MSc thesis
Retargetable User Interface for Health Effects of Air Quality

Santiago Renato Balladarees Ona
s1575554

Master of Science
School of Informatics
University of Edinburgh
2016
Abstract

Continuous advances in mobile technology has enabled the use of smartphones in healthcare assistance targeted at vulnerable users such as older adults. However, difficulties in interacting with information and communication technologies affect a wider percentage of the population around the globe in both the developed and developing nations. This project describes the design and evaluation process of the User Interface (UI) for a healthcare mobile application, AirRespeck, designed to calculate the dosage of air pollution inhaled during physical activity. The UI aims to be retargetable to users from different age groups. The application will include various configuration options in order to allow the UI to be customized according to the user’s needs and preferences. The results and findings of this project are expected to contribute to the broader research community when designing interfaces for smartphones.
Acknowledgements

First, I would like to thank my supervisor, Prof. D. K. Arvind, for the opportunity to work in such an interesting topic, and his support and guidance throughout this dissertation project.

Secondly, I would like to express my gratitude to the team at the Centre for Speckled Computing, research associate Andrew Bates and centre administrator Christy Brewster, for their advice and help during the development of this project.

Finally, I would like to acknowledge the Ministry of Higher Education, Science, Technology and Innovation in Ecuador for the financial sponsorship which was vital in order to achieve this MSc degree.
# Table of Contents

1 Introduction ........................................ 1

2 Background & Related work ..................... 5
   2.1 Health effects of air pollutants .............. 5
   2.2 Mobile technology in healthcare ............. 6
       2.2.1 Mobile phones .......................... 6
       2.2.2 The elderly population ................. 7

3 Designing for diversity ......................... 11
   3.1 UI design approaches ......................... 12
       3.1.1 Experimental approaches .............. 12
       3.1.2 Non-Experimental approaches ........... 13
       3.1.3 Scenario-based approaches ............. 13
   3.2 Problem analysis ................................ 15
       3.2.1 Users .................................. 15
       3.2.2 Technology ............................ 20
       3.2.3 Activities .............................. 20
       3.2.4 Environment ............................ 21

4 Implementation .................................. 23
   4.1 Existing applications ......................... 23
       4.1.1 RESpeck ............................... 24
       4.1.2 AirSpeck .............................. 25
   4.2 The combined application: AirRespeck ......... 25
   4.3 Development ................................ 27
       4.3.1 Scope .................................. 27
       4.3.2 Tools and set-up ....................... 28
4.3.3 Methodology ........................................ 28
4.3.4 Scenarios and mock-ups ......................... 29
4.3.5 Final UI designs ................................. 35

5 Evaluation ............................................. 39
5.1 Objective ........................................... 39
5.2 Data collection ..................................... 39
  5.2.1 Subjects ....................................... 39
  5.2.2 Methodology ................................... 40
5.3 Data analysis ...................................... 41
  5.3.1 Technical skills ................................. 41
  5.3.2 Information presentation ..................... 43
  5.3.3 User interaction ............................... 44
  5.3.4 Feedback ..................................... 46

6 Conclusions & Future work ......................... 51

Glossary .................................................. 55

Acronyms ............................................... 57

Bibliography ........................................... 59

Appendices ............................................. 69

A Evaluation questionnaires ......................... 69
  A.1 Previous experience with technology ........... 69
  A.2 Experience with the application ................ 71
  A.3 Navigation and interaction timed tasks .......... 73

B Air pollutant scales ................................. 75
  B.1 Particulate matter 2.5 (PM2.5) ................... 75
  B.2 Particulate matter 10 (PM10) ................. 75
  B.3 Ozone (O3) ........................................ 76
  B.4 Nitrogen dioxide (NO2) .......................... 76
## List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Mobile ownership (%) for Northern Ireland by age group [7].</td>
<td>7</td>
</tr>
<tr>
<td>2.2</td>
<td>Age pyramid in the EU-25,2005 and 2050 [71].</td>
<td>8</td>
</tr>
<tr>
<td>3.1</td>
<td>RESpeck and AirSpeck main screens.</td>
<td>21</td>
</tr>
<tr>
<td>4.1</td>
<td>The RESpeck sensor in comparison to a £2 coin.</td>
<td>24</td>
</tr>
<tr>
<td>4.2</td>
<td>The AirSpeck sensor.</td>
<td>26</td>
</tr>
<tr>
<td>4.3</td>
<td>Initial sketch for the basic UI.</td>
<td>32</td>
</tr>
<tr>
<td>4.4</td>
<td>First mock-up for the basic UI: Version A features a list view.</td>
<td>33</td>
</tr>
<tr>
<td>4.5</td>
<td>First mock-up for the basic UI: Version B features a cyclic view.</td>
<td>34</td>
</tr>
<tr>
<td>4.6</td>
<td>First mock-up for the advanced UI featuring more menu options.</td>
<td>35</td>
</tr>
<tr>
<td>4.7</td>
<td>Segmented bar and Semi-circular gauge for displaying temperature.</td>
<td>36</td>
</tr>
<tr>
<td>4.8</td>
<td>Final design for the basic UI.</td>
<td>37</td>
</tr>
<tr>
<td>4.9</td>
<td>Final design for the advanced UI.</td>
<td>38</td>
</tr>
<tr>
<td>5.1</td>
<td>Self-estimated time taken to use new technologies.</td>
<td>41</td>
</tr>
<tr>
<td>5.2</td>
<td>Technological skills with different mobile OSs.</td>
<td>42</td>
</tr>
<tr>
<td>5.3</td>
<td>Preferred information presentation method.</td>
<td>43</td>
</tr>
<tr>
<td>5.4</td>
<td>Average task completion time on Basic UI.</td>
<td>44</td>
</tr>
<tr>
<td>5.5</td>
<td>Average task completion time on Advanced UI.</td>
<td>45</td>
</tr>
<tr>
<td>5.6</td>
<td>Task completion times for subject S16 and average of subjects S13, S14, S15 on the BasicUI.</td>
<td>46</td>
</tr>
<tr>
<td>5.7</td>
<td>Average task completion time on Settings screen.</td>
<td>47</td>
</tr>
<tr>
<td>5.8</td>
<td>Subjects’ feedback on the mobile application.</td>
<td>48</td>
</tr>
<tr>
<td>5.9</td>
<td>Subjects’ feedback on the UI.</td>
<td>49</td>
</tr>
<tr>
<td>B.1</td>
<td>Scales used for PM2.5 [28].</td>
<td>75</td>
</tr>
<tr>
<td>B.2</td>
<td>Scales used for PM10 [28].</td>
<td>75</td>
</tr>
</tbody>
</table>
B.3 Scales used for O3 [28] .................................................. 76
B.4 Scales used for NO2 [28] .................................................. 76
# List of Tables

2.1 Classification of air pollutants [4]. ................................. 6
2.2 Healthcare mobile applications organized by intervention strategies and phone features used [52]. ................................. 9

3.1 Age groups, or stages of development for children [61]. ....... 17
3.2 Problems of the Elderly [41]. ................................. 18
3.3 Age groups considered in the AirRespeck project. ................. 18

4.1 Common UI issues and recommendations. ........................... 31
Chapter 1

Introduction

Poor air quality is a world-scale issue and is the source of many ailments such as asthma, cancer, and heart disease around the globe. Various studies have documented numerous adverse effects of air pollution in human health. The quality of air in outdoor environments in particular remains a subject of concern despite decreasing levels of some of the major pollutants like particulates, sulphur oxides, and carbon monoxide [32]. In the attempt to mitigate air contamination, various emission controls have been imposed in many developed countries. However, outdoor air quality issues persist in developing nations. Consequently, the relevance of monitoring levels and exposure to air pollutants in order to enable significant advances in medicine, science, and policy.

