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Sensors and Analytics for Monitoring Mobility and Memory
Capteurs et analytique de suivi mobilité-mémoire

SOINS CONTINUS Bruyère CONTINUING CARE

IARIA

Ambient Sensing of Vital Signs and Wellbeing through Sensors and Signal Processing

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The Twelfth International Conference on eHealth, Telemedicine, and Social Medicine
eTELEMED 2020
November 21, 2020 to November 25, 2020 - Valencia, Spain

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Research Focus: Ambient assessment of well-being and supportive smart systems to support independence and aging in place.

Acknowledgement

This tutorial includes the works of many students that have studied with Dr. Rafik Goubran, Dr. Frank Knoefel and myself over many years and our many other collaborators from Carleton University, University of Ottawa, Bruyere Continuing Care and many other organizations.

Agenda

- Why Ambient Assessment?
- Ambient Assessment of Vital Signs
  - Respiration
  - Circulation/Heart
  - Other measures
- Ambient Sensing of Wellbeing
  - Mobility
  - Cognition
  - Activities of Daily Living
- Bringing Everything Together
- Future Directions

Why Ambient Assessment?

- Critical to support the independence of the aging population
- Ongoing assessment of aging adults can provide the needed information to care partners, family and supporting health professionals
- Ongoing assessment must not intrude into the lives of the aging adult and require them to do new or different behaviours
- Challenge: Is the correct person being assessed?

Ambient Assessment of Vital Signs

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Respiration

Assessments to consider

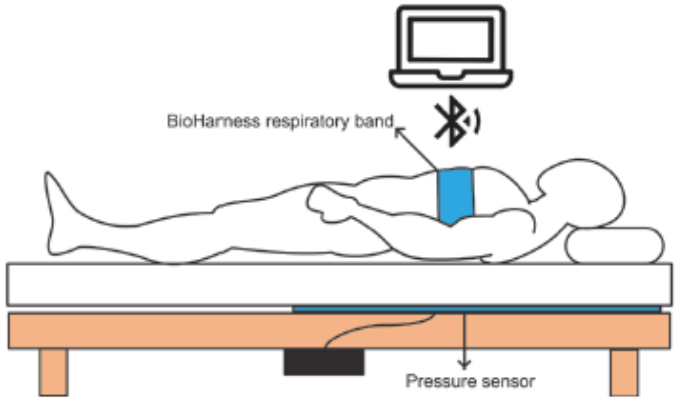
- **Respiration Rate**
- **Sleep Apnea**
- **Cough**

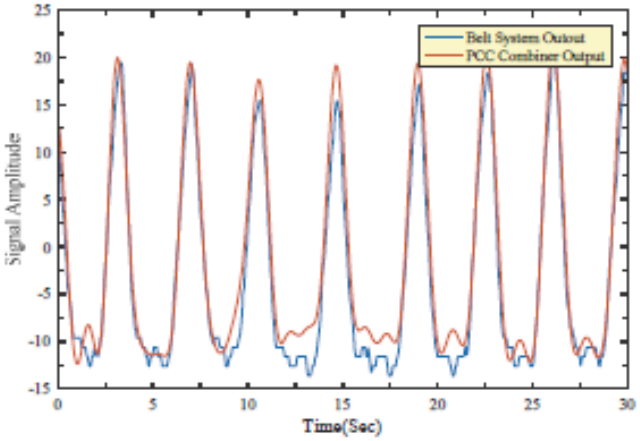
Pressure Sensitive Mat Sensors

- Arrays of pressure sensors
  - force sensitive resistors
  - vibration/sound sensors
  - piezoelectric film sensors
  - fibre optic
  - infrared proximity
- Can be placed in many locations
  - Under bed mattress
  - Under seat cushion
  - On grab bars
  - On floor

Respiration Rate

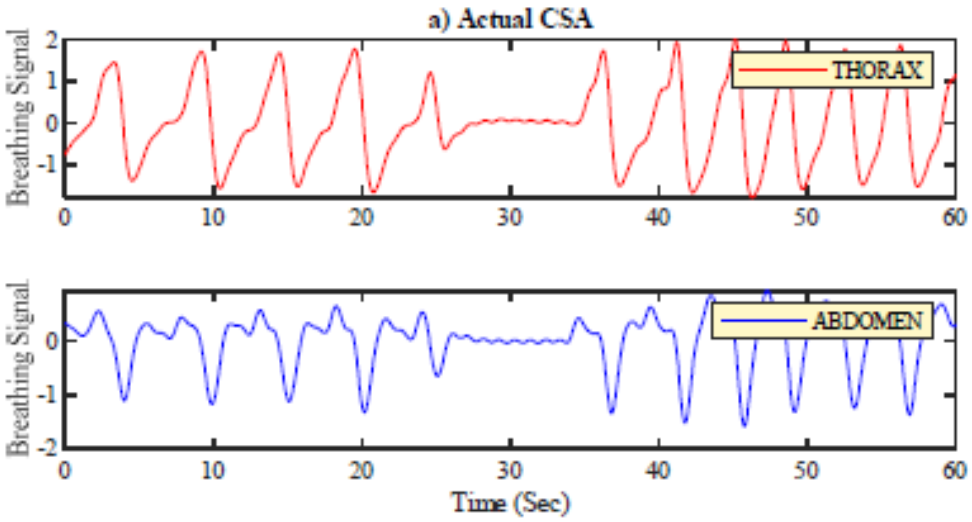
- Pressure sensitive mat deployed under the mattress
- Can detect pressure changes associated with chest and abdomen motion associated with breathing
  - Note in some positions, chest and abdomen changes are is opposite direction.
- Resulting ability to detect each breath event





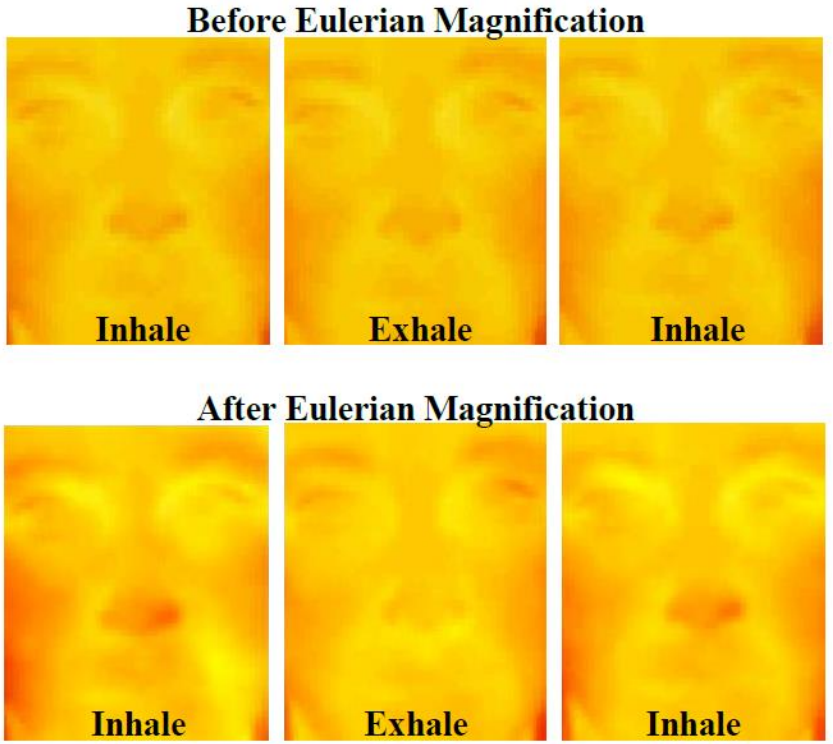
Sleep Apnea

- Sleep Apnea is a cessation of breathing of 10 or more seconds.
  - Central Sleep Apnea – no chest motion.
- With the ability to measure respiration, Machine Learning algorithms have been developed to allow detection of central sleep apnea events.



