Using wearable image sensing to measure physical activity & sedentary behavior

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International consensus on health benefits of physical activity

- Physical activity can reduce the risk of:
  - Cardiovascular disease
  - Hypertension
  - Obesity
  - Some forms of cancers
  - Non insulin-dependent diabetes mellitus
  - Strokes
  - Osteoarthritis, by maintaining normal muscle strength, joint structure and joint function
  - Osteoporosis
  - Cognitive function
  - Crime reduction and community safety
  - Economic impact and regeneration of communities
  - Education and lifelong learning
  - Psychological well-being
  - Self esteem
  - Management of anxiety and depression
  - Social capital and community cohesion
  - Drug misuse
  - Carbon use

61% of men and 71% of women do not meet the U.K. Chief Medical Officer’s minimum recommendations for physical activity in adults.
Sedentary Behaviour

Sitting (or lying down), involving < 2 MET (metabolic equivalent)

Public Health Physical Activity Guidelines: time spent in moderate-vigorous activity

Our modern ‘sitting-oriented’ society

Awake 7 am

Breakfast 15 mins

Transport to work 45 mins

Work on computer 3.5 hrs

Lunch 30 mins

Evening meal 30 mins

Work on computer 4 hrs

Transport From work 45 mins

Watch TV 4 hrs

Walk – 30 min

Sleep 11 pm

Sitting Opportunities 15.5 hrs
AusDiab: are 5-year changes in TV viewing time associated with 5-year changes in:

- Overweight (waist circumference) and other metabolic syndrome variables
- Independently of physical activity, diet quality, and other confounding factors
- In population-based sample of healthy Australian adults (AusDiab)
Daily Sitting Time and All-cause Mortality in 17,013 Canadian Men and Women

Canada Fitness Survey 12-year Mortality Follow-up, 1981-1993

From: Pucher & Buehler. Transport Reviews, 2008. OECD (age 15 and over). Data from various sources.
Obesity and active travel

• Each additional kilometre walked per day is associated with a 4.8% reduction in likelihood of obesity.
• Each additional hour spent in a car per day associated with a 6% increase in likelihood of obesity.
• Active travel interventions must contain environmental supports to sustain individual choice (i.e. public transport).


NICE review – physical activity and environment
32% risk reduction all cause mortality (Hamer and Chida, 2008)

28% risk reduction all cause mortality (Anderson et al, 2000)

Pressure on transport systems

Sedentary behaviour Carbon emissions
Aims

Why research active travel?

SenseCam

Study results

Other applications

Sedentary behaviour

Establish links between physical activity & health

Measure physical activity

Identify correlates

Test interventions

Translate into practice

Sallis and Owen (1999)

Behavioural epidemiology framework
Current tools and technologies

- Pedometer
- Accelerometer
- Travel Diary
- GPS tracker
Percentage of adults from same study meeting physical activity recommendations:

NHANES (self report): 50%
Accelerometer: 5%
(Troiano et al, 2009)

Self-report questionnaire: 38%
Accelerometer: 5%
(HSE, 2009)
<table>
<thead>
<tr>
<th>JOURNEYS</th>
<th>STAGES</th>
<th>ONLY FILL IN THESE COLUMNS IF YOU USED A CAR OR OTHER MOTOR VEHICLE</th>
<th>ONLY FILL IN THESE COLUMNS IF YOU USED PUBLIC TRANSPORT</th>
<th>ONLY FILL IN THIS COLUMN IF YOU USED A TAXI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Go to Work</strong></td>
<td>1</td>
<td><strong>Car</strong></td>
<td>18</td>
<td>45</td>
</tr>
<tr>
<td><strong>Go Home</strong></td>
<td>2</td>
<td><strong>Car</strong></td>
<td>18</td>
<td>50</td>
</tr>
<tr>
<td><strong>Go out for meal with friends</strong></td>
<td>3</td>
<td><strong>Walk</strong></td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td><strong>Go Home</strong></td>
<td>4</td>
<td><strong>Train</strong></td>
<td>8</td>
<td>30</td>
</tr>
<tr>
<td><strong>Go Home</strong></td>
<td>5</td>
<td><strong>Bus</strong></td>
<td>15</td>
<td>4</td>
</tr>
<tr>
<td><strong>Go Home</strong></td>
<td>6</td>
<td><strong>Taxi</strong></td>
<td>10</td>
<td>25</td>
</tr>
</tbody>
</table>
The gold standard is direct observation
**Human Digital Memory (HDM)**

<table>
<thead>
<tr>
<th>Why do HDM?</th>
<th>HDM Software</th>
<th>Future Opportunities</th>
</tr>
</thead>
</table>

**Visual Lifelogging Devices**

- Much past research focus on miniaturising hardware and increasing battery-life + storage e.g. visual lifelogging domain

TIMELINE


Tano et. al. University of Electro-Communications, Tokyo, Japan

Microsoft Research SenseCam
Daily Browser Overview

SenseCam Images of a day (about 3,000)

Event Segmentation

EVENT SEGMENTATION
Using MOTION sensors – very quick & accurate
Visual Search Facilities

SenseCam Images of a day (about 3,000)

