Using digital sensors to understand activity in the home

Nigel Gilbert,

Klaus Moessner,

Kristrún Gunnarsdóttir

and Jie Jiang







5G INNOVATION CENTRE









HomeSense: digital sensors for social research

• The project will make it easier and more productive for social researchers to use the digital sensors that are becoming available as a result of the rise of the 'internet of things' and ubiquitous computing.



• The project will yield guidelines for and examples of the use of digital sensors, including consideration of **technical**, **methodological** and **ethical** issues.



The project

- Started formally on 1 January 2016 (actually, February 2016)
- Three years
- Staff
 - Dr Kristrún Gunnarsdóttir
 - Dr Jie Jiang
 - + PI
 - Nigel Gilbert
 - + Co-l
 - Klaus Moessner, Surrey 5G Centre
 - + Advisor
 - Ewa Luger, Microsoft Cambridge















Three strands

- I. Demonstrate the use of sensors via household trials
- 2. *Catalogue* technical, methodological and ethical issues
- 3. Create guidelines for using sensors and analysing sensor data







Life at home

- What do we know about activities and interactions in households?
- Time use diaries can find out but are tedious to complete and often inaccurate
- 20-30 volunteer households
- Fitted with sensors for 3 months
- Triangulation with
 - + Time use diaries
 - + Questionnaires
 - Walking interviews





Strand 1: Adapt, develop and test sensors

- In home fixed sensors
 - + Temperature, humidity, dust, noise, movement, brightness
 - + Electricity consumption
- Wearable sensors
 - + Movement, location in the home
- Smart phones
 - + Geo-location, answers to questions





Sensors

Wearable sensor: MiBand

Ultra-thin 8mm battery

Battery capacity: 41 mAh Battery type: lithium polymer Input current: 25 mA(TYP) Input voltage: DC 5.0 V

0



Bluetooth[®] version: 4.0

Energy monitor: IAM



Fixed sensor: the Egg

Microphone Ranging sensor Particulate sensor Temperature & humidity RGBC Light & gesture sensor

