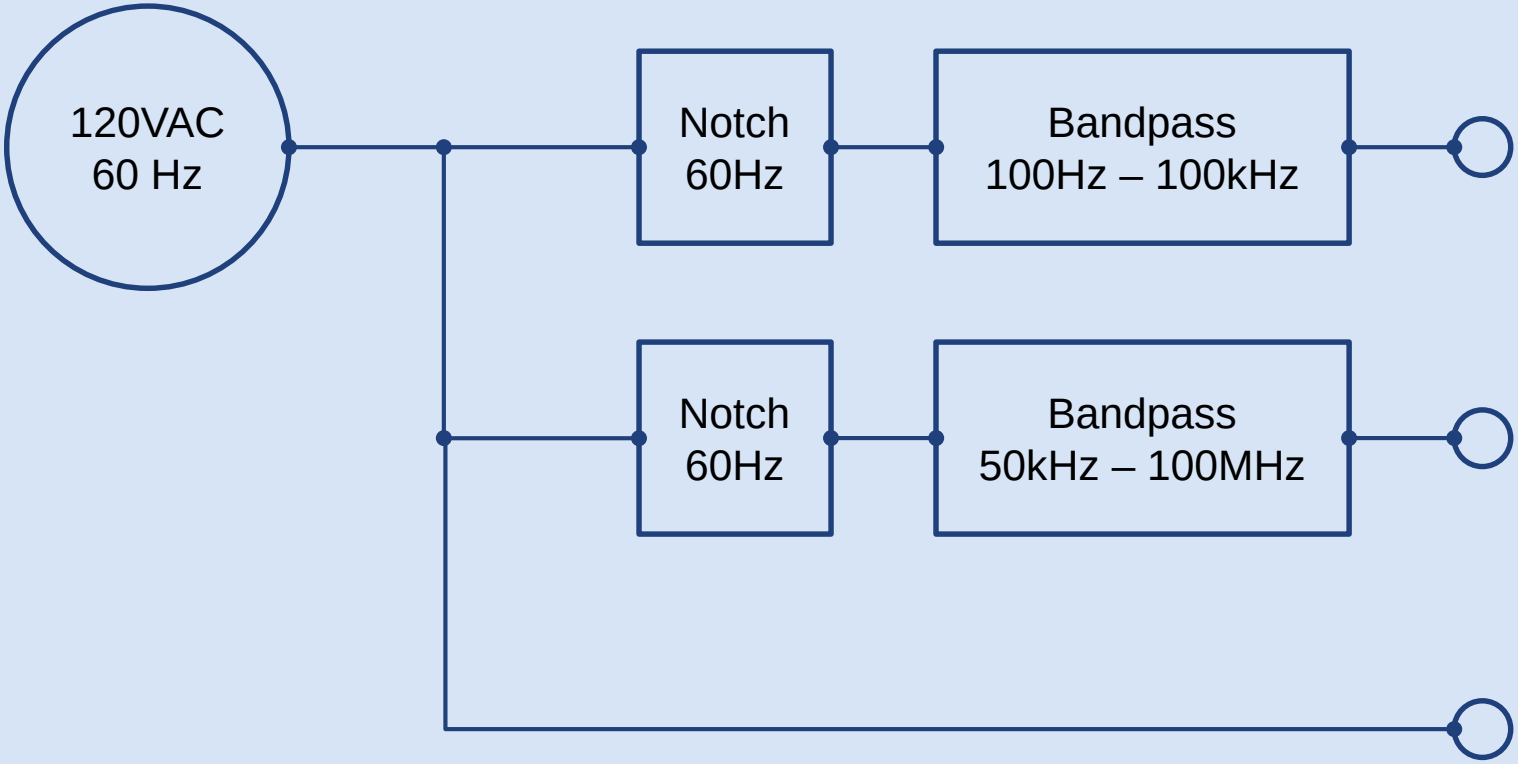
- Inductive loads
  - Breaking/connecting of motor brushes