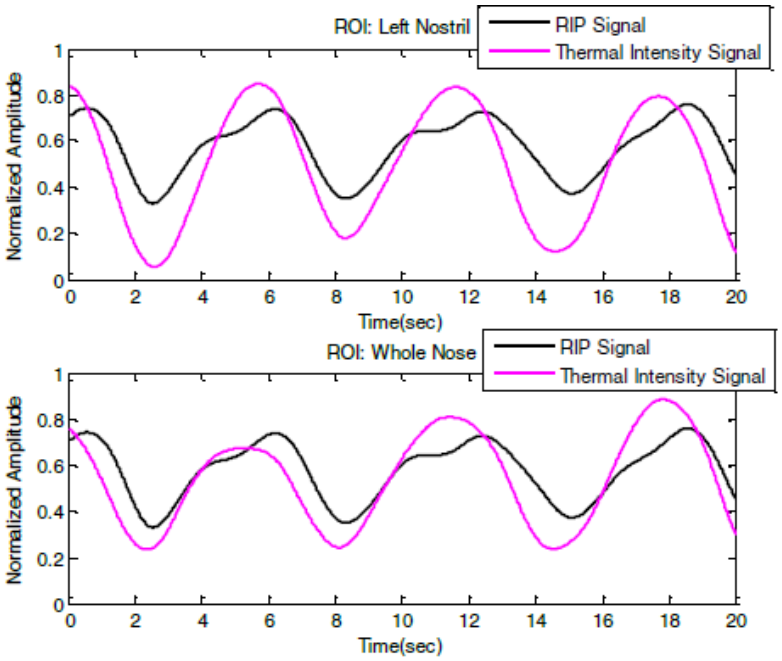
Video Magnification

- Signal processing technique to identify minute changes in video
- Used with thermal and colour video
- Technique
  - Pick region of interest
  - Detect and enhance small differences in the frame to frame image



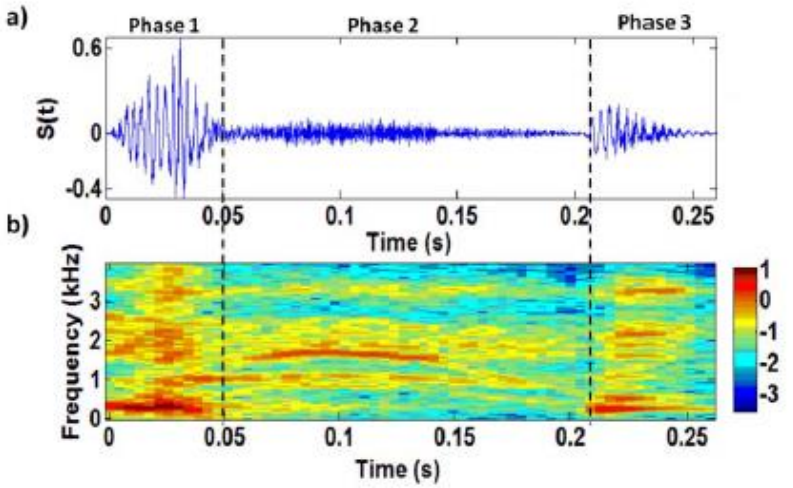
Respiration Rate – Thermal Video

- Inhaled air is at room temperature while exhaled air is at body temperature.
- Detect the warm/cool air flow events around the noise and/or mouth

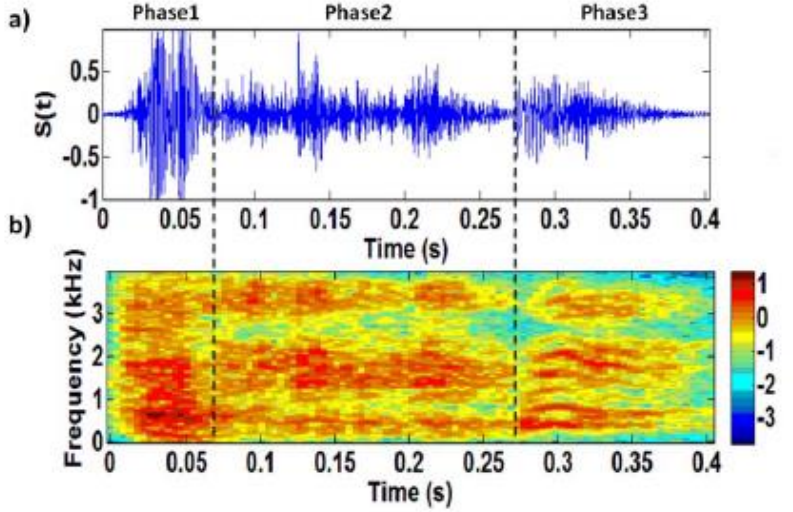


Cough - Audio

- Coughs are described clinically as wet, dry, whooping, wheezing.
- Assessment of frequency and type
- Wet and Dry coughs have very different spectrograms
- Current work focused on distinguishing
  - the 4 cough types
  - exploration of the “COVID” cough



Dry



Wet

Circulation/Heart

Assessments to consider

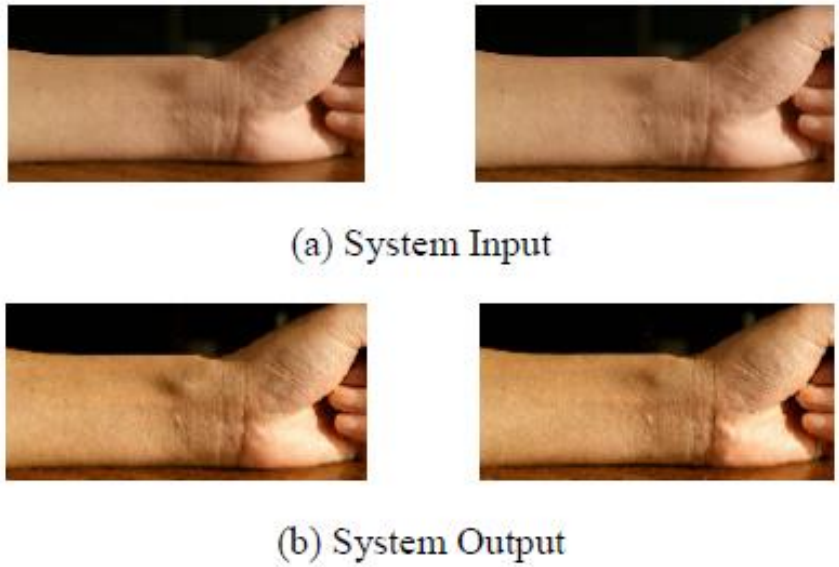
- ***Heart Rate***
- ***Blood Flow***
- ***Blood Pressure***

Heart Rate

- Heart Rate assessment concepts
  - Heart Rate (HR) – average rate (typically beats/min)
    - HR can be assessed as an average or
    - Each beat can be identified in the time sequence
  - HR Variability – small variations in beat to beat timing
    - Small levels of HRV are normal but it can also be indicative of illness or disease
    - Derived from beat to beat time sequence
  - Pulse Transit Time
    - Time delay between heart compression and pulse wave occurrence within artery
    - Depends on distance from heart (vessel anatomy) and Blood Pressure (speed of flow)
    - PTT can be measured through heart rate assessment at two locations
    - Changes in PTT correlate to changes in blood pressure

Heart Rate – Colour Video

- Pulse causes
  - Skin motion where artery located close to skin surface (wrist)
  - Skin colour shift through the pulse wave as capillaries have flowing blood and then empty
- Video magnification
  - Can enhance skin motion to allow it detection leading to beat detection
  - Can enhance colour shift through pulse wave
    - Typically best shown within green colour band. It is visible but less prevalent in red.