Nonetheless, restricted availability to air quality readings endangers the general public health and hinders research efforts. Citizens usually rely on media reports to obtain information about potential adverse respiratory effects caused by air pollution. However, the accuracy of these reports is another topic of dispute [20, 22]. With the purpose of address this gap, numerous research projects have proposed the use of mobile technology in order to aid monitoring and research. Advances in mobile technology has triggered a revolution in mobile communications with considerable increases in the number of mobile applications for smartphones in the last decade [7]. Interaction with mobile devices is therefore inevitable and requires straightforward and amicable UIs. Nonetheless, UIs have not evolved accordingly and various issues exist regarding usability. Mobile applications’ users are diverse and have different requirements and expectations.

The objective of this project is to evaluate recent research on the subject of UI
design and develop a mobile application featuring a retargetable UI that attends the needs of users from different group ages and technological skills. A healthcare application for mobile devices (i.e. smartphones, tables) running the Android operative system will be developed. This application will be centred around two existing applications, RESpeck and AirSpeck, developed by the Centre for Speckled Computing\(^1\). RESpeck offers support for measuring various physical activity levels of a patient such as respiratory rate and flow. AirSpeck, on the other hand, facilitates monitoring of concentration levels of suspended Particulate matter (PM), temperature, relative humidity, nitrogen dioxide and ozone.

The healthcare mobile application, AirRespeck, is a joint-project developed in conjunction with work done in the project Assessing the impact of exercise on personal exposure to air pollution. Its objective is to aid in modelling the dosage of air pollution inhaled during physical activity using wearable sensors via Bluetooth connection. This will assist in understanding the impact of personal exposure to air pollution in exercising and targets a wide range of users from different age groups and backgrounds. Potential users include citizens from both the developed and developing world.

Appropriate design process, for UI and technology in general, must be concerned about different factors that affect user interaction such as characteristics of the customers, context, operational conditions, and user expectations. For the AirRespeck project, principal factors that are taken into account are age and technological literacy. Age, in particular, greatly influences how users interact with technology. Certain user groups such as the elderly experienced usability issues due to lack of experience with technology [85]. Other groups with limited access to technology are underprivileged individuals specially in developing countries [54].

Research has concentrated in specific groups providing tools for improving the user’s quality of life. However, user interaction difficulties prevent users from taking advantage of these solutions. Consequently, various studies have focused in understanding the reality of groups of users affected by usability issues. For instance, common issues in UI design include high information density, ambiguous terminology, complex menus, poor function categorization, limited operability (i.e. small fonts, small controls), and UI not scalable [3, 58, 71, 85]. In addition, the introduction of new technologies such as touch screens has created additional usability issues. While various terms used in traditional desktop computers have been borrowed, i.e. double-click,

\(^1\)Centre for Speckled Computing website: http://www.specknet.org
drag-and-drop, new terms cause confusion, i.e. swipe, scroll [51, 63]. Other issues are specific to certain users, for instance it has been found that old adults struggle performing fine motor control tasks and suffer from inaccurate touches in touchscreens [51, 85].

Evaluation of the mobile application is structured in three phases. First, the subjects were requested to complete a questionnaire in order to gather information about the users’ experience with technology. Then, a brief interview was held, during which the subjects were introduced to the project’s objective. This was followed by a walkthrough of the application, its functionality, features, and options. Finally, the subjects were asked to fill a questionnaire to assess the usability of the UI, information presentation, and interaction.

Overall, the results show that experience with technology plays an important factor in determining a user’s dexterity when interacting with the application. Age, although a key factor does not impact greatly in UI for old adults. This supports findings suggesting that the elderly population exhibit more diversity that younger users. Performance when interacting with the application shows that common tasks, i.e. starting/closing the application, using buttons, understanding the information presented, does not present high difficulties. Possibly due to previous interaction with other mobile applications. However, more complex operations such customizing the settings screen proved to be more challenging with various users requiring assistance in order to complete some tasks.
Chapter 2

Background & Related work

2.1 Health effects of air pollutants

The environmental effects of industrialization occurred in the last century are undeniable. Atmospheric composition has been irreversibly altered causing a number of adverse effects not only on humans but also on animals and vegetation [48]. Although there are multiple sources for air pollution, the principal cause is the combustion of fossil fuels. Air pollutants can be categorized based on different characteristics such as source, chemical composition, size, and release mode into indoor or outdoor environments [4]. Table 2.1 offers a detailed list of air pollutants.

Increase in urbanization has caused a continuous expansion of the current transportation infrastructure which depends on fossil fuels. According to recent reports, there are over 260 million vehicles in the US alone as of 2014 [83]. As a result, air pollution levels have grown significantly in the last years despite efforts to control pollution emissions [16]. The most common air pollutants in urban areas include PMs, O3, Carbon monoxide (CO), Nitrogen oxides (NOx), Sulfur oxides (SOx), lead and heavy metals [1, 27].

Air pollutants are known to cause and contribute to the increase in mortality or serious illness posing hazard to human health. Human organ systems affected include the respiratory, cardiovascular, immunological, hematological, neurological, and developmental systems, [16]. Certain groups such as patients with respiratory problems, heart disease, pregnant women, the elderly and children are particularly more affected by air pollution. What is more, exposure to air pollutants has been proven to be detrimental
to athletic performance, [10].

<table>
<thead>
<tr>
<th>Category</th>
<th>Pollutants emitted directly into the atmosphere: SO2, some NOx species, CO, PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary</td>
<td>Pollutants that form in the air as a result of chemical reactions with other pollutants and gases: O3, NOx, and some PMs</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Indoor</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cooking and combustion, particle re-suspension, building materials, air conditioning, consumer products, smoking, heating, biologic agents</td>
</tr>
<tr>
<td></td>
<td>Products</td>
</tr>
<tr>
<td></td>
<td>Combustion products (tobacco and wood smoke), CO, CO2, SVOC (aldehydes, alcohols, alkanes, and ketones), microbial agents and organic dusts, radon, man-made vitreous fibres</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Outdoor</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Industrial, commercial, mobile, urban, regional, agricultural, natural</td>
</tr>
<tr>
<td></td>
<td>Products</td>
</tr>
<tr>
<td></td>
<td>SO2, O3, NOx, CO, PM, SVOC</td>
</tr>
</tbody>
</table>

| Gaseous      | SO2, NOx, O3, CO, SVOC (PAH, dioxins, benzene, aldehydes, 1,3-butadiene) |
| Particulate  | Coarse PM (2.5-10mm; regulatory standard = PM10), fine PM (0.1-2.5mm; regulatory standard = PM2.5); ultra fine PM (<0.1 mm; not regulated) |

Table 2.1: Classification of air pollutants [4].