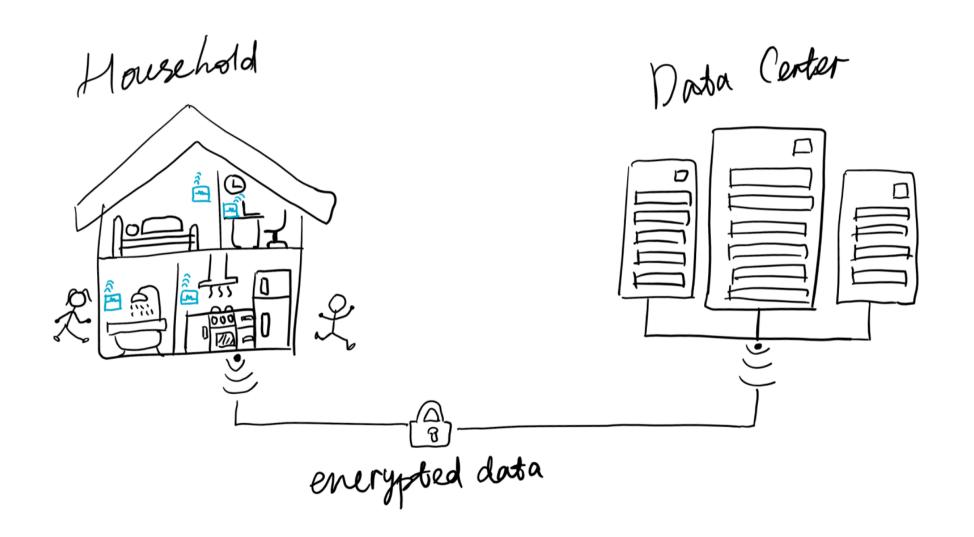






Data flow





Visualization of the data stream in real time

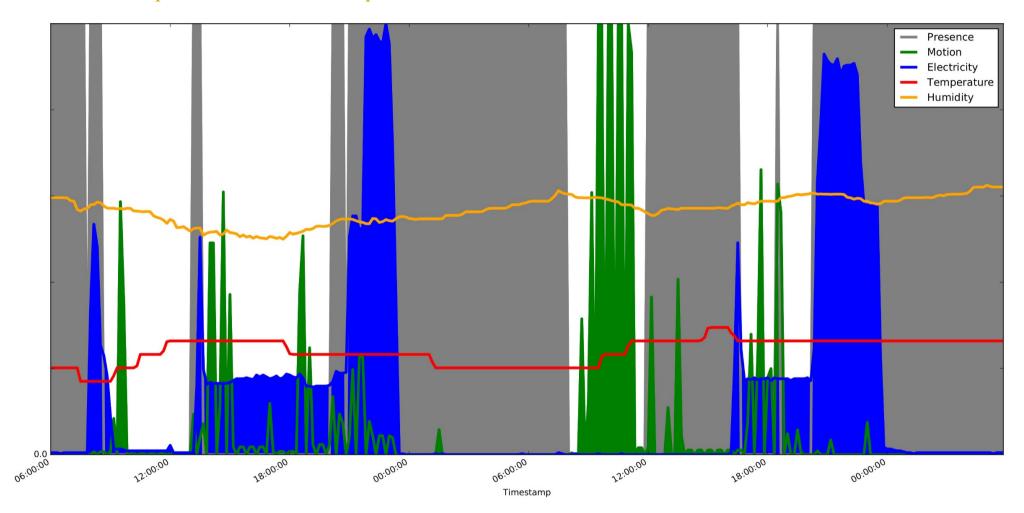




Testing: in a study bedroom

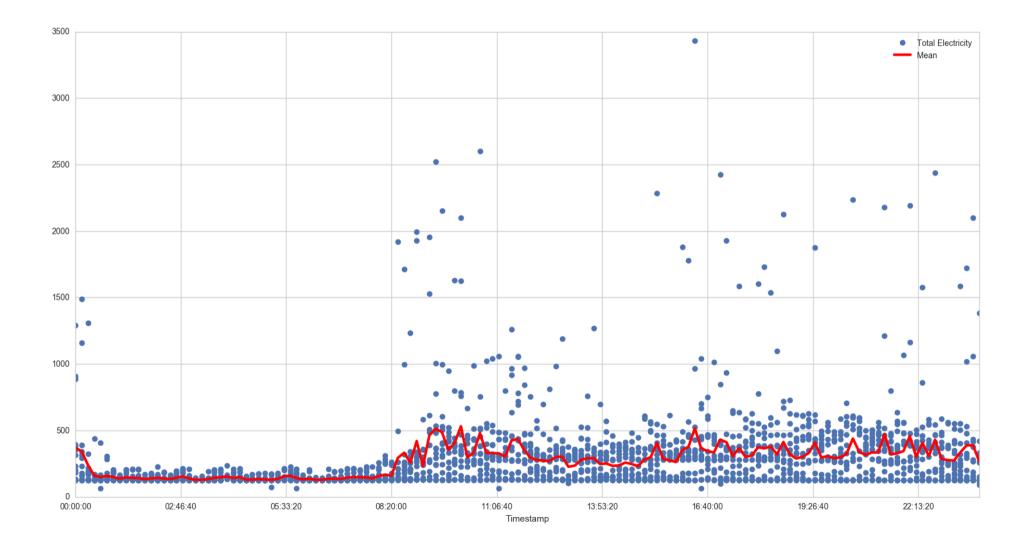
From 23 Sept 6:00am until 25 Sept 6:00am







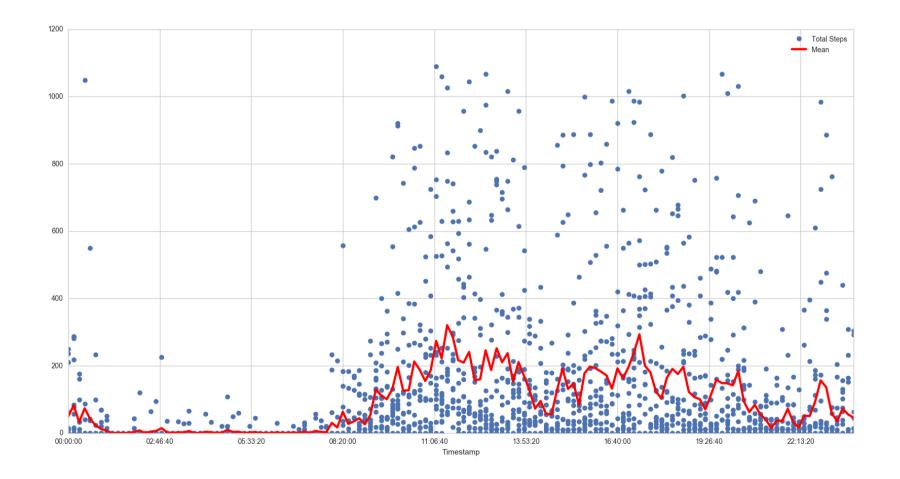
Testing: electricity daily distribution From 05-12-2016 to 05-01-2017