Event Segmentation

Event-Event Comparison within the Multi-day Event database

Event database containing last 7 days' Events

Better: Compare Event Averages from middle \( n \) images

Too slow
Selecting Event “Keyframe”

SenseCam Images of a day (about 3,000)

Event Segmentation

Event-Event Comparison within the Multi-day Event database

Best QUALITY image around MIDDLE of event
Suggest Interesting Events

SenseCam Images of a day (about 3,000)

Day - 1
Day - 2
Day - 3
Day - 4
Day - 5
Day - 6
Day - 7

Event database containing last 7 days' Events

Similar Events - Aiden waiting for bus
Similar Events - Aiden at the office corridor
Similar Events - Aiden working on the desk
Unique Events

Interactive Browser

Event-Event Comparison

VISUAL NOVELTY

FACE DETECTION

CALCULATE INTERESTINGNESS OF EVENTS

Landmark Image Selection
29 May 2006

I was chatting with Gareth on the phone in July. Quite a few chats today. 50%.
So what can the SenseCam be used for?

Case study:
- Quantifying active travel self report error
UK National Travel Survey

Travel Survey

Travel record of

Travel week:
Start day: Finish day:
Start date: Finish date:

Please use black or blue ink if possible
Thank you very much for your help

Your interviewer

Please see the notes on the reverse of this flap

A few points to remember when filling in the travel record:
1. We are interested in all types of transport; walk and bike journeys as well as cars and public transport.
2. Use a new line for each journey (e.g., go to work, go home. From column 1 to 4, write down the mode of transport for each stage of your journey (e.g., car, train, bus, walk).
3. On days 1-7 only include walks of a mile or more. It takes approximately 20 minutes to walk a mile. On day 7 include all walks.
4. Drive: On days 1 and 7 please remember to enter your gauge readings on the Fuel and Mileage Chart.
5. If you make more than 8 journeys there is space at the end of the record to write down extra journeys.
1. Quantifying error on self-report

Widely used, important for trends, used with other devices

Errors potentially come from recall, perception, human factors and social desirability

We intend to investigate the size of any error on self-reported journey behaviour
Error = a + b + c + d +?

a – systematic error
b – intra-person variability
c – inter-person variability
d – modal effects
? – regular vs. irregular
Research questions

1. Will people wear it?

2. How does SenseCam and Self-report compare?

3. What are the sources of any error?
Study

Protocol: Wear SenseCam and complete travel diary for one day

Participants: 20 volunteers

Structured interviews about burden and experience
Will people wear SenseCam?
105 journeys (car, walk, bike, bus)

Self-report
- 96 journeys
- Recorded: 91%

SenseCam
- 99 journeys
- Recorded: 94%

Legend:
- Recorded
- Missed
How do self report and SenseCam data compare?
<table>
<thead>
<tr>
<th>DAY</th>
<th>DATE</th>
<th>STAGES</th>
<th>Journeys Please record each journey using a separate row and remember to tell us about short journeys</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D Where did you start your journey? (Tick home or give the name of the village, town or area)</td>
</tr>
<tr>
<td>1</td>
<td>Work</td>
<td>Time:</td>
<td>Time: 9:00</td>
</tr>
<tr>
<td>2</td>
<td>Shop from Work</td>
<td>Time:</td>
<td>Time: 8:30</td>
</tr>
<tr>
<td>3</td>
<td>To Shop</td>
<td>Time:</td>
<td>Time: 8:30</td>
</tr>
<tr>
<td>4</td>
<td>To Home</td>
<td>Time:</td>
<td>Time: 8:30</td>
</tr>
<tr>
<td>5</td>
<td>To Pub</td>
<td>Time:</td>
<td>Time: 9:30</td>
</tr>
<tr>
<td>6</td>
<td>To Home</td>
<td>Time:</td>
<td>Time: 10:45</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>F</th>
<th>What method of travel did you use for each stage of your journey?</th>
<th>G</th>
<th>How far did you travel? (Miles)</th>
<th>H</th>
<th>How long did you spend travelling? (Minutes)</th>
<th>I</th>
<th>How many people travelled including you?</th>
<th>J</th>
<th>Were you the driver (D) or passenger (P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bike</td>
<td>3.5</td>
<td>20</td>
<td>-</td>
<td>D</td>
<td>O</td>
<td>P</td>
<td></td>
<td></td>
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<tr>
<td>2</td>
<td>Bike</td>
<td>3.5</td>
<td>20</td>
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<td>D</td>
<td>O</td>
<td>P</td>
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<td>O</td>
<td>P</td>
<td></td>
<td></td>
</tr>
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<td>Bike</td>
<td>1</td>
<td>10</td>
<td>-</td>
<td>D</td>
<td>O</td>
<td>P</td>
<td></td>
<td></td>
</tr>
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<td>Bike</td>
<td>2</td>
<td>15</td>
<td>-</td>
<td>D</td>
<td>O</td>
<td>P</td>
<td></td>
<td></td>
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<tr>
<td>6</td>
<td>Bike</td>
<td>2</td>
<td>15</td>
<td>-</td>
<td>D</td>
<td>O</td>
<td>P</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

USE THIS SPACE FOR ANYTHING ELSE YOU WANT TO TELL US
<p>| | | | |</p>
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<td>3</td>
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</tbody>
</table>

Journey time = 20 minutes
How did they compare?

