Mobile Lung Function
Counting Coughs and Spirometry on a Mobile Phone

Sean Liu, Eric Larson, Shwetak Patel
UbiComp Lab | University of Washington

Tuesday, November 2, 2010
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<th>Where Sensed</th>
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Tuesday, November 2, 2010
Where Sensed

Goal of Sensing

Activity

Elder Care

Amft, Inner Ear Mic

Fit-bit

WISP

Dosage Detection

Mobile Sensing Platform

Bathing Detection

UbiFit

Fall Detection

myZeo

Baby Monitors

Sleep Patterns

In-home Physician

Lester, Caloric Intake

Robotic Physician

MyExperience

Remote Physician

Blood Glucose

LUCAS Imager

In Environment

Mobile UltraSound

Paper Sentinel

Reported

Blood Glucose

Remote Physician

AsthmaMD

Peak Flow Meter

Embedded Mobile Phone

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- **Elder Care**: Amft, Inner Ear Mic, UbiFit, LifeShirt, Belkin Heart Rate Stethoscope, iRhythm, Blood Glucose, Peak Flow Meter, Mobile UltraSound, LUCAS Imager, Paper Sentinel, AsthmaMD
- **In-home Physician**: Mobile Sensing Platform, myZeo, Sleep Patterns, MyExperience
- **Robotic Physician**: Mobile UltraSound, Blood Glucose, Peak Flow Meter

Tuesday, November 2, 2010
Blood pressure
Cough Frequency
Lung function
Blood pressure

Cough Frequency

Lung function
Cough Frequency

Cough Bursts

Cough Episodes
Lung Function

Spirometry

Time

Flow
Lung Function

Spirometry
Lung Function

Spirometry

Flow

Peak flow

time

Tuesday, November 2, 2010
Lung Function

Spirometry

Flow

Peak flow

time

Flow
Cough Frequency

Lung Function

INFLUENZA

HUMAN ORGAN
FOR TRANSPLANT
Cough Frequency

Lung Function

INFLUENZA

Asthma

HUMAN ORGAN
FOR TRANSPLANT
Cough Frequency

Lung Function

INFLUENZA

Asthma

Bronchitis

Living with Cystic Fibrosis
Self Report

Cough

1 – 5 Scale

Visual Analog Scale

Symptom Diary

Tuesday, November 2, 2010
Self Report

Cough

1 – 5 Scale

Visual Analog Scale

Symptom Diary

Lung Function

SAMPLE DIARY:

John Mott

ASTHMA DIARY PEAK FLOW

For adults, teens & children five years of age and over

Peak Flow Journal

Tuesday, November 2, 2010
Self Report
Self Report  →  Sensing
Self Report  →  Sensing
What does sound on a phone look like?
What does sound on a phone look like?

![Spectrogram of speech and related sounds](image)

- **noise**
- **speech**
- **speech + laughter**
- **coughs**
- **sniff**
- **throat-clearing**

**Time (s)**

**Frequency (kHz)**

**Mag. (dB)**

*Tuesday, November 2, 2010*
coughs

• five-step process:
• five-step process:
  • initial deep inspiration
• **five-step process:**
  • initial deep inspiration
  • glottal closure
coughs

- five-step process:
  - initial deep inspiration
  - glottal closure
  - contraction of muscles against the glottis
• **five-step process:**
  • initial deep inspiration
  • glottal closure
  • contraction of muscles against the glottis
  • sudden glottis opening, explosive expiration
• **five-step process:**
  • initial deep inspiration
  • glottal closure
  • contraction of muscles against the glottis
  • sudden glottis opening, explosive expiration
  • wheeze or “personal” sound
Coughing?

Come to Lab

data collection
Coughing?

Go back to daily routine for 3-7 hours

pay attention to your cough frequency

Come to Lab
Coughing?

Come to Lab

Go back to daily routine for 3-7 hours

pay attention to your cough frequency

Come back and self-report cough frequency

Tuesday, November 2, 2010
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data collection

data annotation
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Data collection

6 linguistic students

---

Data annotation
Coughing?

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data collection

data annotation

6 linguistic students

annotate each sound type

cough    speech    laughter    breath
sneeze    wind    sniff    noise
throat-clearing    others' cough

Tuesday, November 2, 2010
Coughing?

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4 weeks

One week pilot and set up guideline and shared wiki

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cough    speech    laughter    breath
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throat-clearing    others’ cough

data annotation

4 weeks

One week pilot and set up guideline and shared wiki
72 hours
2542 coughs
1016 episodes
72 hours
2542 coughs
1016 episodes

Self Report Difference:
6-139, avg. 23 coughs/hr
Within Subject Training
<table>
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<th>Within Subject Training</th>
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<tr>
<td><strong>Individual</strong></td>
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<td>84.4% 0.7%</td>
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<td><strong>False</strong></td>
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Lung Function

Flow

Peak flow

time
Our system

airflow from lungs

→

glottal excitation

→

vocal tract

→

lip radiation


scattering

→

microphone

observed signal
Our system

Airflow from lungs → glottal excitation → vocal tract → lip radiation

Desired measurement

Model during forced expiration

Backwards analyze

Microphone → observed signal

Scattering
In Testing...
Spirometry and Lifestyle

I have asthma but asthma doesn't have me.
Spirometry and Lifestyle
Medical research is a testbed of correlations populations and patterns
A Final Thought...
A Final Thought...
Mobile Lung Function