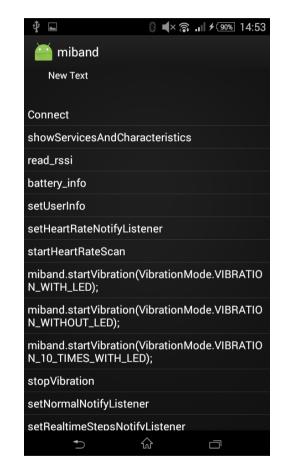


Testing: motion daily distribution From 05-12-2016 to 05-01-2017



Data from wearable device

App to extract data



Real-time data stream of a Mi Band

log 🕷	cat Memory →*	CPU →*	GPU →*	Metwork →*	Log level	: Verbos	e 🗘	Q	🔵 🔽 Regex	Show only selected application	n ᅌ
										F 0,76-540,794 #7f0c0	
📑 🤅	04-04 16:50:01.120	3 30133-3013	3/com.z	zhaox1aodan.m1ba	anddemo I/View:	Touch up d	1spatch	to android.widget.ListView	w{4226ffff8 VFED.VC.	.F.P 0,76-540,794 #7f0c003	Id app
	04-04 10:50:09.49.	2 20122-2012	3/ com. 2	zhaoxiaodan.miba	anddemo I/View:	Touch down	dispat	ch to android widget listV	1ew(42330400 V.ED	E 0 76-540 704 #7f0-6	202d av
+ 2	04-04 10:50:05:450 04-04 16:50:00 62	7 20122-2012	3/com 3	zhaoxiaodan miba	anddemo I/View.	Touch up d	icnatch	to android widget ListVie	JA226fff9 VEED VC		id anni
	04-04 16:50:15.64	30133-3013	7/2001.2		nddeme D(miken	d and no id.	IC EOJ	to and/org.widget.Listvie	w142201118 VIED.VC.		ou app.
	04-04 16:50:15.64							rate: 50			
	04-04 16:50:13.04										
								imeStepsNotifvListener:523	P		
	04-04 16:54:30.576								5		
. 6								imeStepsNotifyListener:523	9		
	04-04 16:54:31.828										
								imeStepsNotifvListener:524	Ð		
* 6	4-04 16:54:32.454	4 30133-3106	7/com. 2	zhaoxiaodan.miba	nddemo D/mibano	d-android:	[121, 2	0, 0, 0]			
								imeStepsNotifyListener:524	1		
6	04-04 16:54:33.078	3 30133-3014	4/com. 2	zhaoxiaodan.miba	nddemo D/mibano	d-android:	[123, 2	0, 0, 0]			
								imeStepsNotifyListener:524	3		
6	04-04 16:54:33.70	3 30133-3014	5/com.z	zhaoxiaodan.miba	nddemo D/mibano	d-android:	[124, 2	0, 0, 0]			
								imeStepsNotifyListener:524	4		
	04-04 16:54:34.32										
								imeStepsNotifyListener:524	5		
	04-04 16:54:34.95								_		
								imeStepsNotifyListener:524	7		
	04-04 16:54:36.20										
	04-04 16:54:36.20	2 30133-3014	5/com.z	znaoxiaodan.miba	inddemo D/==[m10	oandtest]==	: Realt	imeStepsNotifyListener:524	в		
	04-04 16:54:36.829							imeStepsNotifyListener:525			
	04-04 16:54:38.074								0		
								imeStepsNotifyListener:525	1		
	04-04 16:54:38.70										
								imeStepsNotifyListener:525	3		
	4-04 16:54:39.950								-		
								imeStepsNotifyListener:525	5		
	04-04 16:54:40.610										
6	04-04 16:54:40.610	5 30133-3014	5/com.z	zhaoxiaodan.miba	anddemo D/==[mib	bandtest]==	: Realt	imeStepsNotifyListener:525	6		
6	04-04 16:54:41.05	5 30133-3013	3/com.z	zhaoxiaodan.miba	anddemo I/View:	Touch down	dispat	ch to android.widget.TextV	iew{4235d4d8 V.ED	0,135-540,184}, eve	ant = M
										F 0,76-540,794 #7f0c0	
									w{4226fff8 VFED.VC.	.F 0,76-540,794 #7f0c003	d app:
6	04-04 16:54:41.200	30133-3106	7/com.z	zhaoxiaodan.miba	nddemo D/mibano	d-android:	[-118,	20, 0, 0]			
								imeStepsNotifyListener:525	8		
6	04-04 16:54:41.86	5 30133-3014	4/com.2	znaoxiaodan.miba	inddemo D/mibano	d-android:	1-11/,	20, 0, 0]			
								imeStepsNotifyListener:525		0 105 540 1041	
	04-04 10:54:45.250	3 30133-3013	3/ COIII. 2	zhaoxiaodan miba	inddemo T/View.	Touch down	dicpat	ch to android widget listV	100(42330408 V.ED		202d or
										.F 0,76-540,794 #7f0c003	
	04-04 16:54:44.95								w(42201110 0120.00.		in abb.
								imeStepsNotifyListener:526	3		
	04-04 16:54:46.46								5		
								imeStepsNotifyListener:526	5		
é	04-04 16:54:48.109	30133-3106	7/com.z	zhaoxiaodan.miba	nddemo D/mibano	d-android:	[-110.	20. 0. 0]			
								imeStepsNotifyListener:526	6		
	04-04 16:54:48.91										
								imeStepsNotifyListener:526	7		
	04-04 16:54:49.529										
6	04-04 16:54:49.53	2 30133-3014	5/com.z	zhaoxiaodan.miba	anddemo D/==[mib	bandtest]==	: Realt	imeStepsNotifyListener:526	8		
	04-04 16:54:50.20										
6	04-04 16:54:50.200	5 30133-3106	7/com.z	zhaoxiaodan.miba	anddemo D/==[mib	bandtest]==	: Realt	imeStepsNotifyListener:526	9		
	04-04 16:54:50.86										
6	04-04 16:54:50.868	3 30133-3014	4/com.z	zhaoxiaodan.miba	anddemo D/==[mib	bandtest]==	: Realt	imeStepsNotifyListener:527	0		
	04-04 16:54:51.61										
								imeStepsNotifyListener:527	1		
	04-04 16:54:52.16							20, 0, 0] imeStepsNotifyListener:5272	-		
	04-04 16:54:52.830								2		
								imeStepsNotifyListener:527	2		
	04-04 16:54:53.26								,		
								imeStepsNotifyListener:5274	4		
6	04-04 16:54:53.750	5 30133-3106	7/com. 7	zhaoxiaodan.miba	nddemo D/mjbano	d-android:	[-101.	20. 0. 0]			
e	04-04 16:54:53.75	7 30133-3106	7/com. 2	zhaoxiaodan.miba	nddemo D/==[mik	bandtestl==	: Realt	imeStepsNotifyListener:527	5		
6	04-04 16:54:54.614	4 30133-3014	4/com. 2	zhaoxiaodan.miba	nddemo D/mibano	d-android:	[-100,	20, 0, 0]			
								imeStepsNotifyListener:527	6		
6	04-04 16:54:56.329	9 30133-3014	5/com.z	zhaoxiaodan.miba	nddemo D/mibano	d-android:	[6, 94]				
6	04-04 16:54:56.330	0 30133-3014	5/com.z	zhaoxiaodan.miba	anddemo D/==[mik	bandtest]==	: heart				
	04-04 16:54:56.690										
								imeStepsNotifyListener:527			



