m-Health Service Infrastructure for Chronic Conditions

COPD and CHF case study

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Chronic conditions

- Chronic Obstructive Pulmonary Disease,
- Congestive Hearth Failure,
- Diabetes,
- Asthma,
- ...
Burden of chronic conditions

- They are spreading fast
- Considerably lower down life expectancy
- Are expensive for the Health Systems to manage
  - Patients are (mostly) left on their own
<table>
<thead>
<tr>
<th>Rank</th>
<th>Cause (2015)</th>
<th>% deaths</th>
<th>Rank</th>
<th>Cause (2030)</th>
<th>% deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>Ischaemic heart disease</strong></td>
<td>13.2</td>
<td>1</td>
<td><strong>Ischaemic heart disease</strong></td>
<td>13.2</td>
</tr>
<tr>
<td>2</td>
<td>Stroke</td>
<td>11.7</td>
<td>2</td>
<td>Stroke</td>
<td>12.2</td>
</tr>
<tr>
<td>3</td>
<td>Lower respiratory infections</td>
<td>5.6</td>
<td>3</td>
<td><strong>Chronic obstructive pulmonary disease</strong></td>
<td>6.5</td>
</tr>
<tr>
<td>4</td>
<td><strong>Chronic obstructive pulmonary disease</strong></td>
<td>5.6</td>
<td>4</td>
<td>Lower respiratory infections</td>
<td>5.0</td>
</tr>
<tr>
<td>5</td>
<td>Diarrhoeal diseases</td>
<td>3.2</td>
<td>5</td>
<td><strong>Diabetes mellitus</strong></td>
<td>3.5</td>
</tr>
<tr>
<td>6</td>
<td>HIV/AIDS</td>
<td>2.9</td>
<td>6</td>
<td>Trachea, bronchus, lung cancers</td>
<td>3.4</td>
</tr>
<tr>
<td>7</td>
<td>Trachea, bronchus, lung cancers</td>
<td>2.9</td>
<td>7</td>
<td>Road injury</td>
<td>2.6</td>
</tr>
<tr>
<td>8</td>
<td><strong>Diabetes mellitus</strong></td>
<td>2.7</td>
<td>8</td>
<td>HIV/AIDS</td>
<td>2.6</td>
</tr>
<tr>
<td>9</td>
<td>Road injury</td>
<td>2.5</td>
<td>9</td>
<td>Diarrhoeal diseases</td>
<td>2.3</td>
</tr>
<tr>
<td>10</td>
<td>Hypertensive heart disease</td>
<td>2.0</td>
<td>10</td>
<td>Hypertensive heart disease</td>
<td>2.1</td>
</tr>
</tbody>
</table>

* Projections of mortality and causes of death, 2015 and 2030 – Global Summary Projections - World Health Organization
mobile-Health can help

- m-Health can help guiding patients towards optimised self-management

- Daily monitoring

- Wide geographic areas easily covered
General framework schema

- **AWS Cloud Storage**
  - Stores documents, videos, and e-leaflets for fast access
  - High speed download link

- **NHS firewall**
  - Secure data transmission

- **Web Server**
  - Patient confidential data
  - Algorithms & Data analysis
  - Alerting system

- **Password protected access**
  - Non-identifiable information
  - Documents and videos
  - Displays messages to the user
  - Shows data trends to patient

- **Access data through web application**
  - Review vital signs and symptoms
  - Verify automatic alerts
  - Send messages to the user
What we need is just

- Patient-centred design
- Transparent technology
- Modular infrastructure
- Personalisation
- Reliability & Security
Patient-centred design

Through collaboration and iteration

With continuous improvement in mind

Patients

Health professionals

R&D Engineers
Transparent technology

• Intuitive and user friendly
  – Ideally no user manual

• Unobtrusive
  – Should not worry patients with unnecessary data or actions
• Key components and other elements linked to a “Main App”

• Possibility of deactivating elements remotely

• Similar components → Similar behavior
Personalisation

- Customised interface (videos and documents related to the user)
- Health professional → Patient communications
- Access own data
HOW DID WE IMPLEMENT THIS?
Patient-centred design

• Interviews and workshops with patients

• Iterative development and feedback from health professionals
  – Continuous improvements
  – Immediate delivery of updates
Intuitive and user friendly
Transparent technology

- "Easy to read" icons, Big buttons, Big text
Intuitive and user friendly (II)
Transparent technology

• Sequential and clear actions flow
Intuitive and user friendly (III)
Transparent technology

• Seamless technology integration
Unobtrusive
Transparent technology

Data wirelessly transferred from mobile application to server in background

- Lower overhead at start-up
- No problems in case the patient leaves the tablet on
- (Partially) solve connectivity problems
“Main App” concept
Modular infrastructure

• The **Main app** is the application of reference where patients manage their condition

• Each section (theme) is separate in which can be operated singularly

• Possibility of separating each single module as separate app
Remote deactivation

Modular infrastructure

- Allow to turn off some parts of the application according to remote options
Similar components → Similar behaviour

Modular infrastructure

- Similar modules should have same structure and behaviour of others
- Avoid confusion and disorientation

New menus easily encoded by text and pictures. No more than 6 elements per screen.