### 2.2 Mobile technology in healthcare

#### 2.2.1 Mobile phones

The global adoption of mobile phones, in particular smartphones, continues to escalate as a result of the continuous advances in Communications Technologies and related technologies such as 4G technology, storage capacity, audio and video processing [71]. In fact, numerous reports indicate that mobile ownership has experienced a substantial
increase in the last years. In the US, over 50% of the population aged 25–29 live in households with a mobile phone and no land-line telephone [7]. Northern Ireland shows a mobile ownership rate close to 100% in 2009. See Figure 2.1.

Developing countries, which are an interesting market for future growth, have been keeping pace with such rapid uptake. For instance, in 2008 African subscribers accounted for approximately 30% of the total population (around 280 million users), overpassing the number of subscribers in North America [89]. In consequence, various activities of daily life have been affected at a global scale. Not only communication has been transformed but also other aspects of our lives such as culture, community, identity and relationships.

As a result, the number of mobile applications has grown exponentially. It is estimated that the GooglePlay Store offers more than 1,130,000 apps while the AppleApp Store more than 1,000,000 apps by December 2013 [57]. Reports suggest that GooglePlay Store and Apple App Store have over 50 billion and over 100 billion downloads as of July 2013 and June 2015 respectively [43, 88].

### 2.2.2 The elderly population

For the last years, the elderly population has been constantly growing in developed countries. The United Nations estimates that by 2050 the number of adults aged 65
Chapter 2. Background & Related work

and over will reach the 38% of population in Europe [71]. See Figure 2.2. Consequently, old adults are living longer and healthier than ever before. In fact, the life expectancy of the Portuguese population is 81.8 years for women and 75.9 years for men [17]. This trend has raised many concerns in these societies due to the fact that many products and services must be adapted to the needs of this increasing number of senior citizens.

In consequence, several studies have concentrated on this segment of the population in order to address challenges such as providing effective healthcare and offering an overall good quality of life. New fields of study have emerged such as Gerontotechnology which is concerned about technology applied to address the needs of the aging population [71]. In this field, regular improvements in mobile technology have enabled the use of mobile phones as a relevant platform for providing health interventions.

![Age pyramid in the EU-25, 2005 and 2050](image)

Mobile phones are increasingly being used as tools for different health related activities such as promoting physical activity and healthy diets, symptom monitoring...
in respiratory and cardiac illnesses (i.e. asthma and heart disease), preventing smoking, and notifying patients about medical appointments [52].

Depending on the nature of healthcare solutions, different technical capabilities are required from mobile phones. As technical specifications in mobile phones vary greatly, offering different features, research is vast and numerous health applications have been implemented with varying rates of success. Table 2.2 summarizes previous work in healthcare solutions for mobile phones. Five different intervention methods are listed: tracking health information, involving the healthcare team, leveraging social influence, increasing the accessibility of health information, and utilizing entertainment [52].

<table>
<thead>
<tr>
<th>Phone feature / intervention strategy</th>
<th>Text messaging</th>
<th>Cameras</th>
<th>Native applications</th>
<th>Automated sensing</th>
<th>Internet access</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracking health information</td>
<td>[40], [2], [8], [59], [62]</td>
<td>[59], [18], [14, 15], [15], [62], [30], [53], [87]</td>
<td>[59], [18], [14, 15]</td>
<td>[59], [53], [87], [50], [70]</td>
<td></td>
</tr>
<tr>
<td>Involving the healthcare team</td>
<td>[68], [37], [59], [79]</td>
<td>[59], [87], [75], [59], [75], [59], [75], [59], [70]</td>
<td>[24], [49], [86], [78]</td>
<td>[24], [86], [78]</td>
<td></td>
</tr>
<tr>
<td>Leveraging social influence</td>
<td>[68], [29], [74], [73], [90]</td>
<td>[30], [14]</td>
<td>[14]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increasing the accessibility of health information</td>
<td></td>
<td></td>
<td>[15], [13]</td>
<td>[15], [13]</td>
<td></td>
</tr>
<tr>
<td>Utilizing entertainment</td>
<td></td>
<td></td>
<td>[19], [36]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2.2: Healthcare mobile applications organized by intervention strategies and phone features used [52].
Chapter 3

Designing for diversity

Mobile applications have seen considerable growth in recent years with the rapid adoption of mobile devices across a wide section of users [6]. The vast choice of mobile applications has enabled users to transform their mobile devices into tools for activities in a number of different contexts such as photography, navigation, education, or entertainment. These applications have eased the use of mobile devices [71], and their growing influence in the everyday lives of people is undeniable. A key to its success is the design of the UI to guarantee a smooth user experience.

Nonetheless, it has been found that user experience varies greatly among users from different backgrounds. The elderly and children are particularly affected due to the fact that these users have been traditionally considered as homogeneous user groups [61, 71]. This comes from the fact that mobile devices were first introduced in the 1990s and as a result research in UI and usability is limited [77]. Initial studies in Human-computer interaction (HCI) have concentrated on neutral models and design guidelines that focus on the average middle-aged adult, e.g. the western European adult at the workplace [61]. Hence, the issue of diversity in UI persists.

In general, research concentrates in specific user groups like children and/or the elderly population. While the main focus of the former has been education and entertainment, the latter is increasingly using these devices to cover health monitoring needs. In addition, studies are lacking which address usability issues in the design of interfaces targeted at different user groups, and this task has usually been left for future work [58, 63].
3.1 UI design approaches

Before considering the issue of user diversity in UI usability, it is important to understand the implications of human interaction with computers. Human considerations need to be taken into account during all stages of computer systems design [23]. Although the HCI field is approximately 30 years’ old, research is in progress and many questions are still relevant today. UI remains a crucial topic as it can hinder the user experience (i.e. learning, enjoyment) with computers [61].

Evaluation of scenarios and user characteristics is encouraged by HCI literature in various UI design methodologies. Design approaches that rely on interaction with users are usually costly and require extensive periods of time in order to analyse users and their needs. On the other hand, methods based on conceptual design allow designers to propose potential solutions based on previous UI design experience.

3.1.1 Experimental approaches

The experimental approaches proposed in literature depend on experimentation and observation of potential users with the purpose of gathering empirical data to guide the design process. In order to accomplish this, it is necessary to get access to groups of intended users and run experiments and interviews. By observing the prospective users interacting with the system it is possible to refine the design process. Although the information collected might be of great use, this process is usually expensive in time and resources. For this reason, only small-scale projects with easy access to the planned users are able to implement these empirical approaches.

In the case of the AirRespeck project, its broad scope and relatively limited access to focus groups of users with specific backgrounds makes it difficult to implement these kind of approaches. Nevertheless, it may be possible to apply such an empirical approach in a limited context as suggested by [42]. By applying fewer rounds of experimentation in conjunction with other approaches it may be possible to reduce the time required for the design process. Although this will restrict the granularity level of feedback from potential users and will required assumptions in terms of usability.
3.1.2 Non-Experimental approaches

There are numerous full-fledged design frameworks in HCI that offer non-experimental alternatives for UI development. For instance, the User-Centered Design process proposed by [35], or the Star Model by [39]. These frameworks assist designers identify and organize important tasks within the design process. Some of the non-experimental approaches employed in such frameworks are the Task Analysis and the Structured Design.

The Task Analysis approach consists in recognizing the tasks and subtasks the user needs to follow when interacting with the system interface. In addition, different objects and procedures involved in the process of interaction are compiled [46]. On the other hand, the Structured Design objective is building a grammar with various levels of detail including steps, semantics and syntax involved in the interaction process between the user and the interface [67]. One key characteristic of this approach is the formalization of the grammar notation in order to reutilize it through the project lifecycle.