Data from wearable device

Movement



Sleeping



In Bed For Deep Sleep Light Sleep 10h 53m 3h 08m 7h 45m Fell Asleep At Woke Up At Awake For 20:43 09:05 1h 29m

 $\hat{\omega}$

₽

Heart rate

< F	0 🖏 🗟 💵 🥯 15:50 leart rate 58 _{вРМ}
03/07 17:09 Heart rate is normal	85 врм
03/06 13:52 Heart rate is fast	106 врм
03/05 19:52 Heart rate is normal	65 врм
03/05 19:51 Heart rate is normal	65 врм
03/04 20:55 Heart rate is normal	61 врм
03/04 17:38 Heart rate is slow	57 врм
03/04 17:26 Heart rate is normal	<mark>68</mark> врм





Strand 2 research questions

- What are the practical problems of installing sensors in homes?
- How should one handle privacy and security?
- What are the ethical issues to be considered?
- What are the risks that need to be managed?
- How does one obtained informed consent, and from whom?
- What is the best way to recruit and motivate participants?





Pilot sample

- Pilot sample of 20-30 households in South-East England, each participating for 3 months
- Recruited by neighbourhood advertising and snowballing
 - + Six households of one adult;
 - + Eight households of two or more adults;
 - Six households of parent(s) with dependant(s) 0-16yrs.
 (roughly corresponding to the proportions in the UK population)





Fieldwork

- One key respondent in each household
 - + Interviewed twice, before and after the trial
 - + Fills in two 10-15 minute **questionnaires**, one before and one after the trial
 - first to record information about the household
 - second to record the experience of living with sensors
 - Asked to fill in a diary of **Time Use** for 4 consecutive days, at 10 minute intervals
 - + Given a **MiBand** to wear for the whole trial period
 - + Rewarded with £100, in staged payments
- Other household members (if any)
 - + Optional MiBand
 - Rewarded with £25





First visit

- Preliminary consent obtained from key respondent and other household members aged 16+
- Operation of sensors explained and demonstrated: principle of demystification
- Walking interview around the home, to:
 - Observe the narratives of what goes on, who does what (where with whom), what routines are common, what devices are typically used, what is shared, what is private, and so on.
 - + identify ideal / acceptable spots for Eggs and energy monitors.
- Information sheet given to key respondent to hand to visitors and houseguests.





Second visit

- Install:
 - + Up to 10 sensor boxes (Eggs)
 - + Up to 8 energy monitors
- I or 2 MiBand(s) distributed
 - MiBand data accessible to the wearer on their own smart phone, but also transmitted to data centre
 - + MiBands retained by respondents after the data collection finishes as an additional reward
- Data capture demonstrated during installation
 - + Consent confirmed or revoked (incremental consent)
 - + Children allowed the opportunity to assent



Adapted HETUS format time use diary

Dav 2 Evening

Day 2	Evening							re yo	ne?							
Time: 6pm – 12am			Using any devices?	Where were you?			Member(s) of househo					holo	1:			How much did you enjoy this time?
Evening 6pm – 12am	What were you doing? Please name one main activity	Were you doing something else at the same time? If so, please name one secondary activity	1 = smartphone 2 = tablet 3 = computer practical 4 = computer game 4 = TV / entertainment 5 = washing machine 6 = kettle 7 = stove / oven 8 = other (please name)	a she and the main state	1 = hall(way) 2 = nursery 3 = bedroom 4 = kitchen 5 = living+dining area 6 = dining room (if separate from kitchen) 7 = living room 8 = bathroom 9 = play room (if separate area) 10 = study / workshop 11 = living+dining+study area 12 = bedroom+study 13 = other (please name)	Alone	Spouse / partner	Mother	Father	Dependant(s) 0-18yrs	Other relative(s)	Lodger(s)	House mate(s)	Other(s) you know	Stranger(s)	Scale 1-7 1 = not at all 7 = very much
7:50-8pm	going to Survey University			to the universel	/	Ŕ										5
8pm-8:10	V			V		6										J
8:10-8:20	going back	To K with		Walking from Univ. to have			Ŗ									5
8:20-8:30							4									_
8:30-8:40							þ									
8:40-8:50				*												
8:50-9pm	V	V	2	J			F									V
9pm-9:10	had Dimmer	Talk With my Will	7		4		Ø									6
9:10-9:20							4									
9:20-9:30	V	V	V		V		4									J
9:30-9:40	Organizing set day lende	had help my wife			Ч		Ŕ									5

Were you alone or with someone?

