Accurate & Easy-to-Deploy In-Home Energy Sensing

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Professors James Fogarty¹, James Landay¹, Shwetak N. Patel¹,²

¹Computer Science and Engineering
²Electrical Engineering
mpg?
1998 RANGER
XL 112" WHEEL
5-SPEED

STANDARD EQUIPMENT INCLUDED AT NO EXTRA CHARGE

SAFETY/SECURITY
- Driver & Passenger SRS Air Bag
- Rear Anti-Lock Brakes
- Adj. Height FR Tilt Seat Belts
- Side Door Guard Beams
- Rear High Mount Stop Lamp
- 24-HR Roadside Assistance

FUNCTIONAL
- Power Steering/Brakes
- Front/Rear Mud Flaps
- Battery Saver
- Gas-Filled Shocks
- 100k Mile Tune-Up Interval
- Prepped for Tow Harness
- SLA Suspension

EXTERIOR
- Solar Tint Glass
- P205/75R14 BSW A/S Tires
- Argent Styled Steel Wheels w/Bright Hub Covers

INTERIOR
- Intermittent Front Wipers
- Black Tailgate Mirrors
- Med. Flat Grille/FRT Bumper
- Med. Rear Step Bumper
- Easily Removable Tailgate

INTERIOR
- 60/40 Vinyl Split Bench Seat
- 170W Power Front Floor Console
- Gauge Package
- Cigarette Lighter
- Inside Hood Release
- Full Door Trim Panels
- Day/Night Rear View Mirror
- Sun Visors

WARRANTY
- 3/36 Bumper to Bumper

Compare this vehicle to others in the FREE FUEL ECONOMY GUIDE available at the dealer.

CITY MPG
22

HIGHWAY MPG
27

Actual mileage will vary with options, driving conditions, driving habits and vehicle's condition. Results reported to EPA indicate that the majority of vehicles with these estimates will achieve between 18 and 26 mpg in the city, and between 22 and 32 mpg on the highway.

1998 RANGER PICKUP 4X2, 2.5 LITER ENGINE (FEEDBACK FUEL SYSTEM), 5-CYLINDER, FUEL INJECTION, CATALYST, 3-SPEED MANUAL.

Estimated Annual Fuel Cost: $781

For Comparison Shopping
all vehicles classified as
STANDARD PICKUP
have been tested using ratings
ranging from 11 to 22 mpg city
and 15 to 27 mpg highway.

SOLD TO

1408 N WALL AVE
OGDEN, UT 84401

SHIP TO (IF OTHER THAN SOLD TO)
how much energy does your dryer use?
why the disconnect?
what about in-home “eco-feedback” displays?
### Municipal Services Statement

**Account Number:**

**Utility Amount Due:**

**Voluntary Donation:**

**Total + Voluntary:**

**Date Due:**

Enter Amount Paid

Mark if address change requested on reverse side

Return the top portion of this statement with your payment.

Keep the bottom portion of this statement for your records.

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**Your electric statement**

For: May 27 2008 to Jun 25 2008 (39 days)

**Statement: Service address:**

**Amount of your last bill:**

**Payments Received:** Thank You

**Water Charge:**

**Total meter reading:** 16305

**Previous meter reading:**

**Account Activity**

<table>
<thead>
<tr>
<th>Date</th>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>12/12</td>
<td>Water Charge</td>
<td>100.00</td>
</tr>
<tr>
<td>12/12</td>
<td>Water Quality Fee</td>
<td>0.13</td>
</tr>
<tr>
<td>12/12</td>
<td>State Tax</td>
<td>0.61</td>
</tr>
<tr>
<td>12/12</td>
<td>Sewer Service Charge</td>
<td>2.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.28</td>
</tr>
</tbody>
</table>

**Balance before new charges:**

**New charges due by:**

**Balance after new charges:**

**Total amount you owe:**

**Account number:**

**Amount of your last bill:**

Payment received: Thank you

Balance before new charges:

New charges due by:

Total amount you owe:

A late payment charge of 1.5% will apply if not paid by July 16, 2008, and your account may be subject to being billed an additional deposit.