Allow easy “escape” from unexpected menus

Info menu always available
Customised interface

Personalisation

Content customized to the patient needs:

- Medication based
- Diet based
- Location based
HCP ➔ Patient communications

Personalisation

- Messages sent from the nurse are customised to the user

Hi, I will be giving you a call next week to arrange to come and visit you, as you have reached the end of the trial. Please continue to use the hand held computer until I visit. Thanks Heather

Tap here to continue
Access to own’s data

Personalisation

- Vital signs and symptom level as graphs
Reliability – Signal Quality

Signal Quality

Do you wish to retry recording your data?
Best recording are done when relaxed, with your hand and wrist on a flat surface.
If you wish so, tap TRY AGAIN otherwise tap SKIP to go to the main screen.

Heart rate: 68  Oxygen level: 99%
Thank you very much. Your symptoms have been recorded and stored.
You can now remove your finger from the Onyx probe.

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SECURITY

- No personal information on tablet
- Possibility of remote wipe-out
- Secure “Amazon-like” data verification
HOW DID PATIENTS RESPOND?
EDGE-COPD CASE STUDY
Daily usage

[Bar chart showing daily usage across different hours of the day.]
# Application sections

<table>
<thead>
<tr>
<th>Section ID</th>
<th>Section name</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>LAY: Activity</td>
</tr>
<tr>
<td>1</td>
<td>LAY: Breathing</td>
</tr>
<tr>
<td>2</td>
<td>LAY: Diet</td>
</tr>
<tr>
<td>3</td>
<td>LAY: Emotions</td>
</tr>
<tr>
<td>4</td>
<td>LAY: Inhalers</td>
</tr>
<tr>
<td>5</td>
<td>LAY: Smoking</td>
</tr>
<tr>
<td>6</td>
<td>Self-Management: Graphical view</td>
</tr>
<tr>
<td>7</td>
<td>Self-Management: Plan</td>
</tr>
<tr>
<td>8</td>
<td>Messages</td>
</tr>
</tbody>
</table>

![Median duration per section](chart1.png)

![Section views](chart2.png)
Educational Videos

<table>
<thead>
<tr>
<th>ID</th>
<th>Video Title</th>
<th>ID</th>
<th>Video Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>How to use the Handihaler</td>
<td>8</td>
<td>Manage my mood</td>
</tr>
<tr>
<td>2</td>
<td>How to use the Accuhaler</td>
<td>9</td>
<td>Manage my breathing</td>
</tr>
<tr>
<td>3</td>
<td>How to use the MDI</td>
<td>10</td>
<td>Manage my worry</td>
</tr>
<tr>
<td>4</td>
<td>How to use the Turbuhaler</td>
<td>11</td>
<td>How to use the Respimat</td>
</tr>
<tr>
<td>5</td>
<td>Pulmonary rehab. importance</td>
<td>12</td>
<td>Relaxation technique</td>
</tr>
<tr>
<td>6</td>
<td>Stay active</td>
<td>13</td>
<td>My breathing exercises</td>
</tr>
<tr>
<td>7</td>
<td>How to use the Aerochamber</td>
<td>14</td>
<td>How to use the Volumatic</td>
</tr>
</tbody>
</table>

![Graph 1: Total percentage over length per patient](image1)

![Graph 2: Average percentage duration](image2)
Learning curve

• Graphs showing the learning curves
SHOW US THE DATA!

EDGE-COPD CASE STUDY
Automatic Generation of Personalised Alerts for Patients with COPD

Objective:
- Reduce episodes of exacerbation (progressive worsening of symptoms)

Methodology:
- System Development (described earlier)
- Data Collection
  - 6-month pilot study with 18 patients
  - Randomised Control Trial with 165 patients
- Algorithms and Evaluation
**EDGE System**

**Symptom Diary**

<table>
<thead>
<tr>
<th>Question</th>
<th>Range of values</th>
</tr>
</thead>
<tbody>
<tr>
<td>How are you feeling today?</td>
<td>[0, 5]</td>
</tr>
<tr>
<td>How is your breathlessness?</td>
<td>[0, 5]</td>
</tr>
<tr>
<td>How is your wheeze or chest tightness today?</td>
<td>[0, 5]</td>
</tr>
<tr>
<td>Do you have a cough?</td>
<td>yes/no</td>
</tr>
<tr>
<td>How is your cough today?</td>
<td>[0, 3]</td>
</tr>
<tr>
<td>What color is your sputum?</td>
<td>white, brownish</td>
</tr>
<tr>
<td>Do you have a cold (such as a runny/blocked nose) or sore throat?</td>
<td>yes/no</td>
</tr>
<tr>
<td>Did you wake up last night due to breathing problems?</td>
<td>[0, 5]</td>
</tr>
</tbody>
</table>