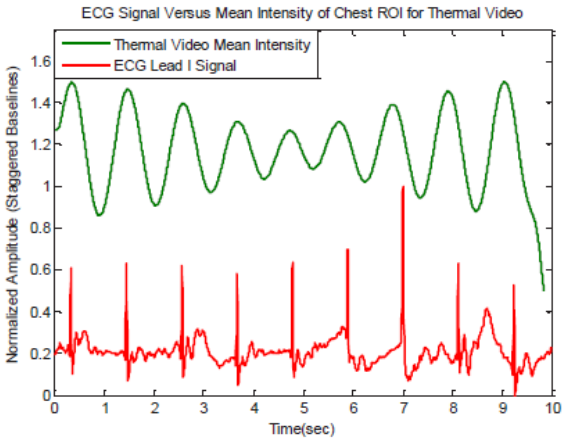
(a) System Input

(b) System Output

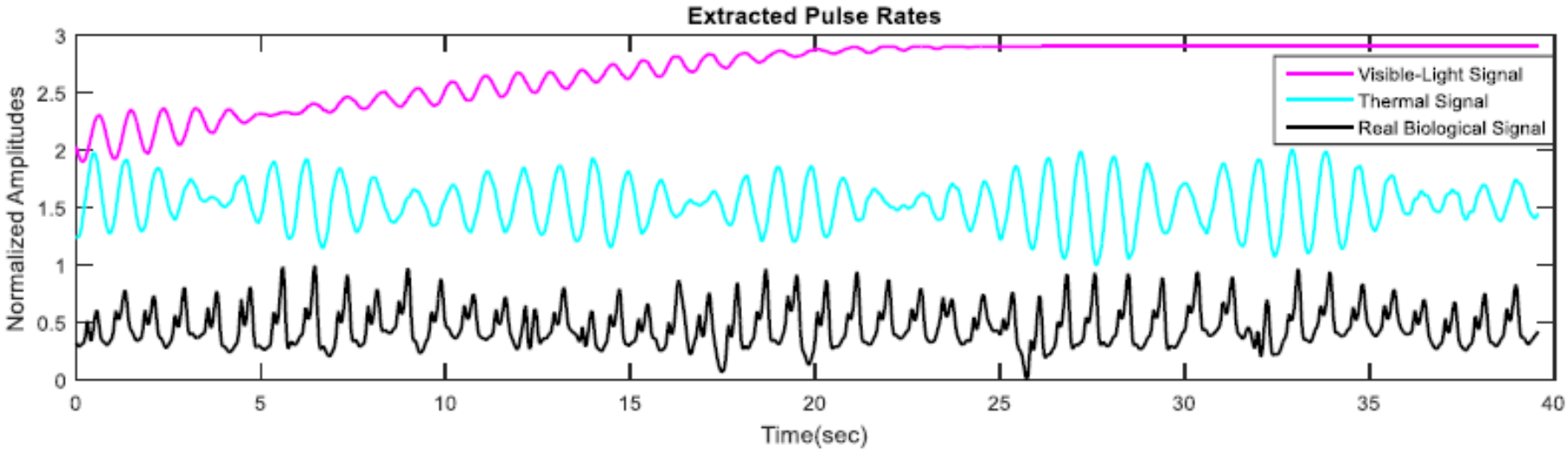
Heart Rate – Thermal Video

- Video magnification can also be applied to thermal video to also detect the beat level events
- Advantage
  - Does not require light to work!
  - Is not affected by skin tone

Fig. 2. Depiction of the thermal video ROI.

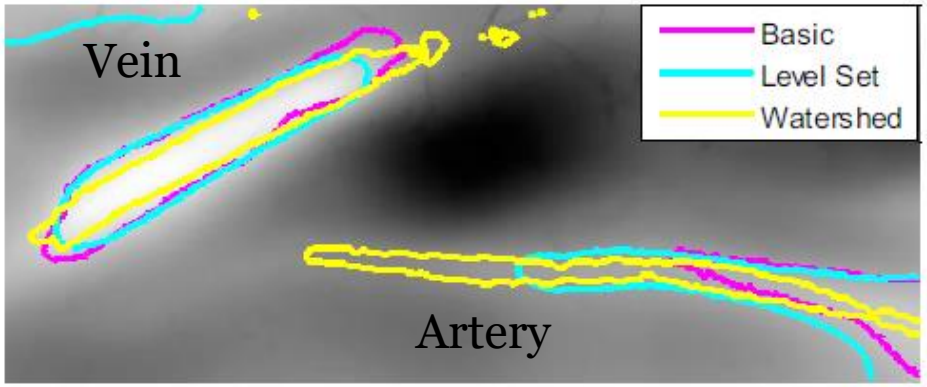


Heart Rate – Thermal vs Colour

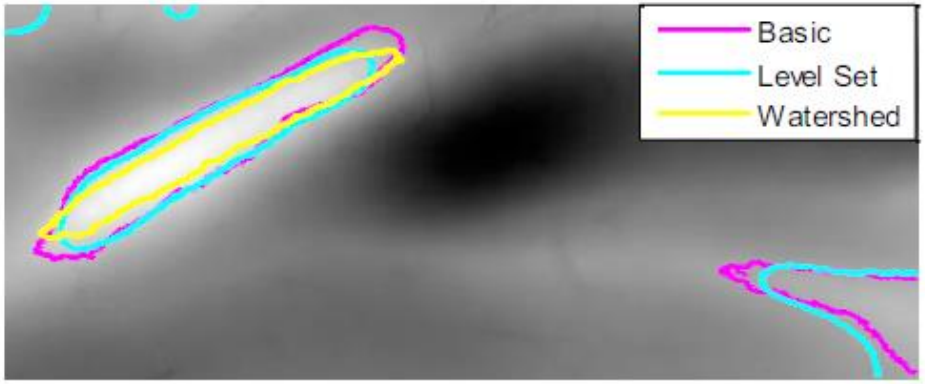


Blood Flow – Thermal Video

- Focused assessment of blood flow showing flow stopping in artery below a pressure cuff occluding flow



Normal



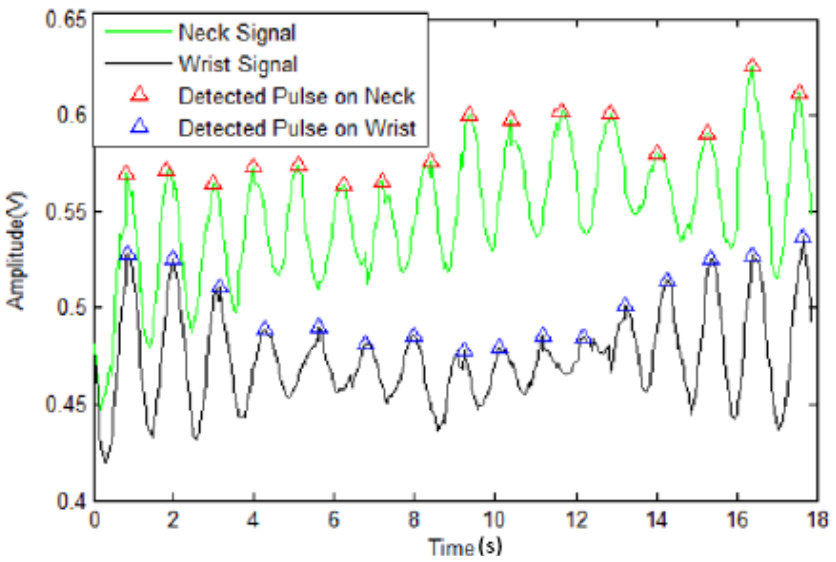
Occluded Flow

Blood Pressure – Video Magnification

- If HR assessed at two locations, PTT can be derived
  - Head and hands are two potential locations
- From these two locations the relative delay between peak in the pulse wave provides PTT measure
- PTT changes provide indication of relative Blood Pressure Change
  - Lower PTT → higher BP

(a) Input

(b) Output



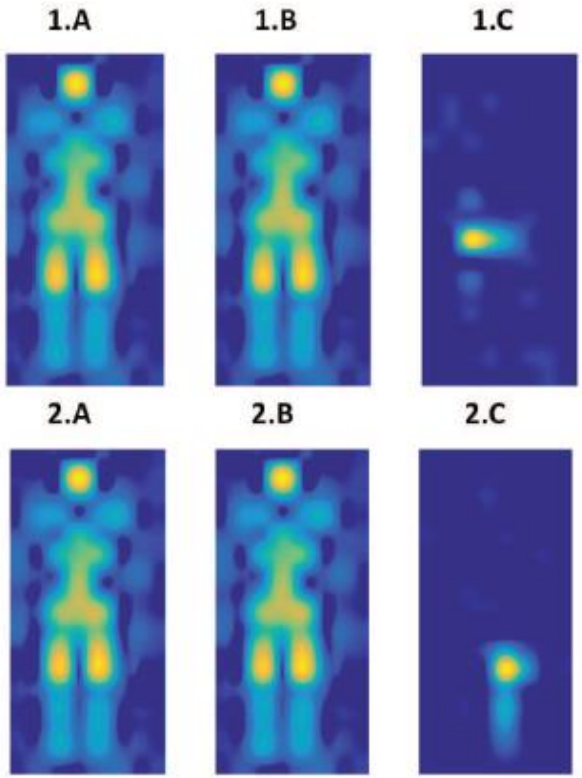
Others

Assessments to consider

- **Fluid Retention**
- **Temperature**

Fluid Retention

- Fluid retention is a symptom associated with Congestive Heart Failure and Kidney (Dialysis)
- Fluids will gravitate towards feet during day (because of gravity and standing).
- Fluids will return to torso while lying in bed at night.



400G to Bladder and thigh

Temperature - Thermal Camera

- Body temperature is a direct indication of illness and infection
- It can also be indication of circulation issues such as associated with sustained pressure
  - Limbs with limited/no mobility

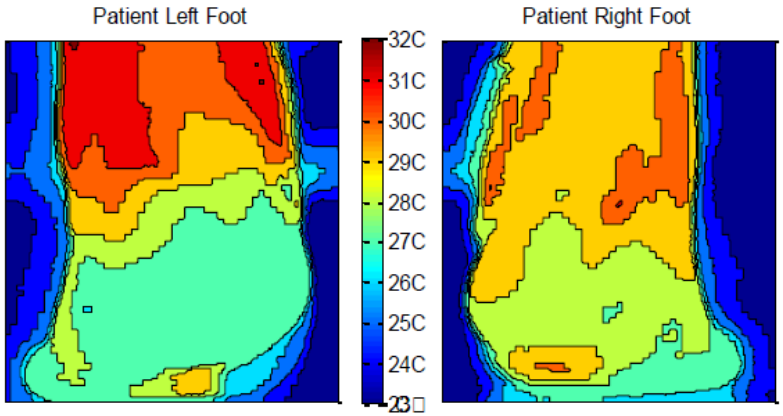


Figure 3. Contour plots of the patient heels.