Another alternative, more intuitive and practical, uses visual representations of possible designs for the system. The Holistic Design employs mock-ups and sketches to create and evaluate early UI designs [67]. Various cycles creating and presenting alternative designs to intended users so as to collect feedback are conducted. The advantage of this approach resides in the continuous feedback, collected through these repetitive cycles, which will ultimately produce the final UI.

The discussed approaches suffer from various disadvantages nonetheless. For instance, the high granularity and over-specification nature of the Task Analysis and Structured Design approaches can lead to inadequate design decisions. Also, both approaches required that considerable amounts of effort be put into the specification and cognitive analysis for only small portions of the final UI [42]. In contrast, the Holistic Design early design process can cause designers to create interfaces without proper analysis and miss critical elements.

3.1.3 Scenario-based approaches

The basis behind Scenario-based approaches, which are introduced as analytic methods by [38], is the specification of users and their needs within a specific scenario. In
HCI literature, scenario-based approaches have received considerable attention due to their capability to provide concrete descriptions of the activities that users perform in order to accomplish a specific task. Such description is detailed enough to allow design implications to be inferred and reasoned by designers and software developers [11]. Different scenarios where users interact with the system need to be identified with complete details about all possible issues that may influence this interaction. This process encourages designers to analyse possible problems that may arise and consider procedures to solve them [42].

One important advantage of scenario-based approaches over empirical approaches is that “scenarios have the important property that they can be generated and developed even before the situation they describe has been created” [12, p. 190]. Furthermore, it is possible to utilize scenario-based approaches in combination with empirical methods such as experimental approaches in order to render possible use situations concrete and available for exploration.

For the AirRespect project various considerations were made in order to choose a suitable design approach. First, this project targets users from various age groups who have a remarkably diverse technological expertise and backgrounds. Since this imposes some difficulties in terms of access to the intended users, an experimental approach that relies on empirical data could not be used. This is because experimental approaches are expensive in time and resources as they require numerous experiments and interviews to be carried out with the intended users. Therefore, non-experimental approaches offer a better solution. However, these approaches need substantial amounts of effort for specification and cognitive analysis in order to identify all tasks and subtasks involved in user interaction. Given that time is a constraint in this project, these approaches cannot be implemented.

After some considerations, it was agreed that the Holistic Design is the most suitable approach due to the characteristics of this project. This approach encourages a creative process where the designer creates visual representations of various alternative designs for user to evaluate. Cycles of mock-ups conception and feedback from users are carried out until the final design is implemented hopefully addressing all the users’ needs. This will help reduce development time and improve design evaluation. Finally, given the diverse nature of the target users, it is important to take into consideration all possible user interactions with the system. This means considering other factors
such as the environment. Thus, elements of Scenario-based approaches, which places emphasis on the users’ needs and what technology can offer, were used such as analysis of different scenarios.

3.2 Problem analysis

As discussed previously in Chapter 2, air pollution is a matter of concern to the general population due to numerous harmful effects on human health. While in developed countries air pollution is relatively limited due to strict air quality legislation, in the developing world pollution levels are considerably higher [16]. In consequence, the pool of potential patients is comprised of a big percentage of the population with citizens from different backgrounds. The implementation of the AirRespeck project with such a considerable number of aimed users experiences various complications. One important problem, which is the subject of the present project, is the issue of UI usability and user diversity.

UI, and computer systems in general, required careful analysis during development in order to produce a software product that is sufficiently usable for the anticipated users. Various considerations must be taken into account such as the users of the system, the technology which it will use, the activities which it will assist undertaking, and the environment in which it will be deployed.

3.2.1 Users

Possibly the most important factor to be taken into consideration are the end users of the system. Designers that do not understand the needs of the system’s user will most likely fail to implement a sensible UI. HCI research has often generalized theories, models, and methodologies about usability and has approached users in a neutral way [61]. However, universal accessibility has raised questions about diversity in user groups. Persons from different backgrounds required different functionalities from UIs.

The AirRespect target users include individuals from diverse segments of the population, distinctive factors include age, social and cultural backgrounds, and both technological and written language literacy.
3.2.1.1 Age

Age plays an important factor in how a person behaves and with the environment and ultimately its performance in completing certain tasks. Nowadays, mobile devices are experiencing an extraordinary integration in people’s everyday life. This has highlighted notable considerations about the users’ age and UI interaction. For instance, children and senior citizens exhibit particularly diverse interactions with UI [58, 61]. Hence, it is crucial to study and understand users’ behaviours towards mobile technology.

**Children.** - The fact that children have early access to technology has promoted the thought that children feel more comfortable using new technologies than young and old adults. Nonetheless, it has been argued that children and adults experience similar difficulties using UIs in certain mobile phones and UIs [3]. In fact, it has been recognized that children have different requirements and expectations than adults [63]. Children are in a constant state of learning and discovery. Therefore, UIs that provide assistance with this is critical in order to ensure learning and skill development from early age.

An important characteristic of this group is that it is remarkably diverse depending on the different ages of children. Various subgroups have been identified in [61] highlighting the difficulty of designing models that can be adapted to diverse user groups simultaneously, see Table 3.1. Age specific considerations like terminology and interaction styles need to be taken into consideration.

<table>
<thead>
<tr>
<th>Age group</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>The dependency/exploratory</td>
<td>Repetitive sensory motor actions</td>
</tr>
<tr>
<td>stage (ages: 0 – 2 years)</td>
<td>Simple concepts, offer feelings of safety and stimulate learning</td>
</tr>
<tr>
<td></td>
<td>E.g. activity game (buttons, slides, pictures)</td>
</tr>
<tr>
<td>The emerging-autonomy stage</td>
<td>Autonomy develops</td>
</tr>
<tr>
<td>(ages: 3 – 7)</td>
<td>Simplicity, concepts not too abstract</td>
</tr>
<tr>
<td></td>
<td>E.g. fantasy computer games (puzzles, riddles, symbols, animations)</td>
</tr>
<tr>
<td>The rule/role stage</td>
<td>Shift gradually from fantasy to reality, past and future concepts</td>
</tr>
<tr>
<td>(ages: 8 – 12)</td>
<td></td>
</tr>
</tbody>
</table>
3.2. Problem analysis

### Age group Characteristics

<table>
<thead>
<tr>
<th>Age group</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early and late adolescence</td>
<td>Increasingly independent, abstract thinking and logical skills, socially and goal oriented activities</td>
</tr>
<tr>
<td>(ages: 13 and up)</td>
<td>E.g. Adult like products focused on activities like social and sports</td>
</tr>
<tr>
<td>E.g. Laptops and hand-held computing devices with adult like design (complex interfaces, multiple functions per button and nested menus)</td>
<td></td>
</tr>
</tbody>
</table>

Table 3.1: Age groups, or stages of development for children [61].

**The Elderly.** - Research has documented the considerable changes that older adults are undergoing in recent years. These days the elderly people display greater diversity in their cognitive, sensory and motor skills than the younger generation thanks to different exposures to technology, experiences, impairments and social status [58]. Continuous advances in mobile technology has enabled all kinds of mobile devices, in particular smartphones, to be used as tools to attend the needs of the ageing population.