Consent

- Respondents can withdraw from the study at any time
- Eggs can be temporally turned off or on by household members by waving a hand over them (they turn on again automatically an hour later)
- MiBands can disconnected at any time

CONSENT



Freely Given Reversible Informed Enthusiastic Specific





Data management issues

- All data streams are encrypted at point of generation and decrypted at the data centre
- Data are identified only with an ID, with the link to the household address kept separately
- Only aggregate data (not individual data streams) will be available outside the project
- Time use diaries, questionnaire responses, interview transcripts will be available after anonymization
- Specific issues for household studies:
 - One household member recognising another member of the same household in data
 - + Unlawful or compromising activities in the household





Strand 3: Data analysis

- Time use diaries
 - + Self-assigned descriptors of activity
 - Every 10 minutes for a few days
- Data streams from the 'Egg'
 - + A limited number of environmental measurements in a limited number of locations
 - Every 3 5 seconds
 - 3 Megabytes (MB) from each Egg every 24 hours
- Data streams from the energy monitors
 - + Electricity usage of to 8 appliances monitored
 - + Also total household electricity consumption
 - Every 6 seconds
 - 2.4 MB from each energy monitor every 24 hours
- Data streams from the MiBand
 - + Motion
 - Every 15 minutes
 - 17 kB per day
- Up to 42 MB every day per household
- 76 Gigabytes for 20 households over 3 months







Triangulating the data

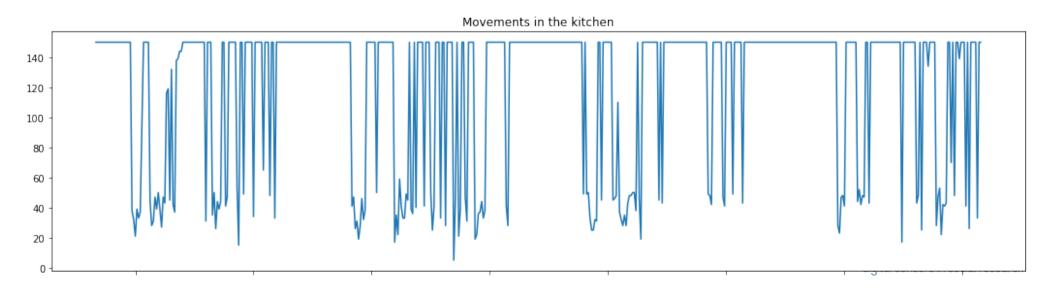
- Time use data
 - + Start and end times of activities may not be accurate
 - + Activities may be recorded out of sequence
 - + Some activities may not be recorded
 - + Descriptors may be idiosyncratic
- Sensor data
 - + Activities may take place out of range of the sensors
 - Sensors do not observe activities, but only their physical effects (e.g. 'cooking' could be recorded as an increase in temperature and noise in the kitchen)
- Hence there is a problem of inference: from sensor data to activity





Sensor data processing

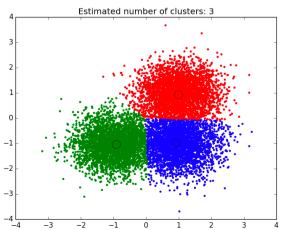
- I. Preprocess sensor data
- 2. Smooth the data
 - + Mean shift clustering
 - + Change point detection
- 3. Recognise activities
 - + Hidden Markov Modelling
- 4. Output a stream of activities