**Pulse Oximeter**

- Records 30-seconds photoplethysmogram (PPG) and provides heart rate, and SpO2

**Medication Questions**

- Part of the diary
- Inhaler, antibiotics, relievers
- Our ‘gold’ standard
## Patient Demographics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male/Female</td>
<td>9 / 9</td>
</tr>
<tr>
<td>Age(^a)</td>
<td>71 (9)</td>
</tr>
<tr>
<td>Days in the study(^a)</td>
<td>179.8 (0.3)</td>
</tr>
<tr>
<td>COPD Severity</td>
<td>6 moderate, 1 likely severe, 9 severe, 2 very severe</td>
</tr>
<tr>
<td>Pulse rate (beats/minute)(^a)</td>
<td>83.2 (18.3)</td>
</tr>
<tr>
<td>Blood oxygen saturation (% SpO(_2))(^a)</td>
<td>93.5 (4.1)</td>
</tr>
</tbody>
</table>

\(^a\): values reported as mean (standard deviation)

2523 sessions in total containing symptom diary questions and pulse oximetry data
Existing Solutions
• Fixed threshold on SpO2 (e.g. 92)
• Subjective assessment without detailed knowledge of patient’s previous data
• High false alerts

Our Approach
• Data driven
• Patient-Specific
• Probabilistic
• 6-weeks learning period

Started with univariate, and improved with multivariate methods
Multivariate Approaches

**Distance-based**

Each variable is normalised as standard score, \( \hat{x} = \frac{x-\mu}{\sigma} \) where \( \mu \) and \( \sigma \) are the mean and the standard deviation of the variable \( x \) using the training data. After normalisation, the Euclidean distance of each data point is computed using \( md = \sqrt{diary^2 + pulse^2 + spo2^2} \). A threshold is then applied to \( md \) to determine if the data point is abnormal.

**KDE-based**

Non-parametric density estimation technique using Parzen windows

\[
p(z) = \frac{1}{n} \sum_{j=0}^{n} \left( \frac{1}{2\pi^2\sigma^3} \right) e^{-\frac{|x-x_j|^2}{2\sigma^2}}
\]

\[
mp = -\ln(p(z)) \quad \text{(novelty score)}
\]
Performance Evaluation

Sensitivity = \frac{\sum TP}{\sum TP + \sum FN}

Specificity = \frac{\sum TN}{\sum TN + \sum FP}
Alerts generated over the period of monitoring (Patient ID: 58)
ROC curves for the univariate and multivariate methods *

AUC: Parzen (0.88), Pulse (0.84), SpO2 (0.81), Distance (0.77), Combined (0.77) Diary (0.76)

* AUTOMATIC PERSONALISED ALERT THRESHOLDS FOR PATIENTS WITH CHRONIC OBSTRUCTIVE PULMONARY DISEASE
Respiratory Rate Information in Photoplethysmogram (PPG)

- **Amplitude variation (AM)**
  - Thoracic pressure changes
  - Interferers
    - Breathing pattern
    - Tidal volume
    - Blood loss

- **Frequency variation (FM)**
  - Respiratory sinus arrhythmia
  - Interferers
    - High respiratory rate
    - Cardiac / neurological conditions
    - Pharmacological interventions

Visual guidance and use of Nonin flags resulted in a very low number of recording sessions corrupted with movement artifact.
Addition of respiratory rate for the automated generation of personalised thresholds

2523 sessions with diary and oximetry data

2379 sessions after 144 sessions (5.7%) with less than 20 seconds recording removed

2308 after 71 PPG recording sessions (2.9%) with low quality removed
Respiratory Rate Estimation

PPG from patient → detrending → Kaiser window based, pass-band cut-off=0.5*cardiac frequency, stop-band cut-off=1.2*cardiac frequency → downsampling

Respiratory rate from the novel method → 7th order AR model, pole with the lowest angle corresponds to respiratory rate

Average respiratory rate (std): 22.4 bpm (5.1)
Alerts generated over the period of monitoring (includes respiratory rate)
ROC curves for the univariate methods including respiratory rate

AUC: Resp (0.88), Pulse (0.84), SpO2 (0.81), Diary (0.76)
ROC curves for the multivariate methods with and without the inclusion of respiratory rate *

<table>
<thead>
<tr>
<th>Respiratory rate included?</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parzen</td>
<td>0.91</td>
<td>0.88</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Respiratory rate included?</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance</td>
<td>0.83</td>
<td>0.77</td>
</tr>
</tbody>
</table>

*Personalized alerts for patients with COPD using pulse oximetry and symptom scores
Future Work

• Extend m-Health framework for complete modularity
• Automate internal fault detection mechanism
• Increase number of sensors
• Relabeling data using symptom diary *
  – Slight change of labels
• M-N algorithm
  – Time adaptive approach
• Bayesian framework
  – New machine learning approach
• Data from the RCT (with 165 patients)
  – Bigger dataset → better results validation

* Time Course and Recovery of Exacerbations in Patients with Chronic Obstructive Pulmonary Disease
Terence A.R. Seemungal, Gavin C. Donaldson, Angshu Bhowmik, Donald J. Jeffries, and Jadwiga A. Wedzicha
American Journal of Respiratory and Critical Care Medicine 2000 161:5, 1608-1613
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Questions?