Nevertheless, a number of old age related issues such as slower motor-skill tasks using input devices (e.g. mouse, keyboard, light-pen) and fine motor control tasks (e.g. double-click, drag-and-drop) affect this group of the population making it difficult for them to fully utilize technology. Additionally, the lack of experience with new technology is also relevant [85]. Consequently, the development of applications for elderly people is especially difficult. Table 3.2 summarizes the main issues that this group experience when interacting with technology [41].

<table>
<thead>
<tr>
<th>Category</th>
<th>Issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive Complexity</td>
<td>Cognitive performance slows down with age</td>
</tr>
<tr>
<td></td>
<td>Complex material reduces the ability to perform accurately</td>
</tr>
<tr>
<td></td>
<td>Long-term memory is required to store certain knowledge and procedures</td>
</tr>
<tr>
<td>Motivational</td>
<td>Poor understanding of the benefits that mobile applications offer</td>
</tr>
</tbody>
</table>
Chapter 3. Designing for diversity

<table>
<thead>
<tr>
<th>Category</th>
<th>Issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reluctance to learn new</td>
<td>Reluctance to learn new skills when benefits are not clear</td>
</tr>
<tr>
<td>Low concentration and</td>
<td>Low concentration and tendency to boredom</td>
</tr>
<tr>
<td>Physical Impairments</td>
<td>Age-related illnesses such as rheumatoid arthritis</td>
</tr>
<tr>
<td>Slow response times,</td>
<td>Slower response times, coordination reduction and loss of flexibility</td>
</tr>
<tr>
<td>Fine motor skills</td>
<td>Fine motor skills impairment</td>
</tr>
<tr>
<td>Perception (Vision and</td>
<td>Visual impairment due to ARMD</td>
</tr>
<tr>
<td>Audition)</td>
<td>Audio impairment due to Presbycusis</td>
</tr>
</tbody>
</table>

Table 3.2: Problems of the Elderly [41].

As it has been evidenced, even when considering simply the users’ age, the diversity of the potential users is vast. For this reason, for the AirRespck project the target group of patients has been limited to a portion of all the possible users. Specifically, children are not considered in this project. Table 3.3 shows the age groups that have been taken into account.

<table>
<thead>
<tr>
<th>Group</th>
<th>Ages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adolescents</td>
<td>12 - 18</td>
</tr>
<tr>
<td>Young adults</td>
<td>19 - 39</td>
</tr>
<tr>
<td>Middle-aged adults</td>
<td>40 - 59</td>
</tr>
<tr>
<td>Elderly adults</td>
<td>60 and over</td>
</tr>
</tbody>
</table>

Table 3.3: Age groups considered in the AirRespck project.

3.2.1.2 Technological and written language literacy

Traditionally, mobile technology marketing efforts have been primarily targeted at the developed world. As a result, certain groups of users have been affected by the lack of access to technology, particularly unprivileged users in developing nations. However, this has changed in recent years and the rate of adoption of mobile devices is promising and has been growing steadily [21]. This has attracted the attention of the research community and various projects are undergoing in affected areas with the aim
of closing this gap. For instance, the Indian government is working in rural Indian communities in order to introduce television and radio to increase access to information [72].

Another major problem is the inability to master one’s primary language. Not being able to understand written sources and/or create sentences imposes serious disadvantages in today’s society. In consequence, it is important to develop computer systems with this issues in mind when targeting certain groups of users. One common assumption is to replace written text with visual alternatives such as images and icons. However, it is understood that visual aids work better when accompanied by text descriptions [91]. Moreover, audio notifications can help increasing the rate of comprehension in illiterate users, although its use needs to be controlled in order to avoid confusion (e.g. bimodal audio-visual interfaces) [64].

Research is being carried out in this area and various studies have found that context plays an important part in this group of users. Other subtle issues unrelated to usability affect user interaction, e.g. the reluctance to use touch-screens [54].

### 3.2.1.3 Social and cultural background

Recent reports confirm that both developed and developing nations are participating in the mobile revolution, although at different rates [5, 7, 55]. However, different access and usage exists within and throughout markets. Various factors such as technology, technical and aesthetic design choices, income, marketing, and social preferences affect penetration and usability.

Established UI design models proposed in research are generally conceived for developed societies which contrast with the reality of many emerging markets. Therefore, it is not advisable to reuse these models with populations from the developing world [54]. Moreover, some concepts cannot be transferred easily across cultures. Symbols, colours and even words are interpreted and perceived in different ways across societies. For instance, the stork is seen as symbol of maternal death in Singapore [76]. Likewise, in Japan, four (四) can be read as "yon" (よん) or "shi" (し). The Kanji for death is "shi" (死), which is why the number four is considered unlucky [93]. Other examples include the Christian cross not having the same meaning in non-Christian countries and the number 7 being seen as unlucky in Ghana, Kenya and Singapore.
Furthermore, it has been documented that organized information such as menus should be avoided when designing for users from African countries. “For Africa at least, be wary of interfaces that rely on users’ understanding hierarchically classified data (such as hierarchical menus) – we have found that hierarchies are not a common way of thinking across all cultures.” [47, p. 334].

3.2.2 Technology

The AirRespeck project measures the amount of air pollution inhaled during physical activity using wearable sensors. It is a continuation of two existing mobile applications maintained by the Centre for Speckled Computing: RESpeck and AirSpeck. Both applications were developed for the Android operative system and run on mobile devices such as smartphones and tables. The AirRespeck application is intended to re-implement various of the functionalities of the stand-alone applications.

In general, the Android OS offers two main advantages, ease of development and a relatively big target audience. Flexibility and easy access to development hardware and environment, i.e. Windows (XP or higher), Mac OS X (10.5.8 or higher), Linux (kernel 2.6 or higher), renders it greatly available to almost any developer [31]. Also, widespread familiarity with the programming language used in Android, Java, is another advantage for developers. With regards to market penetration, the Android market share has continuously been growing, especially in emerging markets due to availability and competitive pricing [9].

Nonetheless, the reason for developing the AirRespeck application for the Android OS comes down to the fact that both, RESpeck and AirSpeck were written with this programming language. So, it makes sense to use the same technology in order to smooth out development and allow for reuse of pieces of code that are already implemented.

3.2.3 Activities

Another important understanding that designers need to consider is how user interaction affect the usability of the system. It is important to identify which interactions are the most valuable to the intended users in order to provide a UI that supports the system requirements and user needs [42]. For the AirRespeck project, two main functions
are taken into account, air quality and health monitoring. Both, have already been implemented in previous work related to this project. Although this has been done independently, it may help understanding the user needs.

After examining previous work, the RESpeck and AirSpeck applications, it becomes apparent that the UI suffers from one particular problem: It fails to communicate information to non-technical users in a clear manner. Figures 3.1 shows the main screens for the RESpeck and AirSpeck mobile applications. The information presented appears cluttered and navigation is not always clear. Moreover, the overloading of controls, e.g. buttons and tabs in AirSpeck, is likely to create confusion among users with less experience with technology.

Two main uses for the AirRespeck application are apparent: Monitoring of air quality and the patient’s respiratory rate and flow. In addition, other uses that may appeal to potential users can be found. For instance, the interest in understanding the readings given by the sensors and what are their implications in the user’s health. Also, given the possible correlation between both, air quality and physical activity, this will probably result in changes to the patient’s exercising routings.