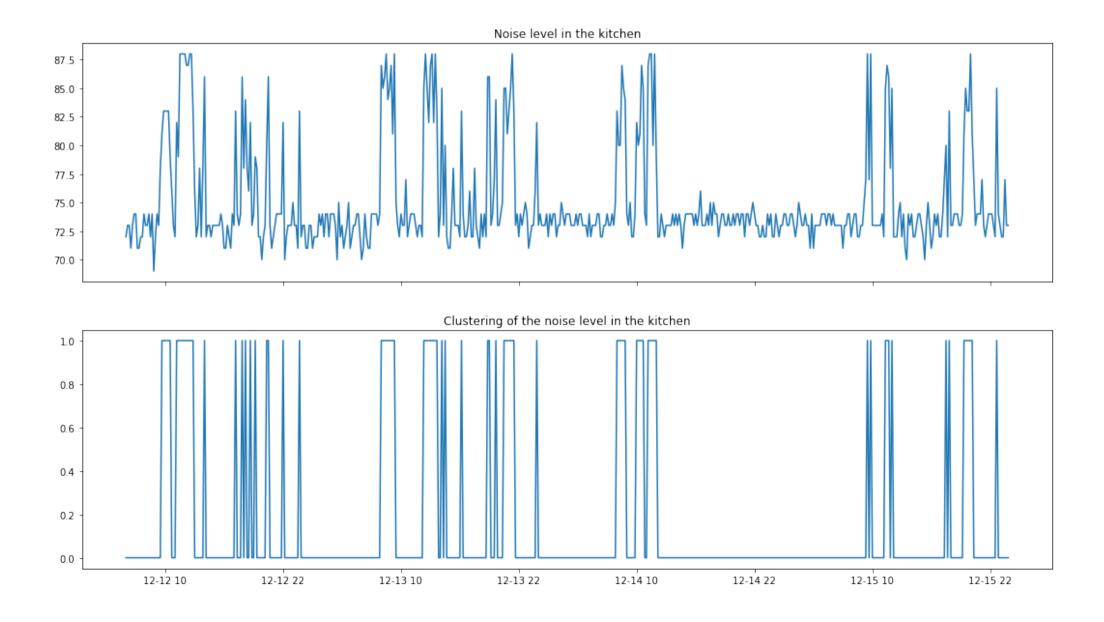
Normalising the sensor data

- Preprocessing
 - Find maximum value within each 10 minute to yield a data stream with values every 10 minutes for each sensor (10 minutes to match Time Use Diary time intervals)
- Discretisation
 - Transform data stream from a continuous value to an set of integer values (representing e.g. on/off; near/middle/far; hot/warm/cold)
 - + But where to change from one value to another?
 - Mean shift clustering

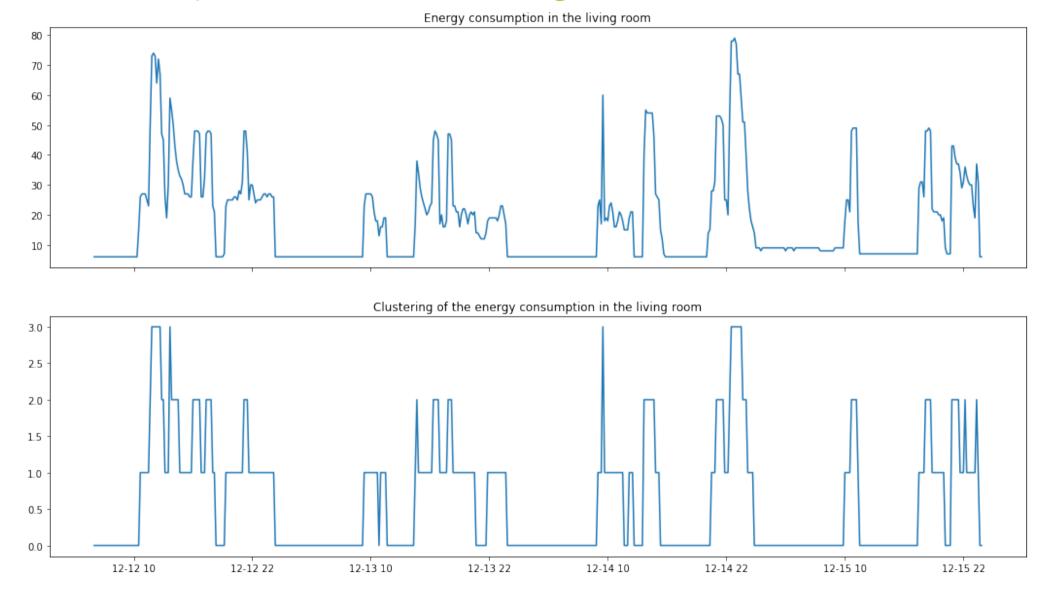




Mean shift clustering of noise-level readings from the sensor box placed in the kitchen