- Loads with solid state switching
  - Synchronous to internal oscillator

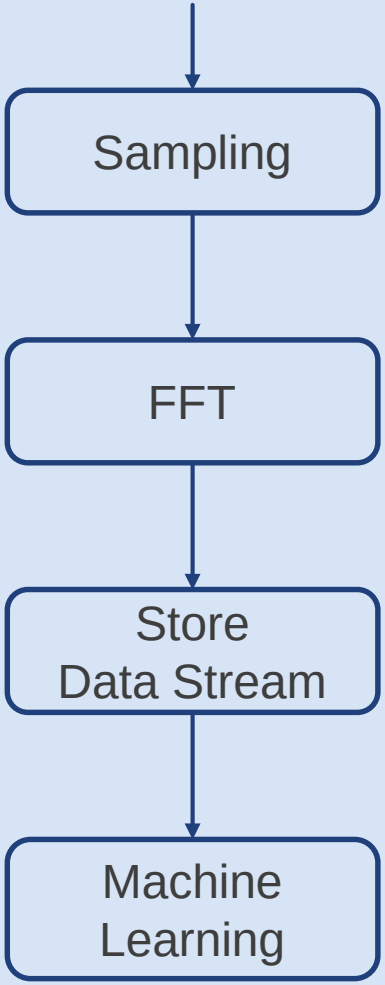
Patel et al. (2007) – Sensing Infrastructure



Patel et al. (2007) – Hardware

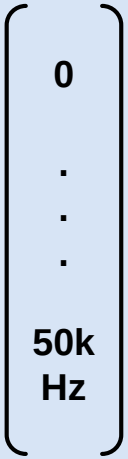


Patel et al. (2007) – Software

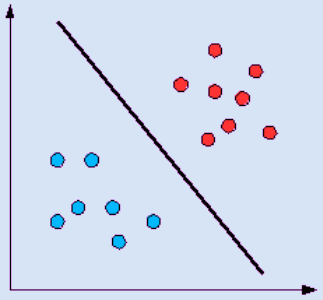


- Sliding window acquires 1us sample

- Store 2048 frequency components in vector
- $|| V_{t_i} - V_{t_{i-1}} ||_2 \geq$ threshold
- Detect ‘start’ and ‘end’ of pulse
- Average over n vectors
- Store feature vector



- Support Vector Machine SVM
  - N-dimensional hyperplane
  - Labeled training data
  - Separates data in classes



When can an event be recognized?

- Strong and reproducible signatures
- Loads drawing less than 30mW are undetectable
  - Solution: more than 10 bits resolution
- 0.5s delay between subsequent toggles
  - Due to sampling & processing latency

Type of events recognized by Patel et al.

Device Class/Type	Devices Observed	On to Off Transition Noise?	Off to On Transition Noise?	Continuously On Noise?
Resistive	Incandescent lights via a wall switch	Y	Y	N
	Microwave door light	Y	Y	N
	Oven light/door	Y	Y	N
	Electric stove	Y	Y	N
	Refrigerator door	Y	Y	N
	Electric Oven	Y	Y	N
Inductive (Mechanically Switched)	Bathroom exhaust fan	Y	Y	N
	Ceiling fan	Y	Y	N
	Garage door opener	Y	Y	N
	Dryer	Y	Y	N
	Dishwasher	Y	Y	N
	Refrigerator compressor	Y	Y	N
	HVAC/Heat Pump	Y	Y	N
	Garbage disposal	Y	Y	N
Inductive (Solid State Switched)	Lights via a dimmer wall switch	Y	Y	Y
	Fluorescent lights via a wall switch	Y	Y	N
	Laptop power adapter	Y	N	N
	Microwave Oven	Y	Y	Y
	Television (CRT, plasma, or LCD)	Y	Y	N

Patel et al. (2007) – Evaluation

Training Phase

- Deployment in six homes
  - Home 1 with a six-week period
  - Homes 2-6 in one-week study
- Manually label each on-to-off event

Results

- Overall accuracy of 88%

Home	Distinct events	Training set (events)	Test set (events)	Accuracy (%)
2	82	328	100	87
3	48	192	96	88
4	76	304	103	92
5	64	256	94	84
6	38	152	80	90