![Figure 3.1: RESpeck and AirSpeck main screens.](image)

### 3.2.4 Environment

The context in which a system is used is as relevant as the system itself because it will not be operated in a vacuum. There is a number of factors inherent to the environment that affect user interaction such as the style of life (i.e. rural, urban), social and economic reality, and language. For instance, both technological and written language literacy would be of least concern when designing systems for populations from the developed world. In contrast, citizens from developing nations will be affected by
limited access to education and technology.

In countries with a particularly high density of spoken languages and dialects, language support is important. India in particular exhibits a high concentration of different dialects and literacy issues [42]. Therefore, it is encouraged to use a combination of audio and audio descriptions when providing instructions [51, 58, 71]. This way, users are likely to get used to the UI and memorize the steps needed to accomplish certain tasks through continuous repetition. However, a possible side effect of this approach is boredom and annoyance once users had become accustomed to operate with a particular UI.

The AirRespeck project is aimed to a great diversity of users from various age groups and with different experience with technology. Hence, the scope is defined by the intended users’ age. Age groups defined in Table 3.3 are considered. The environment conditions that need to be taken into consideration respond to the usage of the mobile application by these users.

For this project, three main scenarios were identified: Exercising in recreational areas such as parks, the patient’s home, and commuting road and streets. Initially, subjects come from the developed world. However, it is possible that this project will be extended to other markets including the developing world.

Finally, the application is intended to be used not only by patients but also by researchers.
Chapter 4

Implementation

The objective of this project is to design, implement, and evaluate a retargetable UI for a healthcare mobile application for users from different age groups. The resulting mobile application, AirRespeck, was developed in cooperation with the project Assessing the impact of exercise on personal exposure to air pollution by MSc student Luis Escudero. It brings together work implemented in two previous projects in order to assist monitoring of exposure to air pollution and its impact in physical activities such as exercising.

The UI layout is comprised of various elements which are arranged primarily on the patient’s age. This process is performed when the application is first launched, afterwards changes are allowed through a settings screen. This settings screen contains various configuration options so as to allow patients to customize the UI according to their needs and preferences.

A short introduction to the two existing applications will be given, after which, this discussion will focus in the design process and considerations taken for the UI development.

4.1 Existing applications

AirRespeck extends previous work done in two existing stand-alone projects developed by the Centre for Speckled Computing: RESpeck and AirSpeck. Both applications were developed for the Android operative system and make use of Bluetooth Low
Energy (BLE) to connect to sensors in order to collect live data. This data is used for processing and analysis purposes; it is also presented to users in an informative manner.

### 4.1.1 RESpeck

The objective of the RESpeck application is to measure the patient’s respiratory rate and physical activity levels. In order to do this, the application connects to a wireless accelerometer called *RESpeck* to collects acceleration readings in x, y, and z axis which are used to calculate the respiratory rate and flow of the subject. The RESpeck sensor can be attached to the patient’s chest right below the ribcage with an adhesive bandage.

![Figure 4.1: The RESpeck sensor in comparison to a £2 coin.](image)

While most respiratory methods such as spirometers, nasal cannulas, and thoracic belts are big and obtrusive, the RESpeck sensor is rather small and lightweight offering a noteworthy advantage against other monitoring methods, see Figure 4.1. What is more, the RESpeck sensor can be used by patients to record the respiratory rate at
home without the need for a researcher or physician to be present unlike traditional monitoring approaches.

Important features implemented in this application require some libraries such as Okhttp, Retrofit, Tape, Kotlin. Some of the functionalities from this application that were re-implemented in the AirRespeck project include BLE connection to the RESpeck sensor, calculation of the respiratory rate, real-time uploading of data to the server, automatic checking of updates pushed to an on-line repository.

4.1.2 AirSpeck

The AirSpeck application is a continuation of previous work with AirSpeck devices. Its purpose is to measure concentration levels of suspended PM, temperature, relative humidity, nitrogen dioxide and ozone. This is done by establishing a BLE connection with an AirSpeck device which collects data about particles suspended in the air as well as other readings such as temperature and relative humidity.

Limited availability and low precision of readings are common limitations of conventional air quality monitoring, usually taken by official organizations, [22]. In addition, these monitoring methods require expensive equipment placed at fixed locations. In consequence, various studies are implementing mobile monitors in participatory sensing approaches in order to collect air quality data [20, 22].

The AirRespeck sensor operates in a similar manner, it is a dedicated device that offers portability and real-time measurements of air pollution. The prototype version used in the AirRespeck project is small enough to be carried in a small running satchel belt, see Figure 4.2. The main feature that was re-implemented in the AirRespeck application is the BLE connection to the AirSpeck sensor.

4.2 The combined application: AirRespeck

The AirRespeck project was conceived with the purpose of modelling the dosage of air pollution inhaled during physical activity using wearable sensors. This is done by using BLE to connect to two sensors, RESpeck and AirSpeck, in order to collect data simultaneously for processing and analysis. At the same time, the data gathered is uploaded in real-time to a server for storage and further processing.
The UI is configured with different controls and information presentation methods based on the patient’s age. The readings data collected by both sensors are presented to the user in various ways including text and graphical forms. This is done automatically during initial boot-up of the application. However, a settings screen is available to allow further customization so as to satisfy the user’s needs and preferences.

The usage of the system is relatively simple and requires the subject to wear both sensors and start the mobile application before initiating physical activity. The RESpeck is attached to the patient’s chest, below the ribcage, with a sticking plaster. The AirSpeck can be worn in any running belt or small bag. Upon starting the mobile application, it will connect automatically with both sensors after a short period of time. A message will be displayed when the connection is completed and information will be displayed on the mobile device screen and data streaming to the server will start.

The AirRespeck application is the product of two projects. The first project, Assessing the impact of exercise on personal exposure to air pollution is concerned in modelling the dosage of air pollution inhaled and its impact in exercising; and the present project, Retargetable User Interface for Health Effects of Air Quality which is aimed at retargeting the UI for healthcare mobile applications to a wider audience including users from different age groups. Hence, the development process was carried
out in collaboration with the former project’s author.

4.3 Development

4.3.1 Scope

For this project the scope is limited to user diversity based on age and technological literacy only. Literature and research in HCI, however, evidences that user diversity is influenced by a number of other factors such as context, language, social and cultural backgrounds. Although many of these factors are interrelated among each other, not all of them were considered in this work.

Additionally, due to the high diversity exhibited by children, this group was omitted from this work [61]. It was found, early in the design process, that supporting the UI usability requirements of this group of users would increase significantly the complexity of the UI design process.

Nonetheless, the mobile application developed provides limited support for users with special needs. For instance, icons and other graphical methods for information presentation were implemented giving support, up to a extend, to illiterate users. Many other considerations were made and some work remains for future work. Finally, the application includes support for four different languages: English, Spanish, Mandarin (Chinese simplified), and Hindi.

Note 1.- During the development process it was requested the implementation of a functionality to create users in the mobile application on initial boot-up. This feature was added to the AirRespeck application. However, it requires certain web services to send and receive user information to/from the server. As these web services were not implemented in the server, this functionality was disabled.