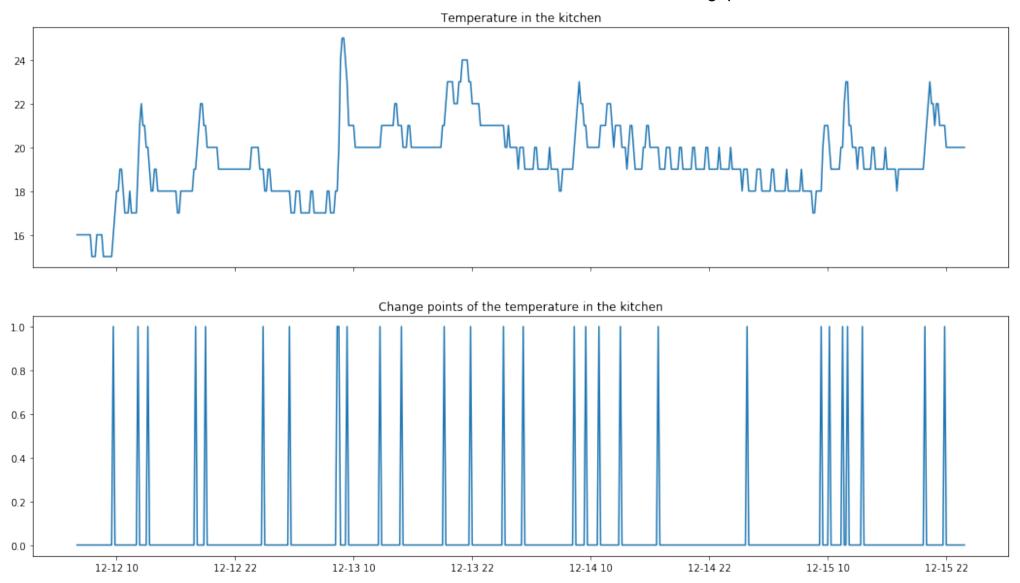


Mean shift clustering of electricity readings from the electricity monitors in the living room



Change point detection

Assumes that the data points are drawn from some PDF with parameters that change at the changepoint.



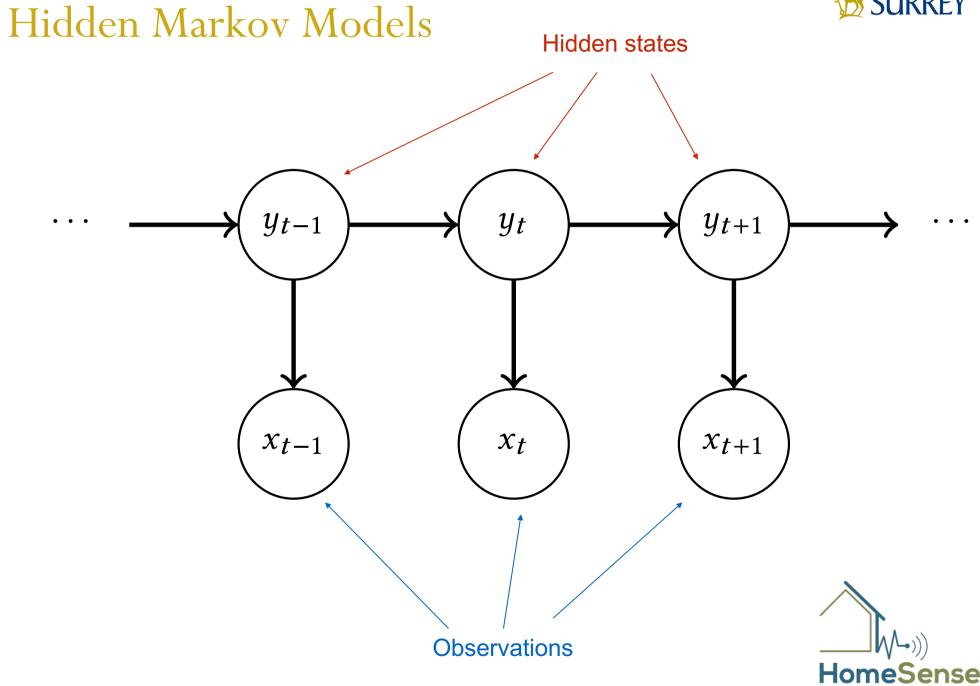


Labelling the data

- The household members are carrying out some activities.
 - + These activities result in data that the sensors can detect.
 - One of the members fills in a Time Use Diary that records the activities and gives them names.
- The activities correspond to states that are 'hidden' or 'latent' but which generate observable sensor data and observable marks in the Time Use Diaries. We want to reveal the hidden activities and label them.
- Use a Hidden Markov Model (HMM)