Would you like one less bill to think about & help the environment too? Enroll in FPL Automatic Bill Pay & your bill is always paid on time. Save time, postage, check writing & paper. Plus, cut fuel consumption of cars & trucks that transport checks. Enroll at FPL.com or see authorization form in this bill.
<table>
<thead>
<tr>
<th>Item</th>
<th>ResPrice</th>
<th>CardSav</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFY PRITZLE STICK</td>
<td>1.50</td>
<td></td>
<td>6.00</td>
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<tr>
<td>RespPrice 1.79 CardSav .29</td>
<td>3.79</td>
<td>3.99</td>
<td>7.78</td>
</tr>
<tr>
<td>BLKBERY PRES</td>
<td>2.39</td>
<td></td>
<td>2.39</td>
</tr>
<tr>
<td>SFY CANOLA OIL</td>
<td>3.69</td>
<td></td>
<td>3.69</td>
</tr>
<tr>
<td>CEREAL PNT BUTTER</td>
<td>2.29</td>
<td></td>
<td>2.29</td>
</tr>
<tr>
<td>CHILI SAUCE SUT</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>CHF-B PIZZA</td>
<td></td>
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<tr>
<td>LK GRLC SCE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LUC CHEESE</td>
<td>6.79</td>
<td></td>
<td>6.79</td>
</tr>
<tr>
<td>RespPrice 6.79 CardSav .29</td>
<td>8.99</td>
<td>9.29</td>
<td>18.28</td>
</tr>
<tr>
<td>SPINACH ARTICHOKE</td>
<td>3.79</td>
<td></td>
<td>3.79</td>
</tr>
<tr>
<td>RespPrice 3.79 CardSav .29</td>
<td>5.99</td>
<td>6.29</td>
<td>12.28</td>
</tr>
<tr>
<td>3S CRUN VEG RSTD</td>
<td>3.79</td>
<td></td>
<td>3.79</td>
</tr>
<tr>
<td>RespPrice 3.79 CardSav .29</td>
<td>5.99</td>
<td>6.29</td>
<td>12.28</td>
</tr>
<tr>
<td>282.50 SFY SEL M</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RespPrice 7.58 MARGARINE</td>
<td>7.58</td>
<td></td>
<td>7.58</td>
</tr>
</tbody>
</table>

**Month:** April 2006  
**Total Food Units:** 1527  
**Total Price:** $527
high resolution resource consumption sensing for electricity, water and gas
three design goals

- low-cost
- easy-to-install
- device-level information
device-level information

sometimes called *disaggregated* or *disambiguated* data

information down to the *source of consumption*
how much energy does your dryer use?

appliance + sensor = appliance-level data!
distributed direct sensing

overhead lighting

coffee maker

refrigerator

stove

microwave

convection oven
electriSence: appliance level sensing with two sensors

- Powerline event detection sensor
  - Automatically detects and classifies electrical events on the home powerline

- Contactless power consumption sensor
  - Whole-home power consumption sensing from outside breaker panel

Patel et al., UbiComp 2007
Patel et al., To Appear
my colleague, sidhant, will walk around using various electrical switches/appliances

list of recently activated events

currently detected event

graph of power consumption over time

total power being consumed in real-time

not for end users
CFL Torch Lamp ON

Power (kW): 0.50  Voltage: 120.93
movie removed for public posting of slide deck
how does this work?
electriSense: appliance level sensing with two sensors

Powerline event detection sensor
- Automatically detects and classifies electrical events on the home powerline

Contactless power consumption sensor
- Whole-home power consumption sensing from outside breaker panel

Patel et al., UbiComp 2007
Patel et al., To Appear
requirement:

we need

real-time

power consumption data
installing the energy detective (ted)

“Serious injury/death could occur if you’re not familiar with electrical components and the operation of the circuit breaker panel”

– TED website
installing contactless power consumption sensor

installs *on the outside* of the circuit breaker box
how contactless power consumption sensing works

calculate current flow based on the magnetic field generated by the two electrical feeds in the breaker box

use a magnetoresistive sensor to measure magnetic field, which radiates a few centimeters outward, even through sheet metal
electrisense: appliance level sensing with two sensors

- powerline event detection sensor
  - automatically detects and classifies electrical events on the home powerline
  - Patel et al., UbiComp 2007

- contactless power consumption sensor
  - whole-home power consumption sensing from outside breaker panel
  - Patel et al., To Appear
installing power line event detection (ped)

listens for noise on powerline and monitors line voltage

programmable hardware for fourier analysis and feature extraction
Power consumption spikes and temporal patterns correlate to usage.