Note 2.- Initially, the project included the implementation of personalized feedback based on a model for dosage of air pollution inhaled during physical activity. Unfortunately, this feature was not implemented as the dosage model, part of the side project, was not implemented on time. This is the reason why early mock-ups and sketches include this on the main screen.
4.3.2 Tools and set-up

Android Studio\(^1\), the official Integrated Development Environment (IDE) for Android platform development, was employed during the development stage of this project. It is based on JetBrains’ IntelliJ IDEA software and was created in order to replace Eclipse Android Development Tools (ADT) as Google’s primary IDE for native Android application development. There are several reasons for choosing this IDE choice. First, it is designed specifically for Android development. In addition, it offers development flexibility as it is available for the three major operative systems, Windows, Mac OS X and Linux. Finally, it is freely available under the Apache License 2.0.

However, the primary motivation for choosing this IDE is continuity. Both applications, RESpeck and AirSpeck, were developed for the Android operative system. Hence, this has allowed to reuse various functionalities in the AirRespeck project. Moreover, the affordability and compatibility of mobile devices compatible with the Android platform ensures flexibility for potential patients to use the application.

In order to provide a rich featured application and meet the requirements of the AirRespeck project, a number of libraries have been used. Libraries used in the RESpeck application include Okhttp, Retrofit, Tape, and Kotlin. From the AirSpeck application the following libraries were re-implemented: Gson and MPAndroidChart. Other additional libraries were also used such as Active Android, Google Play services.

Finally, a GitHub repository\(^2\) was created in order to allow source code management and Version control, and facilitate distributed development between the two projects’ authors involved in the AirRespeck development. This, will also contribute to the continuation and further development of the AirRespeck project.

4.3.3 Methodology

During the design process for the UI implemented in the AirRespeck project, considerations from two design approaches were followed. A Scenario-based approach which requires specifications of the users and their needs within a specific scenario; and a Holistic Design which makes use of visual representations to model tentative UI designs.

---

\(^1\) Android Studio website: https://developer.android.com/studio/index.html

\(^2\) https://github.com/specknet/air-respeck
4.3. Development

First, we consider possible scenarios where potential users interact with the application in order to identify the steps required by a user during interaction. At the same time, possible usability issues are annotated as they are discovered. Even though detailed descriptions of the interaction between the user and the system is preferred for higher accuracy when recognizing usability issues in the scenario specification, this requires longer periods of time and adds extra complexity to the design process. Therefore, in this project we have employed simplified scenarios only.

Second, we elaborate mock-ups or sketches of various alternative UIs in order to obtain feedback from potential users and implement refinements in the proposed designs. This is implemented as a series of cycles where the result of each single loop becomes an input to the following loop. The purpose of this is to reduce developing times while improving the UI. After a number of cycles, the final UI design will be eventually found. This evolutionary approach should ensure that heterogeneous user feedback will be considered from the very beginning of the project development.

### 4.3.4 Scenarios and mock-ups

As discussed previously, there are several factors that affect user interaction with a system. Consequently, a large number of possible scenarios can arise depending on age, technological literacy, written language literacy, social background, cultural background, etc. For the AirRespeck project, the user’s age has been considered as the main factor for designing the UI. However, other factors are briefly discussed and some limited support is given in the application.

#### 4.3.4.1 Scenarios

First, taking into consideration only the functionalities that the sensors provide, three main scenarios have been identified:

1. When the system is used primarily as a health monitor. In this case, patients stay mostly at home performing typical activities, that are not physically demanding, such as sitting, resting, or walking. The patients are concerned about their health and want to keep track of the respiratory rate and activity levels only.

2. When the system is used mainly as an air quality monitor. Here, users are active
and are likely to walk on nearby neighbourhoods and streets in the local town or city depending on their usual daily life. The users are interested in air pollution in order to avoid certain polluted areas perhaps due to health concerns.

3. When the system is used to keep track of both air quality and health readings. This is probably the most interesting case. In this scenario, users perform demanding physical activities like exercising. The users are aware of the adverse health effect of air pollution in human health. Thus, their interest is to get a detailed overview of air pollution in neighbouring areas where they exercise and commute in general such as parks, roads, and streets.

Next, the patient’s age is taken into consideration. Subsection 3.2.1.1 gives an introduction to the diversity found in users from different age groups. Four age groups, detailed in Table 3.3, are considered in this project. Out of these groups, the elderly raises the most concerns in terms of usability. There are several reasons for this such as issues with the cognitive, sensory and motor skills [17, 41, 71]. What is more, other factors affect UI usability, and interaction with technology in general, in this particular group such as previous experience with technology [58].

Before further analysis, and due to the time constrains of this project, a review on recent and current research in usability issues was conducted in order to accelerate the analysis phase and identify common difficulties experienced by the different age groups considered in this project. Literature and numerous studies in HCI have been carried out producing valuable insights and providing suggestions on this topic. Table 4.1 summarizes the most common issues and recommendations given to address them.

<table>
<thead>
<tr>
<th><strong>UI feature</strong></th>
<th><strong>Issues</strong></th>
<th><strong>Recommendations</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Navigation</strong></td>
<td>Difficulty understanding organization and hierarchy</td>
<td>Display the application’s main menu options in all screens [58]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Display all the application’s options in the home screen [17]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Use the back/home button as a safe point of return [17]</td>
</tr>
<tr>
<td><strong>Complex menus</strong></td>
<td></td>
<td>Use simpler menu structures e.g. one-level navigation [51, 58]</td>
</tr>
<tr>
<td><strong>Visual impairments</strong></td>
<td></td>
<td>Provide instructions in audio and text [51, 58, 71]</td>
</tr>
</tbody>
</table>
## 4.3. Development

<table>
<thead>
<tr>
<th>UI feature</th>
<th>Issues</th>
<th>Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interaction</td>
<td>High information density</td>
<td>Use fewer screens [7]</td>
</tr>
<tr>
<td></td>
<td>Difficult operation due to limited motor skills</td>
<td>Increase spacing between buttons [85]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Use big buttons [7, 85]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Use fewer buttons [85]</td>
</tr>
<tr>
<td></td>
<td>Accessing controls hide the screen</td>
<td>Place buttons at the bottom of the interface [58]</td>
</tr>
<tr>
<td></td>
<td>Side buttons pressed accidentally</td>
<td>Add spacing between buttons and screen borders [85]</td>
</tr>
<tr>
<td></td>
<td>Fixed size UI controls</td>
<td>Implement scalable UI elements e.g. considering screen size [58]</td>
</tr>
<tr>
<td>Text</td>
<td>Visual impairments</td>
<td>Use bigger font sizes [58, 71, 85]</td>
</tr>
<tr>
<td></td>
<td>Naming difficult to understand</td>
<td>Take users vocabulary and context into account [58]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Avoid ambiguous terms [3, 58]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Avoid metaphors [58]</td>
</tr>
<tr>
<td>Visual design</td>
<td>Icons difficult to understand</td>
<td>Add text descriptions [58, 91]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Use distinguishable colours for different icons [58]</td>
</tr>
</tbody>
</table>

Table 4.1: Common UI issues and recommendations.

In the case for the adolescents group, with ages between 12 and 18 years old, findings suggest that the characteristics of this specific age group match abilities and preferences of adults, i.e. Young adults (19–39 years old) and Middle-aged adults (40–59 years old). Specifically, adolescents of 13 years old and over start exhibiting adult like behaviour focusing interest in social and goal oriented activities such as sports and school clubs and societies [61]. See table 3.1.