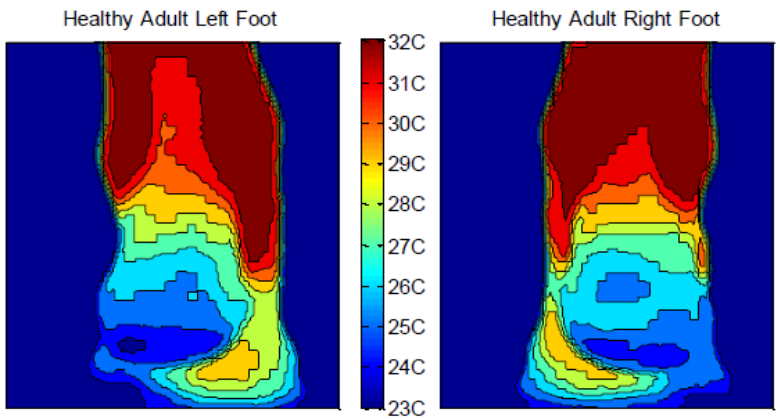


Figure 4. Contour plots of the patient heels.

Ambient Sensing of Wellbeing

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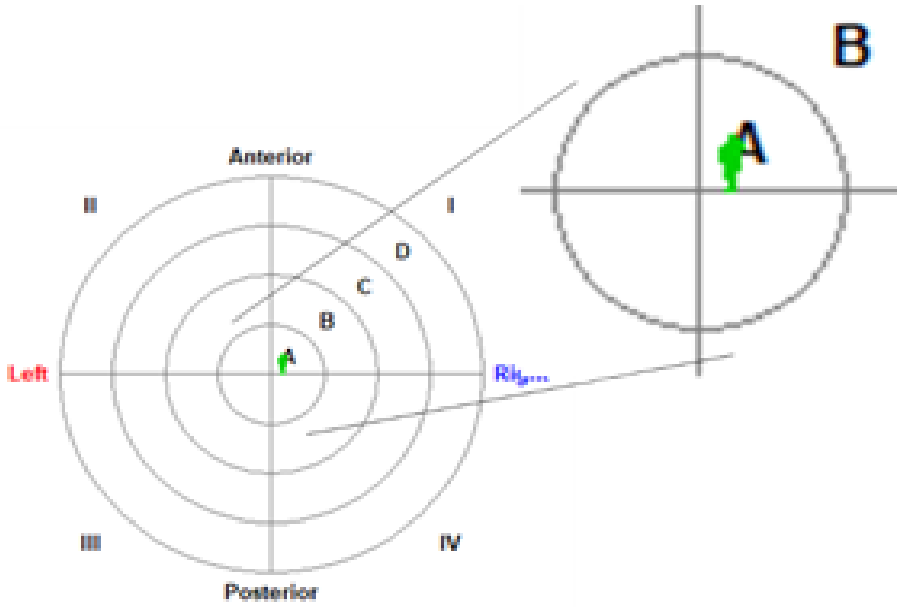
Mobility

Assessments to consider

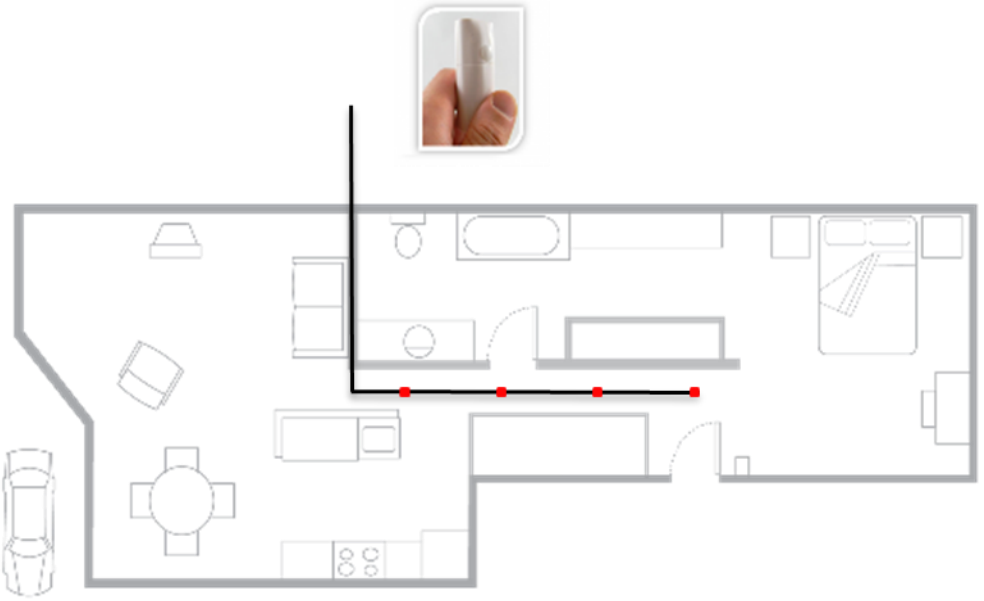
- ***Posture/Sway***
- ***Gait***
- ***Sit to Stand***
- ***Restlessness / Pressure Ulcer***
- ***Bed occupancy***

Posture/Sway – Pressure Sensors

- Floor based pressure mats and signal processing to assess center of pressure
- Allows assessment of stability and changes in stability



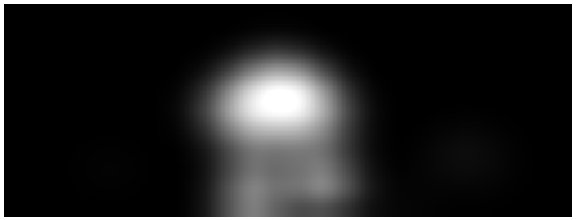
Gait



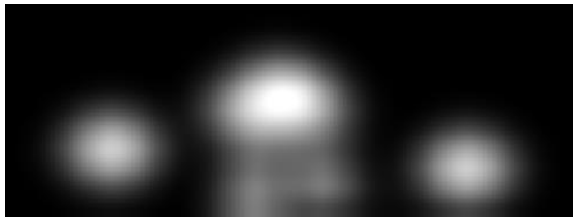
- Gait (walking speed) provides a measure of physical well being.
- Sequence of ceiling mounted motion sensors provide means to measure each time an occupant walks down the hallway.

Sit to Stand – Pressure mats

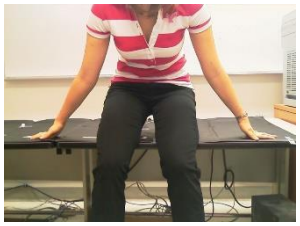
- The morning bed exit provides a daily sit to stand transition
- Changes in mobility can include
  - Speed
  - Failed exits
  - Bouncing/Rocking
  - Increased use of hands
  - Asymmetry
- Video analytics of pressure sequence video allows daily assessment

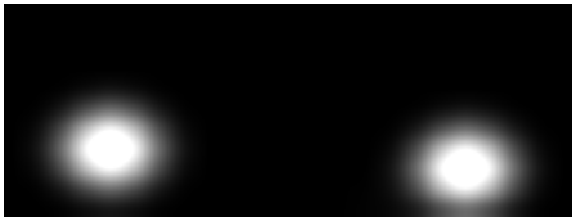


Hip pressure region



Hip and hand pressure regions

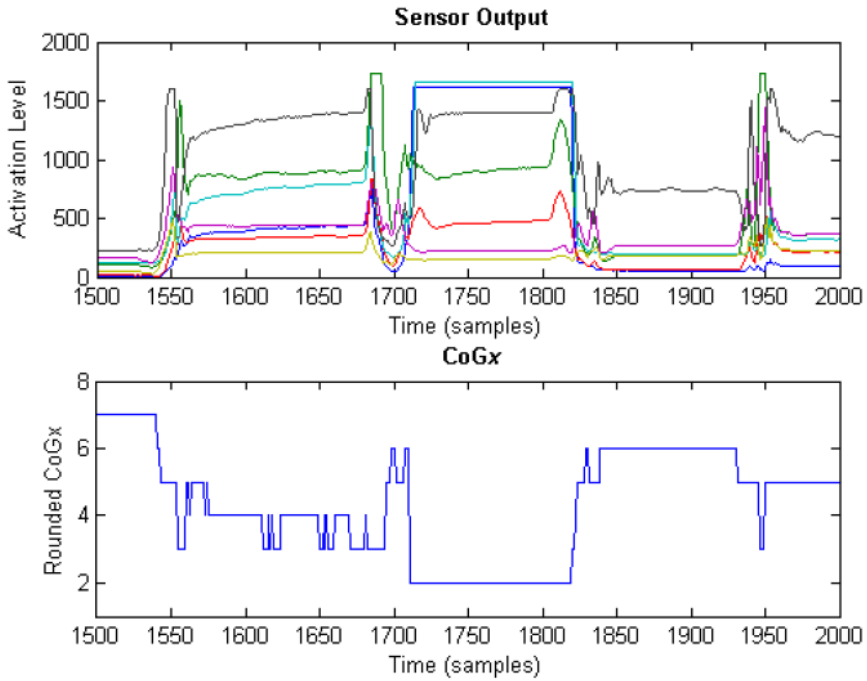




Hand pressure regions

Restlessness / Pressure Ulcer – Pressure mats

- Restless sleep can be indicative of anxiety, pain or many other causes.
- A lack of motion can lead to pressure ulcers
- Motion assessment through pressure sensor under mattress array.