This is only one input feature into our machine learning algorithm!
your noise is our signal
how ped works

mechanical switches

electrical noise transient
how ped works
mechanical switches
electrical noise transient
each switch has a unique transient signature

based on:
1. switching mechanisms
2. load characteristics
3. position on transmission line

switch 1

switch 2
transmission line shapes signal allows us to identify identical devices, which are in different locations in the home
signal is stable over time

day 1

day 2

day 7

switch 1
movie removed for public posting of slide deck
how Ped works

three classes of noise generates continuous noise

- resistive loads
- inductive loads (e.g., from motors)
- loads with solid state switching (e.g., tvs, cfls, computers)
transients
transients

continuous noise

fan resonant noise frequency

tv resonant noise frequency

[Graphs and images of transients and continuous noise]
fan resonant noise frequency

tv resonant noise frequency
movie removed for public posting of slide deck
calibration:

3 approaches
1. the early adopters
2. unsupervised learning
2. unsupervised learning

television events

air conditioning

hot water heater

lighting events
3. the cloud
Infrastructure-Mediated Single-Point Sensing of Whole-Home Water Activity

Jon Froehlich¹, Eric Larson², Tim Campbell³, Conor Haggerty⁴, James Fogarty¹, Shwetak N. Patel¹,²

¹Computer Science & Engineering, ²Electrical Engineering, ³Mechanical Engineering, ⁴Community, Environment, and Planning
water scarcity

Sources: Smakhtin, Revenga and Döll, 2004.
• **single-point** pressure-based sensor of water usage

• **identifies water usage activity down to its source** (e.g., toilet)

• provides **estimates of flow at each fixture**
hydroSense: pressure-based sensor

pressure waves

- toilet
- kitchen sink
- shower
closed pressure system
traditional inline water meter

- only provide aggregate information on water usage
- require pipe modification for installation

typical water meters
movie removed for public posting of slide deck
raw bathroom sink signal

- open valve
- stabilized pressure drop
- close valve

psi vs time (t)
example open events

<table>
<thead>
<tr>
<th>fixture</th>
<th>trend charts</th>
<th>signature dependent on:</th>
</tr>
</thead>
<tbody>
<tr>
<td>toilet</td>
<td><img src="image1" alt="Toilet Chart" /></td>
<td>- fixture type</td>
</tr>
<tr>
<td>faucet</td>
<td><img src="image2" alt="Faucet Chart" /></td>
<td>- fixture location in home</td>
</tr>
<tr>
<td>shower</td>
<td><img src="image3" alt="Shower Chart" /></td>
<td></td>
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</tbody>
</table>
GasSense: Appliance-Level, Single-Point Sensing of Gas Activity in the Home

Gabe Cohn\textsuperscript{1}, Sidhant Gupta\textsuperscript{2}, Jon Froehlich\textsuperscript{2}, Eric Larson\textsuperscript{1}, Shwetak Patel\textsuperscript{1,2}

\textsuperscript{1}Electrical Engineering, \textsuperscript{2}Computer Science and Engineering
gasSense installs on outside of gas regulator
the intensity of this audio signal and its rate of change indicate fixture and directly correlates to flow
how gassense works

1. a gas event
2. instrumented regulator
3. data cleansing
4. extract signal
5. ML Algorithms
6. classify event
example data

Estimated Flow vs. Time for H4 Compound Events

- Water Heater On
- Water Heater Off
- Furnace On
- Furnace Off
- Stove On
- Stove Off
- Fireplace On
- Fireplace Off

Flow Rate (CCF/hr)

Time (sec)

Raw
Smoothened
using the stove
enable new kinds of consumption feedback
redesign bills
redesigned websites
ubigreen home energy table
disaggregated feedback study
advanced home resource consumption sensing

electrisense

hydrosense

easy-to-install

device-level information

low-cost

ubicomp lab

http://ubicomplab.cs.washington.edu

sustain
sustainability research
Thank You!
jonfroehlich@gmail.com
twitter @jonfroehlich

students
Jon Froehlich  Gabe Cohn  Sidhant Gupta  Eric Larson  Tim Campbell  Kate Everitt  Marilyn Ostergren  Shwetak Patel  James Fogarty  James Landay

faculty

http://ubi.complab.cs.washington.edu
http://dub.washington.edu/
Recent technological advances have led to a wave of new generation shared bicycling systems. Bicycles can now be checked out using mobile phones or RFID smart cards enabling real-time tracking of bicycle usage. Currently, there are over forty such programs in the world including Velib in Paris, which has 20,000 bicycles and 1,450 stations, Bicing in Barcelona (2,000 bicycles and 480 stations) and the recently introduced批判 program in Houston (in May 2009).

Our research focuses on how technology can be used to promote shared bicycling usage. In particular, we have built predictive models of shared bicycling usage, which can be used to automatically suggest a station with available bikes or time parking slots along the user’s expected route. We are also exploring how social media (e.g., Facebook, Twitter) can be used to encourage shared bicycling (e.g., via social competition, fitness tracking and feedback).

We surveyed 252 bicycling users about shared bicycling in Spanish, Catalan & English and uncovered temporal and spatial patterns.

where does your drinking water go? hydrosense knows

infrastructure mediated whole home water monitoring via single point sensing