Patel et al. (2007) – Analysis

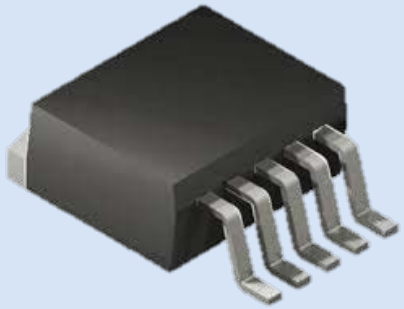
Advantages

+ High accuracy
+ Stable over time

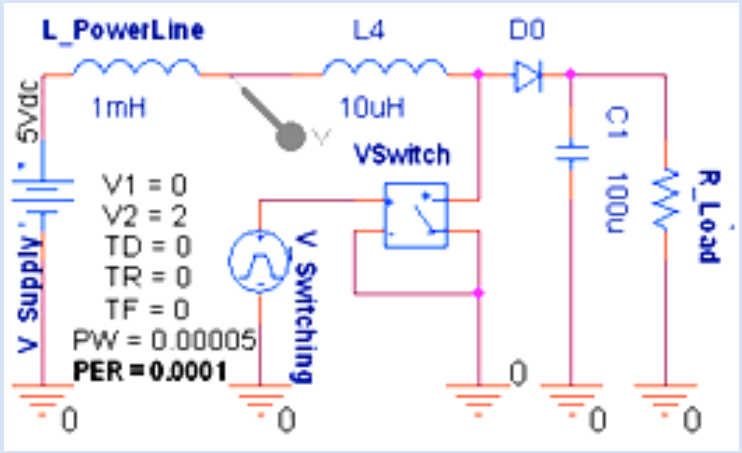
Drawbacks

- Large training set
  - Mislabeling problem
  - Not adoptable for other homes
- Mobile or portable devices

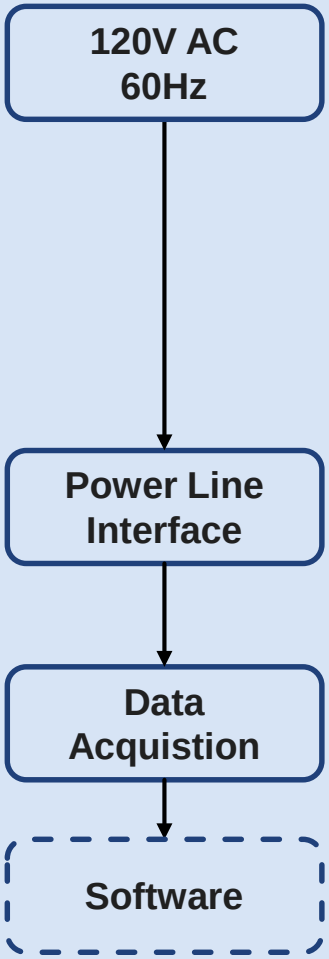
EMI & SMPS



- SMPS switch mode power supplies
  - Creates continuous EMI
- EMI electromagnetic interference
  - Stable and unique for each device
  - EMI signatures independent of the electrical wiring
- ElectriSense analyzes EMI



ElectriSense – Hardware



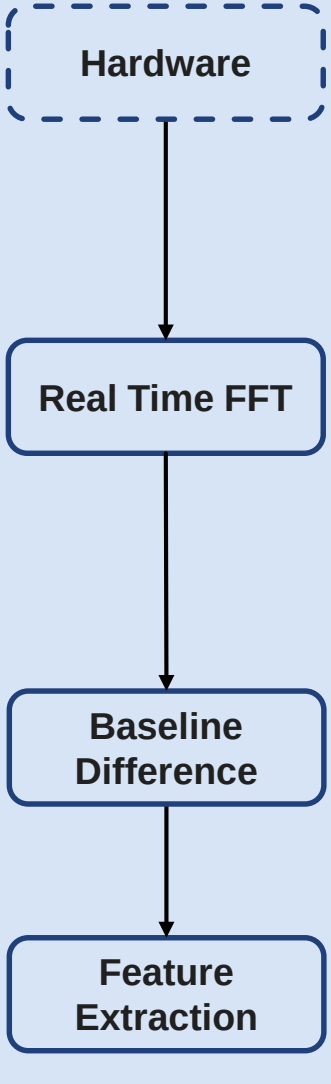
- Motor voltage noise
  - Continuous breaking/connecting of motor brushes
  - Synchronous to AC frequency and its harmonics
- SMPS voltage noise
  - Synchronous to internal oscillator (e.g. 10kHz)