Bed occupancy

- Time in bed is a proxy measure for time asleep
- Frequent overnight bed exits can indicate a number of conditions
  - Urinary Tract Infection
  - Nocturia
  - Disorientation for time

Sensor	Nights (count)	Start Time Error (count)	End Time Error (count)	Mean Time in Bed (min)	St. Dev. Time in Bed (min)
Log	75	na	na	562.4	39.6
W	75	7	9	550.9	44.2
E	75	4	19	580.2	36.9
B	54	0	1	566.2	39.4

Sensor	Actual Exits (n)	Exits Detected (TP)	Exits Missed (FN)	Extra Exits Reported (FP)
W	92	89	3	3
E	92	30	62	0
B bed	73	73	0	0
B motion	73	71	2	0

Cognition

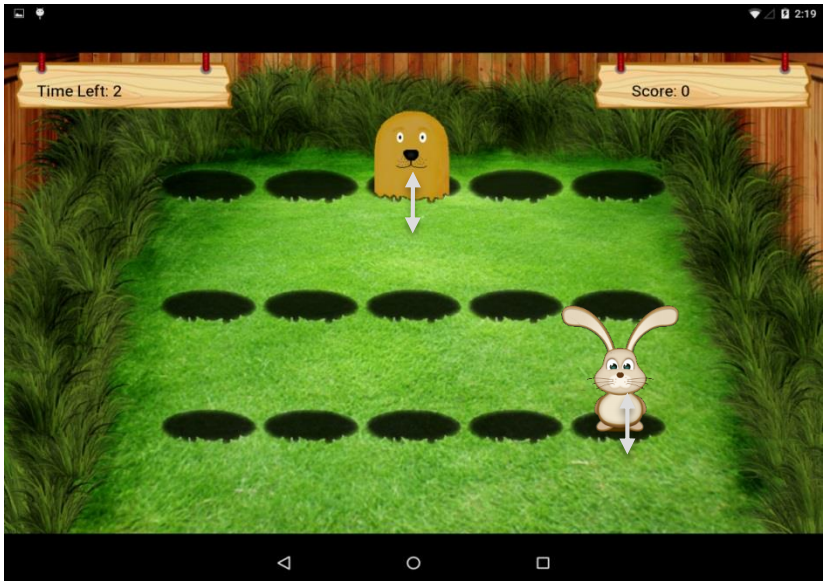
Assessments to consider

- ***Games/Computer Use***
- ***Driving***

Games/Computer Use

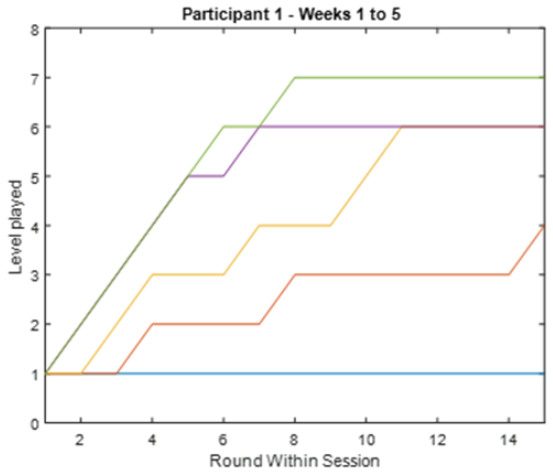
Whack-a-Mole:

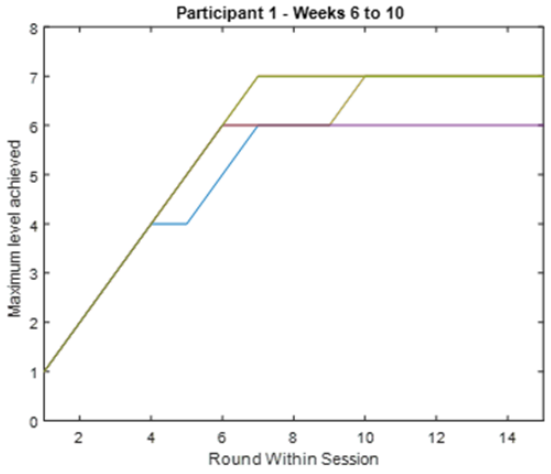
- Tablet-based
  - Some memory? Fair game as kid
  - Speed of processing & Inhibition
- Mole = Collect points
- Bunnies = Lose points
- Game levels – advance if over 80%



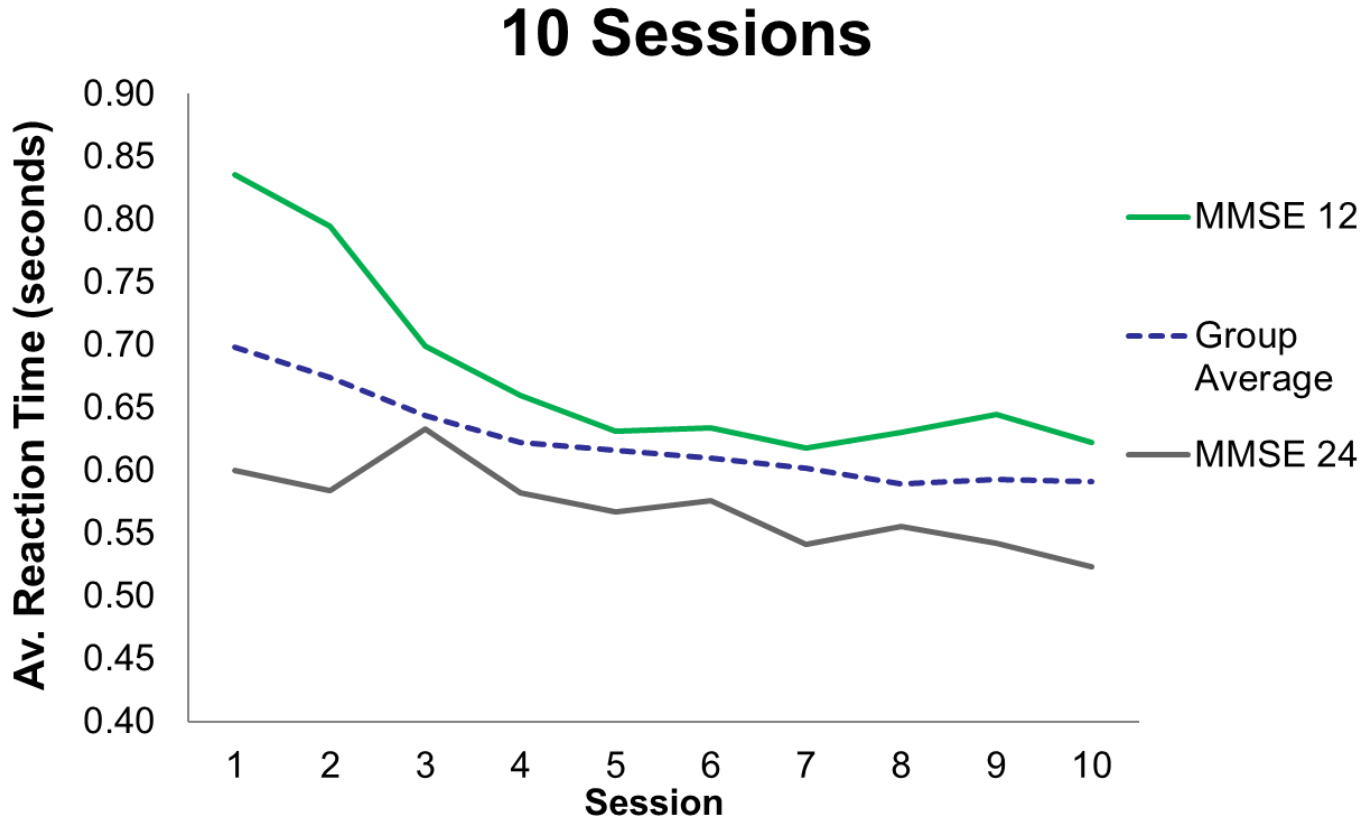
Games/Computer Use

- Participants learn the game
  - Weekly: Are able to progress to higher levels
  - Week-to-week: Improve over first 3-5 weeks then more stable play