Counting Coughs and Spirometry on a Mobile Phone

Sean Liu, Eric Larson, Shwetak Patel
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bystander cough event

- 900 of bystander’s cough were recorded (72 hours)
- 90 of them were extracted as potential cough event and only 5 of them are classified as this participant’s cough.
- potential solution:
  - accelerometer data
  - personalization

This is 1st study on the influence of bystander’s cough!
Working backwards

For the simplest case, using microphone:

\[ F(s) = \frac{\tilde{U}_m}{\tilde{U}_g} = \frac{1}{(CZ_r + D)}. \]

\[ U_m = \left[ f(P / H_{mic}) \right] / Z_r \]
Working backwards

For the simplest case, using microphone:

For simplicity, using microphone:

\[ F(s) = \frac{U_m}{\bar{U}_g} = \frac{1}{(CZ_r + D)}. \]

If parameters are estimated sufficiently, \( U_g \) is an unbiased measure.

\( U_m = \left[ f(P/H_{mic}) \right] / Z_r \)

specified by areas in vocal tract

based on frequency, lip aperture

unknown

estimated

Tuesday, November 2, 2010
Working backwards

For the simplest case, using peak-flow-meter:

\[ F(s) = \frac{\bar{U}_m}{\bar{U}_g} = \frac{1}{(CZ_r + D)}. \]

LOAD = \( Z_r + R_s \)
is biased by the spring resistance,
but has a constant aperture

\( F(s) = \frac{\bar{U}_m}{\bar{U}_g} \)
not calculated
unknown

Measured, taken as glottal flow

Even if parameters are estimated sufficiently, \( U_m \) is a biased measure of \( U_g \), (similar to a plosive)
Counting coughs

• Use a mobile phone microphone!!

• Some approaches exist that require specialized equipment or are not suitable for a mobile phone

• but before...
Why ubicomp?

- Am I in the right session?
Pervasive Health

• Devices that aide navigation through the medical system

• Devices that sense a medical quantity
Pervasive Health

- Devices that aide navigation through the medical system
- Devices that sense a medical quantity
Pervasive Health

- Devices that aide navigation through the medical system

Knowledge Sources
- Diagnostic Search
- Epocrates for Pharmacists
- Pub-med mobile
- Mediquations and Medcalc

DP Aides
- Radiology Assistant
- Wedjat
- HealthMap
- Cannabis App

Journaling
- Medical Record Keeping
- AsthmaMD
Pervasive Health

- Devices that aide navigation through the medical system
- Devices that sense a medical quantity
Pervasive Health

• Devices that aide navigation through the medical system

• Devices that sense a medical quantity
Just a mobile phone?

• Camera
• Accelerometer
• GPS
• IR Emitter
• Microphone
Just a mobile phone?

- Camera
- Accelerometer
- GPS
- IR Emitter
- Microphone → Sound → Breathing and Lungs
Counting coughs

Spirometry
Counting coughs

it is a difficult task
Counting coughs

it is a difficult task

1-5 Scale

Visual Analog Scale
Counting coughs

it is a difficult task

1 – 5 Scale

Visual Analog Scale

Symptom Diary
Counting coughs

it is a difficult task

current approaches:
1) self-report, subjective/inaccurate

Symptom Diary
Counting coughs

it is a difficult task

**current** approaches:
1) self-report, *subjective/inaccurate*

Symptom Diary

LifeShirt

VitaloJAK

Tuesday, November 2, 2010
Counting coughs

it is a difficult task

current approaches:
1) self-report, subjective/inaccurate
2) wearing specialized device, uncomfortable
background:
different ways to quantify cough

explosive cough sounds
cough breaths
cough seconds
cough epochs

[European Respiratory Society guidelines on the assessment of cough, 2007]
background: different ways to **quantify** cough

![Graphs showing cough sounds, cough seconds, cough breaths, and cough epochs.](image)

[European Respiratory Society guidelines on the assessment of cough, 2007]
background:
different ways to **quantify** cough

[European Respiratory Society guidelines on the assessment of cough, 2007]
background: different ways to quantify cough

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[European Respiratory Society guidelines on the assessment of cough, 2007]
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different ways to **quantify** cough

![Graphs showing different ways to quantify cough](image)

*explosive cough sounds*
*cough breaths*
*cough seconds*
*cough epochs*

[European Respiratory Society guidelines on the assessment of cough, 2007]
background:
different ways to **quantify** cough

[European Respiratory Society guidelines on the assessment of cough, 2007]
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<th>LCM</th>
<th>Our Approach</th>
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<tr>
<td>true positive rate (sensitivity)</td>
<td>80%</td>
<td>71 (82)%</td>
<td><strong>88.4%</strong></td>
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<td>false positive rate (1-specificity)</td>
<td>4%</td>
<td>N/A</td>
<td><strong>1.4%</strong></td>
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<td>false alarm (cough/hr)</td>
<td>N/A</td>
<td>13</td>
<td><strong>7.5</strong></td>
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Tuesday, November 2, 2010
correlated with other measurements
correlated with other measurements

large-scale study
Indicators of lung function

Forced Vital Capacity

Flow vs. time

Peak flow

FEV1 / FVC < 65%

Forced Expiratory Volume in 1 second

Flow vs. time
Indicators of lung function

- Peak flow
- Forced Vital Capacity
- Forced Expiratory Volume in 1 second