- Filter out AC frequency (60Hz)
- Bandpass 36.7kHz to 30MHz

- Analog-Digital-Converter

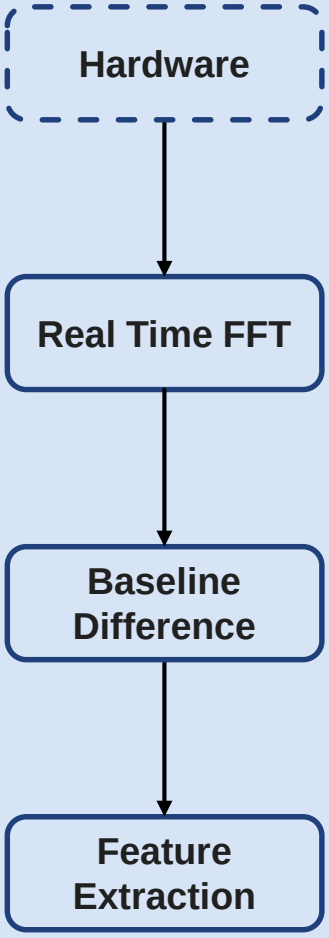
- Digitized signal streamed to software

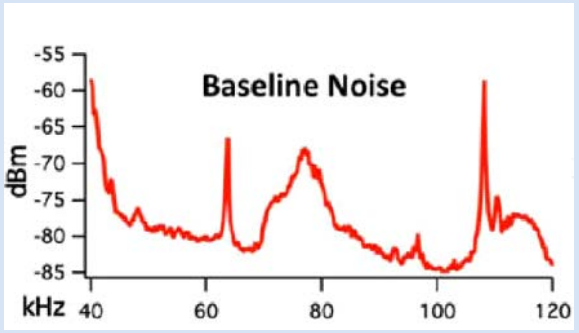
ElectriSense – Software

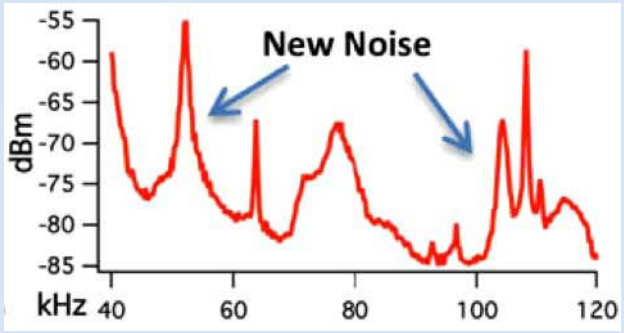


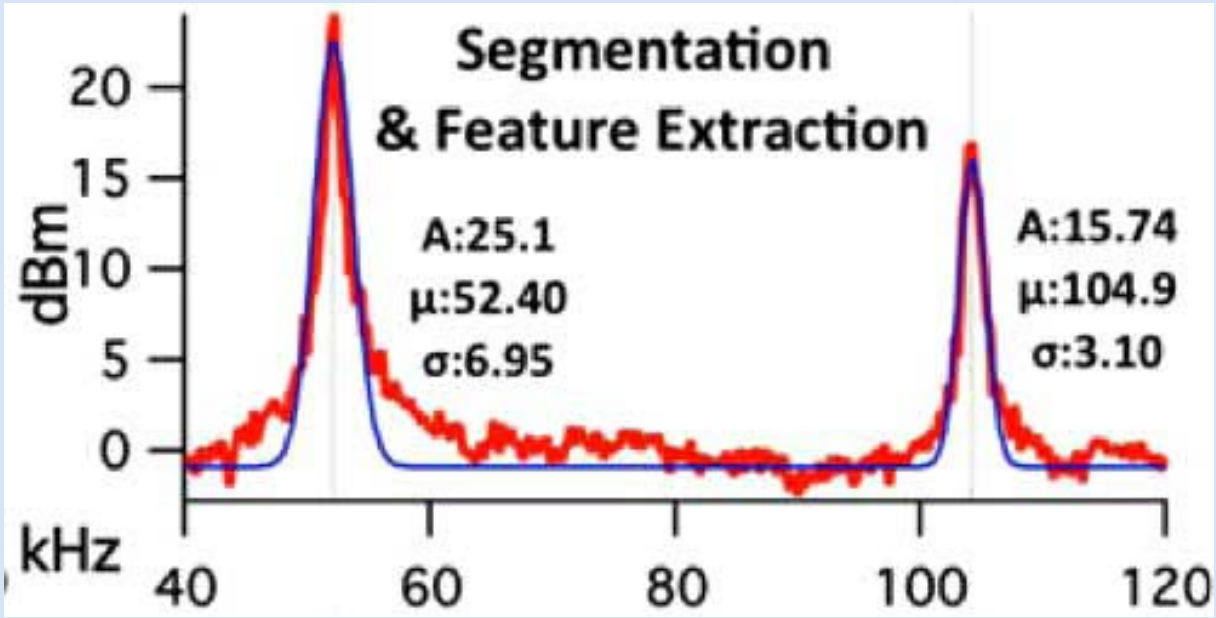
- Buffers incoming signal as 2048-point vector
- FFT to obtain frequency domain signal
- Average with sliding window
  - Too small: false positive
  - Too large: distance between events
- Differentiate with baseline vector
- Difference vector ≥ threshold (8dB)
  - Store amplitude, mean, variance