Games/Computer Use



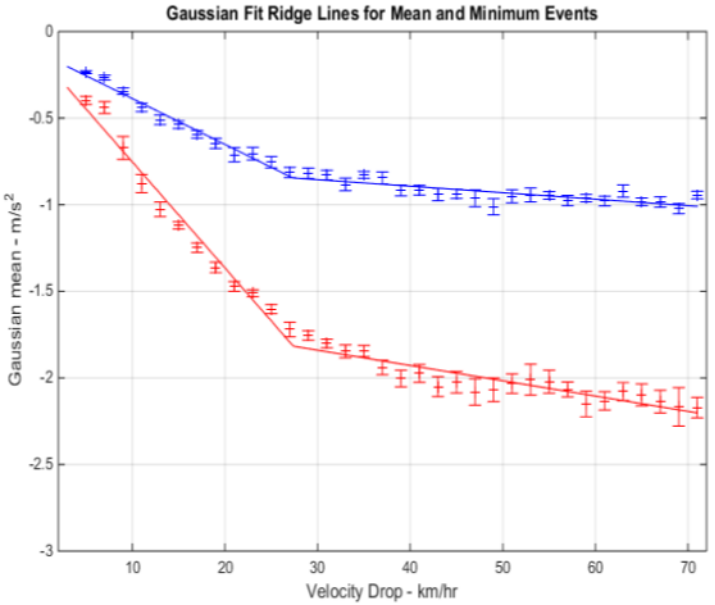
Driving

- **Driving Measures**
  - Velocity, Acceleration, Jerk
  - GPS
  - Time of Day
  - Weather

Driving Fitness

Driving – Driving Signature

- Work has identified that drivers have unique driving behaviours such as acceleration and deceleration etc.
- Allows drivers to be distinguished
- Change in these behaviours can also be assessed.



Driving – Behaviour Change

- Coefficient of variation measures of behaviours during specific driving events
- Drivers with decline show lower levels of variation

$$CoV = \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}\sigma_i^2}}{\frac{1}{N}\sum_{i=1}^{N}|\mu_i|} x100\%$$

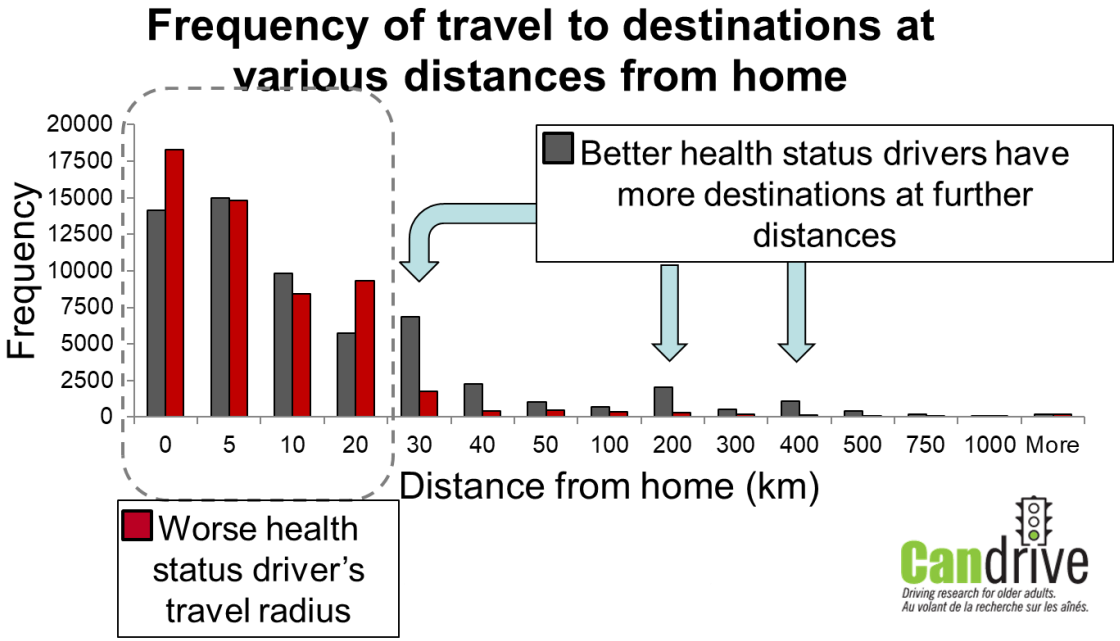
- **Highway vs Urban Driving**


- **Turns vs Straight Driving**

- **Specific Events**
  - Change in speed limit, changing lanes, intersection
  - Merging, turns at intersection

Driving – Behaviour Change

- Trip complexity measures
  - Number of destinations
  - Distance from home
  - Frequency
  - Diversity of destinations



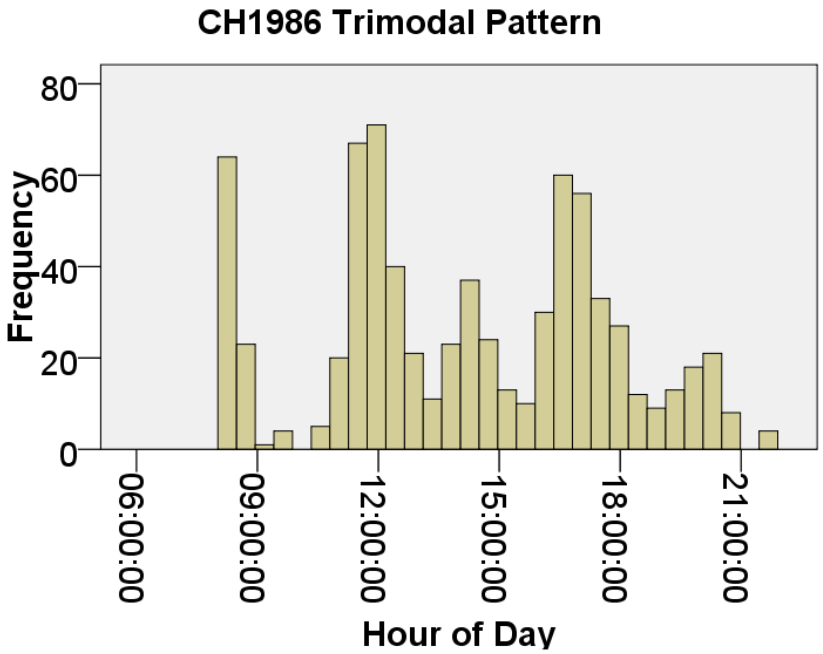
Activities of Daily Living

Assessments to consider

- ***Kitchen use and appliance use***
- ***Odour***
- ***Wandering***

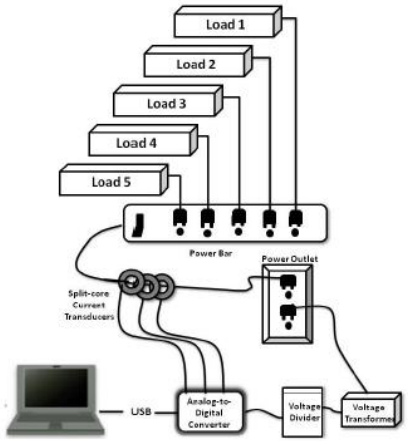
Appliance Use – The Fridge

- Simple contact sensors applied to the fridge door to detect opening events
  - Associate with alarm to alert when left open.
  - Smart Home technology allows this to be spoken message thought-out the house.



Appliance Use – Power Use

- Appliances have differing power consumption properties
  - Transients when turned on/off
  - Total power usage
  - Reactive power
- Monitoring of power at common point enables appliance use analysis.



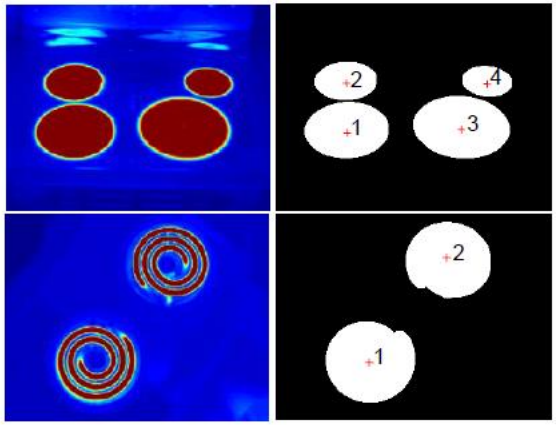
Load	Devices	Real Power (Watt)	Reactive Power (VAR)
1	Microwave	802.1 ± 21.81	214.14 ± 8.08
2	Electric kettle	785.66 ± 5.82	84.59 ± 1.19
3	Coffee maker	602.02 ± 4.57	65.56 ± 0.92
4	Laptop charger	65.95 ± 0.64	84.69 ± 2.01
5	Incandescent lamp	58.44 ± 0.39	9.09 ± 0.12
6	Computer LCD monitor	28.71 ± 0.38	36.04 ± 0.51
7	Fluorescent lamp	18.47 ± 1.44	26 ± 2.81

Thermal Camera

- Historically have been extremely high cost devices that limited their use
- New low cost (smart phone add-on) cameras are readily available.