Journey time = 12 min 48 sec
\[ y = 0.9601x + 190.09 \]
\[ R^2 = 0.8425 \]

Systematic over report = 190 sec +/- 47 sec
Limit of Agreements (Bland-Altman) plot for self-reported journey duration and SenseCam journey duration

Average over report = 154 sec +/- 30 sec
Car +2 min 08 sec (S.E. 60 sec)

Walk +1 min 41 sec (S.E. 45 sec)

Bike +4 min 33 sec (S.E. 64 sec)

All journeys +2 min 30 sec (S.E. 32 sec)
So what...?

154 sec per journey = 6 min 42 sec per day*

= 54 min per week

= 36% of recommended amount**

*3 ‘Active transportation’ journeys per participant per day

**Physical activity recommendations; 30 min per day, 5 days per week...or 150 minutes per week

(Chief Medical Officer, Department of Health)
Why are people over-reporting travel time?

Retrospective interviews:

Example A;

“I said 25 minutes because it took 10 minutes to get the kids in the car”

Example B;

“I think about the time I leave the house and the time I walk into the office, not the time spent cycling”
OK it’s promising to investigate inherent error in active travel self-report ... what else can it be useful for with respect to physical activity?
2. Combination with GPS

Location important for many reasons

Limitations include cold start, signal loss and estimation of mode from speed or self-report
3. Combination with accelerometer

Intensity important

Challenge to verify mode or behaviour from trace
5. Environmental audit or determinants
Cycle lane use
Automated activity detection
Wednesday
09 September 2009

2903 Photos  (07:07 AM - 22:09 PM)
You can touch one of the events below to view the photos within it.
Wednesday
09 September 2009

2903 Photos  (07:07 AM - 22:09 PM)

You can touch one of the events below to view the photos within it.

1. Driving  76m 34s
2. Driving  73m 33s

- 07:07 am  2m 9s  07:09 am  76m 34s  08:26 am  474m 8s  16:28 pm  1m 56s
- 16:31 pm  73m 53s  17:45 pm  264m 38s

Show Calendar

Touch the button above to view different days

Add Photos

Help
Identifying Activities
Sitting/Standing = 75% accurate
Using a range of classifiers: Logistic Regression, Naïve Bayes, J48, SVM, Etc.
Identifying Activities
Walking = 77% Accurate
Identifying Activities
Driving = 88% Accurate
Activity Recognition using Images

- 27 “activities”
- Validated on 95k annotated images
Concept detection process

- **Colour Layout**
- **Feature Fusion**
  - **Scalable Colour**
  - **Visual features**
- **Lifelog images**
- **SVM**
  - **Classifier Fusion**
  - **Labeled examples**
  - **Concept probability**
Comparison of Lifestyle Within Social Groups

The graph shows the comparison of lifestyle within different social groups, with standard deviations away from the sample mean for various activities: steeringWheel, eating, insideVehicle, vehiclesExternal, reading, and holdingPhone. Each activity is represented by a different line, and the graph displays the data for five users: user 1, user 2, user 3, user 4, and user 5.
But let’s use more people (34x)...

<table>
<thead>
<tr>
<th>Participant Group and (#)</th>
<th>Median # of Days of SenseCam data</th>
<th>Median # of Events per Day</th>
<th>Median # SenseCam Images per Day</th>
<th>Median SenseCam wear per Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office Workers (6)</td>
<td>7</td>
<td>19.5</td>
<td>1,599</td>
<td>6h 55m</td>
</tr>
<tr>
<td>Researchers (15)</td>
<td>8</td>
<td>20</td>
<td>1,640</td>
<td>7h 15m</td>
</tr>
<tr>
<td>Retired (5)</td>
<td>3</td>
<td>23</td>
<td>1,886</td>
<td>7h 45m</td>
</tr>
<tr>
<td>Regular lifeloggers (8)</td>
<td>42</td>
<td>18.5</td>
<td>1,517</td>
<td>10h 21m</td>
</tr>
<tr>
<td>Overall Averages</td>
<td>15.1</td>
<td>20.9</td>
<td>1,712</td>
<td>8h 45m</td>
</tr>
</tbody>
</table>
Differences between groups...
When do people eat?

Eating Patterns During Average Day

- lifelogger
- office
- researcher
- retired

Hour in Day

0%  5%  10%  15%  20%  25%  30%
When do people look at screens?

"Screen" Patterns During Average Day

- lifellogger
- office
- researcher
- retired

Hour in Day

8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
In Conclusion:

**Computer Scientists:**
Measuring health-related behaviour offers many opportunities

**Physical Activity Researchers:**
SenseCam offers potential as a powerful context reinstatement tool
Using wearable image sensing to measure physical activity & sedentary behavior

Aiden Doherty

Thanks to
Dr Charlie Foster
Paul Kelly
Prof. Alan Smeaton
Dr Steve Hodges

Sensors and Devices Group
Microsoft Research Cambridge