ElectriSense – Software (2)









ElectriSense – Evaluation

Training Phase

- Actuate each appliance on/off
  - Isolate signature
- Label and store signatures in XML database
  - Goal: reuse database

Results

- 2576 electrical events
- 91.75% accuracy

ElectriSense – Analysis

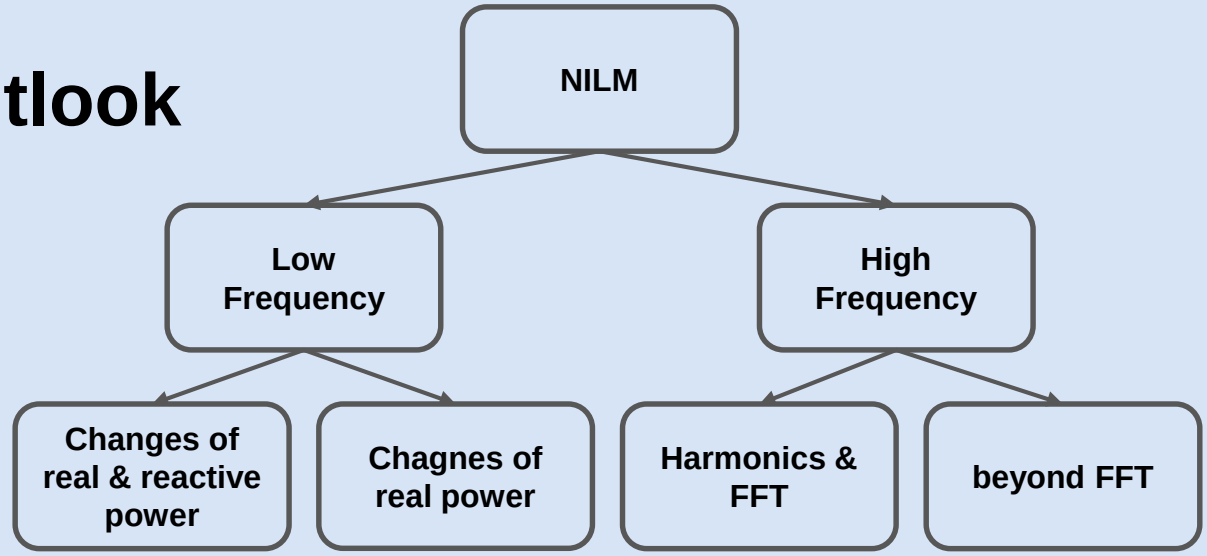
Advantages

+ Detect overlapping events
+ Distinguish two devices of same model
+ Independent of plug-in location
+ EMI signal is independent of the home

Drawbacks

- Expensive training phase
- Resistive loads
- Load and state of appliance

Summary & Outlook



- Hart [1]

- Patel *et al.* [1]
- Gupta *et al.*: ElectriSense [2]

- Combine all approaches
- Extract temporal features
- Build a Finite State Machine
- Crowdsourcing

References

(1) G. W. Hart, Original NILM by MIT
Nonintrusive Appliance Load Monitoring
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(2) S. N. Patel, School of Interactive Computing, Georgia Institute of Technology
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(3) S. Gupta, Electrical Engineering UbiComp Lab, University of Washington
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