Appliance Use – Thermal Camera

- Safety – provides options for alerting
  - Stove left on
  - Pot boiled dry
- Advance analysis of nutrition
  - Meal complexity
  - Cooking behaviours

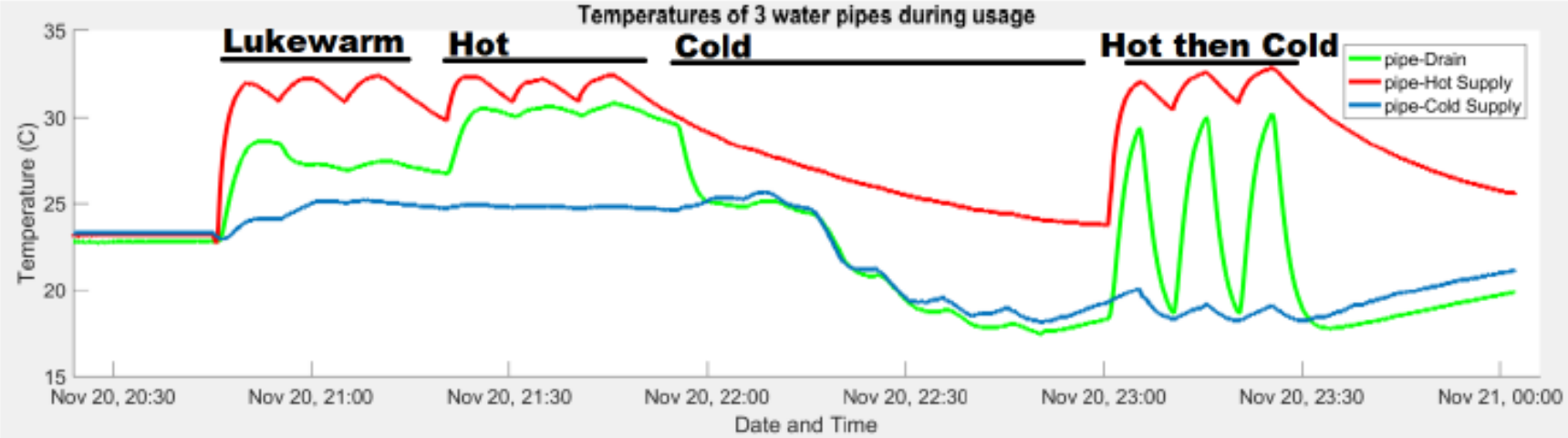


Temperature Sensors

- These sensors are readily available and extremely small in size and at extremely low costs.
- Sensor substitution is a concept where they are used to measure something else.

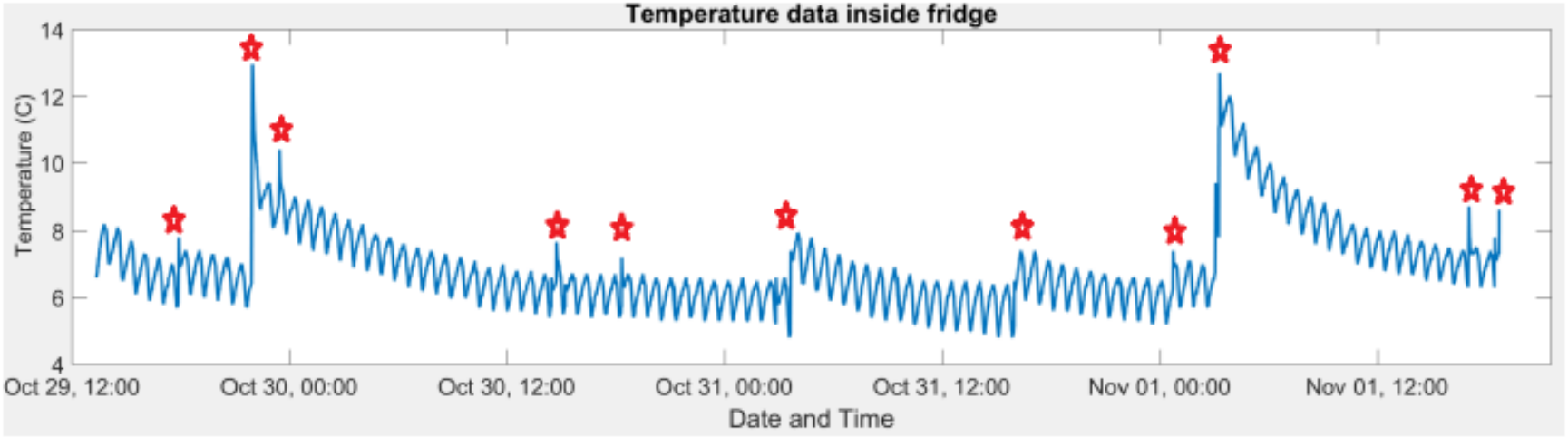
Water Use – Temperature Sensor

- Temperature sensors on supply and drain lines for sink
- Easily applied to pipe externally vs adding some form of flow meter.



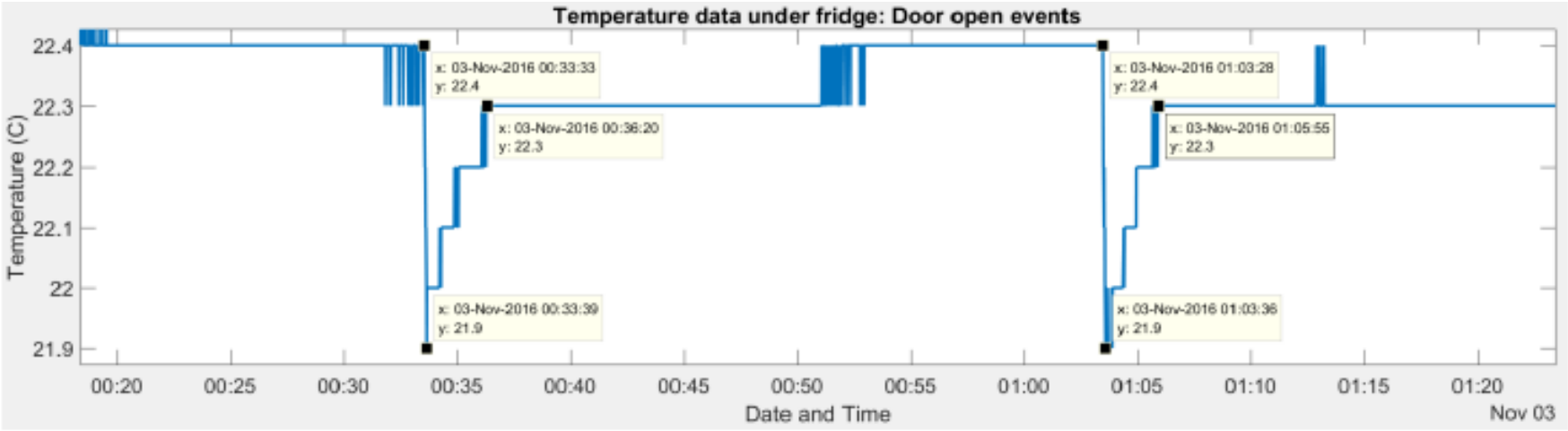
Fridge access – Temperature Sensor

- Temperature Sensor located within the fridge.

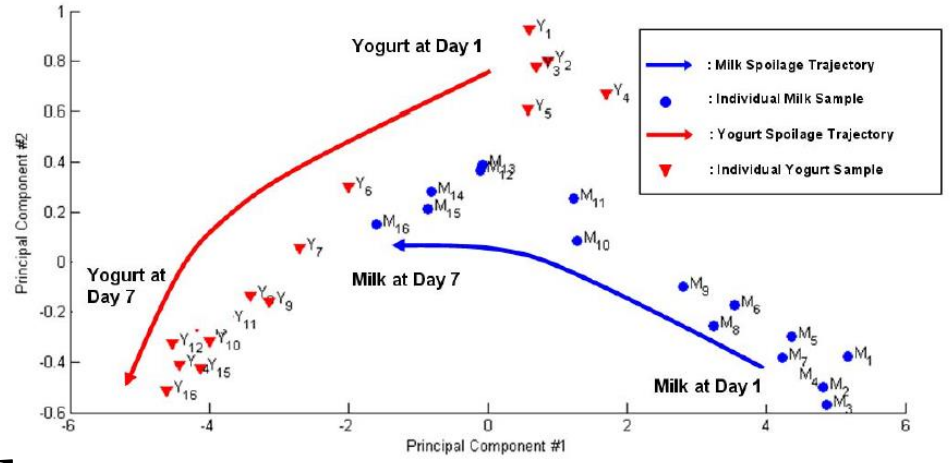


Fridge access – Temperature Sensor

- Temperature Sensor located under the fridge.