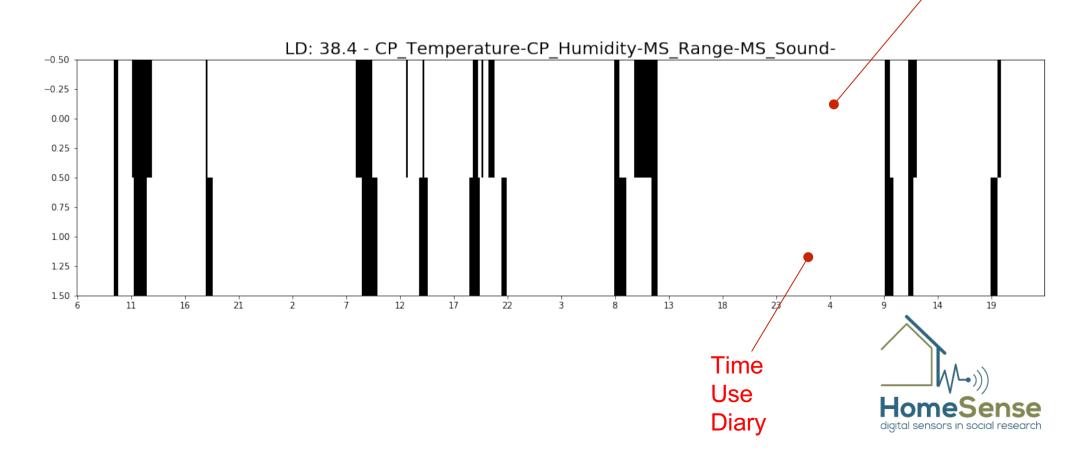




HMM

Hidden Markov Model: example output

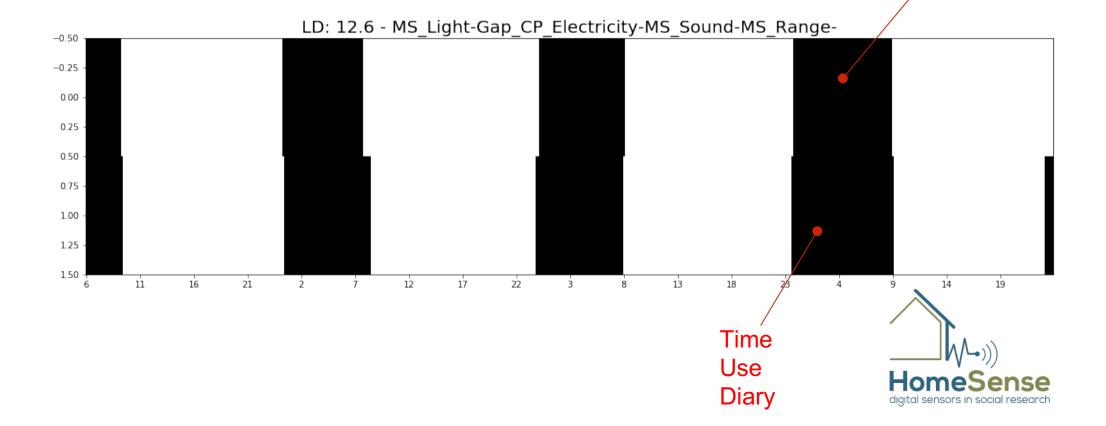
- **Cooking**, using data from the Egg sensors in the kitchen
- Significant data streams: Temperature, Humidity, Range, Sound





Hidden Markov Model: example output

- **Sleeping**, using data from the Egg sensors and energy monitors in the bedroom
- Significant data streams: Whole house electricity, Sound, Light, Range





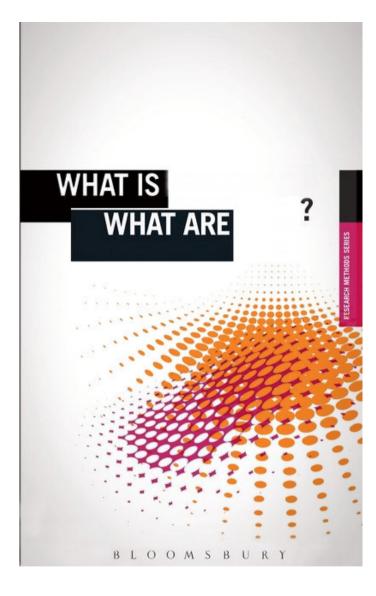
Outputs

INSIGHTS: bringing together sensor technology and social research



- Workshops
- NCRM Short courses, starting in late 2017
- Book: What are sensors in social research?





'What is?' Research Methods series

Graham Crow (ed.) University of Southampton

What are sensors in social research?

- 1. Introduction
- Key terms

 Thinking critically: why use sensors? What kind of data do sensors generate? What is your research question? What is the added value in sensor-generated data? Mixing methods: sensors and ethnographic methods Thinking creatively, asking questions
 A cross-disciplinary research method

What do you need to know to choose and use sensors? Relying on the expertise of others Communicating aims and purposes What are the benefits of cross-disciplinary research

4. Technical considerations

Choosing what to observe and how Adapting sensors and other research instruments Electronic data collection techniques Data transmission, storage and security Accessing sensor-generated data Visualisation techniques Issues of recruitment and participation Installing and monitoring sensors Data-processing and data-analytic techniques Mixing methods: other data sources Interpreting sensor-generated data The Data Management Plan

5. Ethical considerations

What is sensitive about sensor-generated data? Preparing the ethics approval application Consenting to direct and indirect participation Incremental consent Confidentiality and anonymity User/participant engagement Data views and data sharing Understanding the risks Facing ethical dilemmas

6. Where next in using sensors?

The Internet of Things and ubiquitous computing Data mining, data sharing, data protection Debating the right to passive observation Developments in participatory methods Clarity of purpose Sensors everywhere ? Further reading and resources References Index





HomeSense timeline until now

2016

2017



February / March:
Started testing wristbands
First prototype test of the IoT Egg
Reviewed the state-of-the-art in tracking, time use, profile analysis,
etc.
April / May:
Set up database
Developed data processing and visualization techniques
June:
Bloomsbury workshop
Developed quantitative and qualitative research instruments
July / August:
Drafted data collection guidelines
Prepared and submitted ethics approval application
September / October:
Tested sensors and other methods in 'friendly' household
Liaised with meet-ups and other relevant groups to publicise
HomeSense
November / December:
Second pilot test (comprehensive)
January / February:
Ethics approval
Start recruitment
March / April:
Fieldwork
Data collection and visualizations
Submit book proposal
May / June:
Fieldwork
Data collection and visualizations
Start developing data-analytic techniques







What would you like to use digital sensors for?