Odour

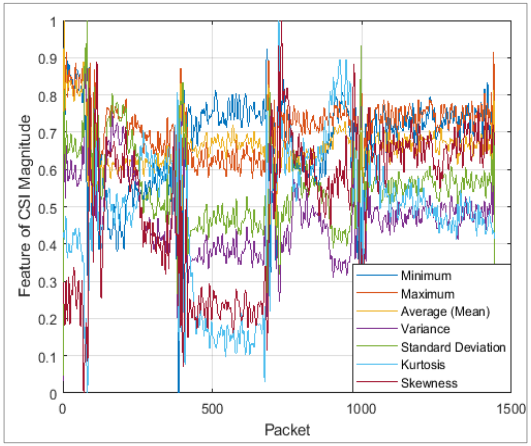


- E-Nose technology
  (e.g. AlphaMOS FOX 3000)
- This is an emerging technology area with products introduced and in some cases removed from market.
- Application to food spoilage has been shown

- Use cases:
  Cognition – is person able to manage food quality?
  Wellness – Quality of nutrition

Standing-Up/Sitting-Down – Wi-Fi

- Hygiene is an important ADL for assessment.
- Washroom is not ideal for many sensors
  - Video vs privacy
  - Humidity/Safety
- Wi-Fi is a low cost wireless signal
  - Human activity affects its propagation
  - Source and receiver can be placed outside the washroom
- Early results show potential for differing movements to be distinguished



		Still	Sitting-down	Standing-up
True Class	*Still*	2411	50	65
	Sitting-down	7	2516	0
	Standing-up	0	0	2523
		Still	*Sitting-down*	*Standing-up*
		Predicted Class		

Wandering

- PLWD:
  77 y.o. Alzheimer since 2010
- CG: wife 69 y.o.
- Live together in 2 storey home

- Wandering for 12 months
  - 2-3 x night
  - Bathroom, kitchen, living room, door
  - 2 exits from the home in the evening
  - No falls
- Spouse: severe problem

Wandering

Hello Peter, it is still nighttime, please come back to bed.

Alarm: the front door has been opened!!

Wandering

- PLWD
  - Got up every night
  - Bathroom: 5-60 minutes
  - Went to kitchen: ONCE
  - No falls / injuries, no elopement
- CG
  - Depression score improved from 13 to 7
- New concept – UI between home and PLWD

Bringing Everything Together

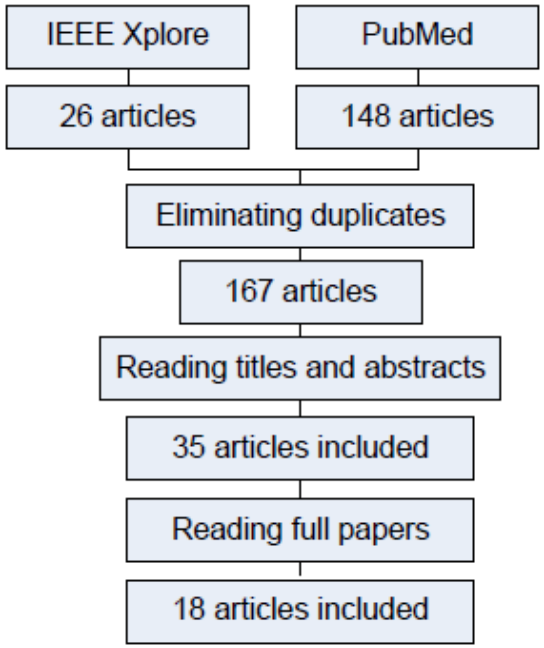
Bringing Everything Together

Assessments to consider

- ***Privacy vs Autonomy***
- ***Episodic Data Model***
- ***Role of the Cloud***

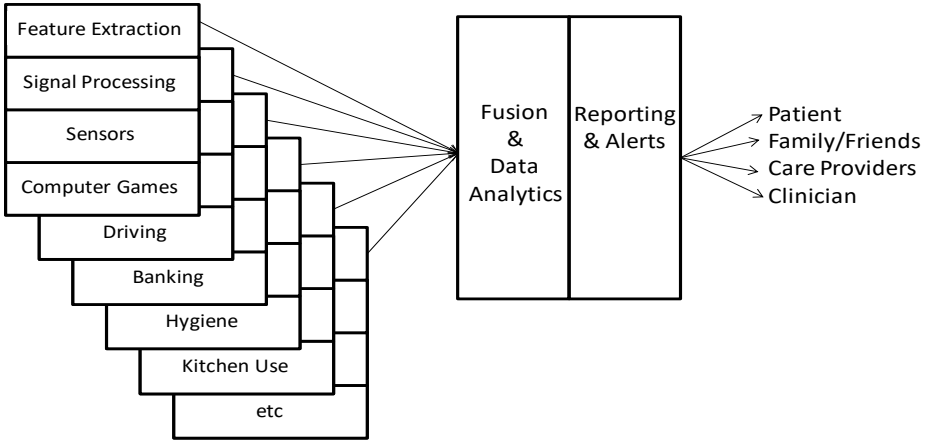
Privacy vs Autonomy

- Desire for autonomy is a driving factor of positive view towards home monitoring
- Many examples of older adults circumventing the use of medical devices.
- Understanding what makes them obtrusive can increase user acceptance.
- Review highlights the overall positive attitude of older adults towards unobtrusive sensor technologies in smart homes when they perceive the need and when they allow an older adult to age-in-place.



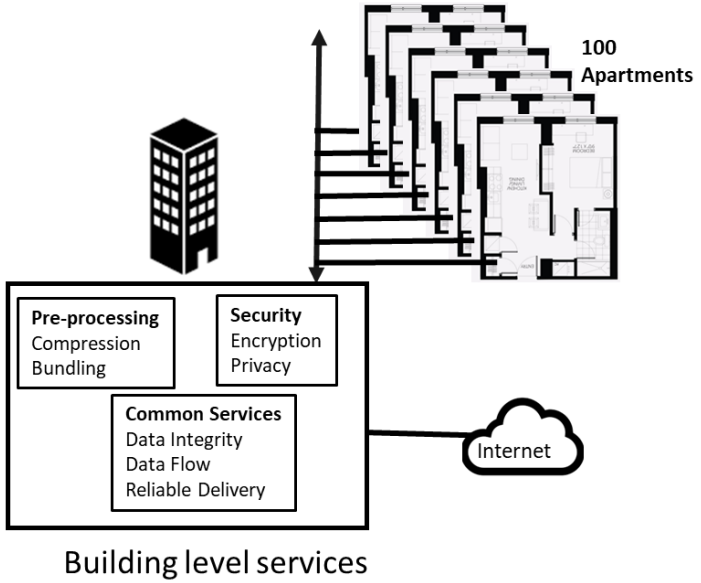
Episodic Data

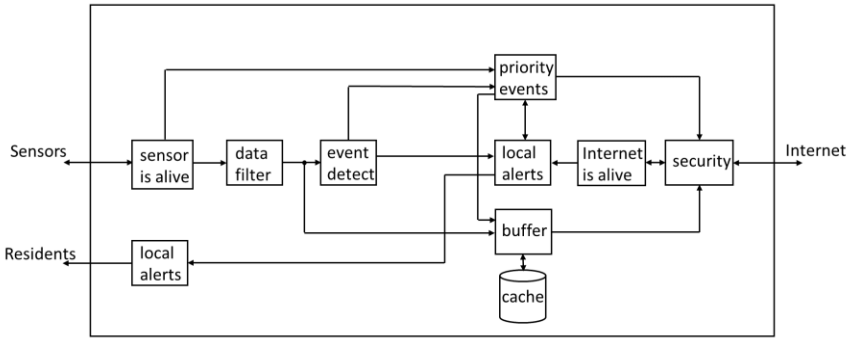
- Most sensor sources provide insight into only a small aspect
- Most measures are discontinuous and is some cases occur somewhat randomly
- Combination of the measures through sensor fusion and deep learning / AI is required to build a holistic model



Role of the Cloud

- In Residence Services
  - Sensor Failure Detection
  - Sensor Data Filter
  - Privacy/Anonymity
- Internet Services
  - Network Connection Health
  - Fail safe mode
- Services:
  - Priority Events
  - Local Autonomy and Alerts
  - Data Buffering and Caching





Looking Forward

Looking Forward

Most of these techniques are emerging and still require work to be usable on a wide scale basis in a general population deployment.

Need to improve specific assessments
Building the bigger picture from the combined data.

User interface as aging adults are interacting with increasingly supportive technology.

Questions

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