Therefore, for this project UI design was simplified and two main design alternatives are proposed: A basic UI for non-experienced users and an advanced UI for experienced users. The first one being targeted at the elderly group and the second one aimed at the other groups of users. Nonetheless, users from any age group will have access to a settings screen where UI customization is available.
4.3.4.2 Mock-ups and sketches

For this phase of the design process some considerations were made in order to determine the number of rounds or cycles to be executed. First, due to the characteristics of this project and the limited time available for design and development, a review of recent research in the field of HCI was carried out to identify common usability issues and consider the suggestions given while decreasing time required for analysis and design. Hence, it was determined that two rounds would be performed in addition to an initial sketch for brainstorming purposes.

**Initial sketch for the basic UI**

In the initial sketch for the basic UI, the focus of the design was placed primarily in the main functionalities of the AirRespeck mobile application, i.e. respiratory rate and air quality monitoring. In this early design buttons are located in the bottom of the screen to avoid the user blocking the view area of the screen when interacting with the controls. Also, the buttons feature both, icons and text, as suggested in previous studies [58]. Information is presented in simple text. See Figure 4.3. However, there is a high information density and buttons are too close to each other [7, 85]. This introduces usability problems for users with motor skill disabilities and it is likely to lead to confusion. These issues are addressed on the first round of mock-ups.

![Initial sketch for the basic UI](image)

Figure 4.3: Initial sketch for the basic UI.

Following, for the first round of mock-ups two alternative UIs were produced: Basic and Advanced. With the basic UI having two variants with different information presentation styles i.e. data collected by sensors.
Basic UI: Version A

In this alternative fewer controls were used allowing for bigger buttons with more spacing between them in order to suit the needs of users with motor skills problems. There are simply two menu options available, i.e. Home, Settings. Taking advice from other studies, functionality was reduced to fewer screens in order to avoid disorientation [17]. The Home screen shows the most relevant values provided by the sensors: Respiratory rate, PM10, and PM2.5. The Settings is intended to contain various configurations options.

Also, other suggestions from previous studies were taken into consideration such as large font sizes for users with limited vision capabilities. The information is presented in a list with all the readings taken by the sensors. The advantage of this style is that all the readings are visible at the same time, see Figure 4.4.

![First mock-up for the basic UI: Version A features a list view.](image)

Basic UI: Version B

For this variant navigation remains the same with two buttons for accessing the Home and Settings screens. Buttons are big and there is sufficient spacing so that users not experience erroneous input when interacting. Information content also stays similar with the same readings being displayed. It, however, offers a different style of information presentation which permits even bigger font sizes. Data collected by the sensors is presented in a cyclic-like fashion. The user can navigate through all the readings using two buttons located on the sides to move left or right, see Figure 4.5.
A possible drawback of this version is that some users may feel disoriented when navigating through the readings as no indication of how many values are available. A solution could be adding a sort of visual paging in order to indicate the number of items available and the current position of the reading on display.

**Advanced UI**

The advanced UI, for experienced users, features more options and screens with additional information such as complete readings from the air pollution sensor and charts. There are small but important differences between the basic and advanced UIs. First, the buttons in the advanced alternative are considerably smaller and there is little spacing between controls. See Figure 4.6. This is a side effect of the need to accommodate more menu options. Moreover, text description in the buttons are affected and become smaller. Although most users will not be affected by this, Middle-aged Adults are likely to experience some difficulties identifying controls as ARMD progress [41].

In addition, there is a sense of high information density similar to the initial sketch, Figure 4.3. This, however, is not expected to be a major concern as this alternative UI is aimed at users with previous experience with technology. Finally, additional screens with detailed data about the sensors’ readings are available.

**Discussion**

The first round of mock-ups was followed by analysis and usability considerations which led to a number of changes for the next iteration of the UIs. Overall, the mock-up...
ups generated during this round contained some correct design decisions due to the preceding literature review that was conducted. However, some issues were evident as well.

First, the format used for presenting information seems to be difficult to read for non-experienced users due to unfamiliar terms. Also, the absence of any sort of scaling hinders the understanding of the values presented. Therefore, graphical approaches were explored. The priority of the various menu options was reconsidered and changes were made. In particular, the Settings button was removed in order to accommodate access to more relevant screens. Various changes in naming were also made.

### 4.3.5 Final UI designs

For the next round, various changes were introduced as well as some new additions with the purpose of improving usability. The most important changes were related to navigation and information presentation.

Even though the font sizes used were appropriate in terms of readability, the information presented was not understandable. The reason being the lack of any sort of scaling system and unfamiliar terms. Therefore, different graphical presentation methods were implemented such as segmented bars and semi-circular gauges. This encouraged the use of colour coding in order to enhance the UI and user experience [25, 65].

**Segmented bar.-** The first graphical alternative offered is a horizontal bar with various
sections according to a given scale. Each segment has a different colour which conveys a better understanding of the reading value being presented. A western colour convention was implemented [60].

**Semi-circular gauge.** The other alternative available is a semi-circular gauge which allows for different colours as well. The reading value presented is bigger and the units of the value is placed at the bottom with a smaller font size. See Figure 4.7.

![Segmented bar and Semi-circular gauge for displaying temperature.](image)

**Figure 4.7:** Segmented bar and Semi-circular gauge for displaying temperature.

In terms of navigation, the Settings menu option removed in order to accommodate a button to access the Air Quality screen. This is because the Settings option is used less frequently and therefore it is not necessary for it to be visible all the time. Access to the Settings screen is now located in the top right side of the interface.

**Basic UI**

For the final basic UI design various considerations were made in order to overcome most of the common usability issues experienced by non-experienced users. This design targets specifically the Elderly Adults group and implements a number of suggestions from previous research about usability for old adults.

Important features include navigation with big controls and information presentation in a graphical manner. Also, the number of screens (or categories) has been reduced to two, Home and Air Quality, to avoid confusion. The Home screen was designed to be simple and present the most relevant sensor readings in one place: Respiratory rate, PM2.5, and PM10. On the other hand, the Air Quality screen is intended for users who are interested in monitoring all the readings provided by the AirSpeck sensor. See Figure 4.8.

Characteristics of this design include:

- Big controls
• Controls are always visible
• Buttons with icons and text descriptions
• Sufficient spacing between buttons
• Few screens/categories
• Big font sizes
• Graphic presentation of the data

![Image of basic UI design](image)

**Figure 4.8: Final design for the basic UI.**

**Advanced UI**

The alternative UI design for experienced users offers similar functionalities as the basic design. However, various UI elements were organized differently and the navigation provided functions in a distinct fashion as well. See Figure 4.9. In terms of navigation, the buttons were replaced with tabs without icons in order to free screen space. This, however can be changed in the *Settings screen*. Navigation can also be done via swipes from left to right or vice-versa. For information presentation, lists are being used but this can also be changed through the *Settings screen*.

Finally, an additional screen was added, the *Graphs screen* with the purpose of presenting relevant data collected by the sensors in charts. This is likely to appeal to advanced users interested in details or researchers when studying the data gathered. Three different charts are available: PMs, Bins, and Respiratory curve.
Figure 4.9: Final design for the advanced UI.
5.1 Objective

The main objective is to assess the usability and information presentation of the proposed UI with users from different age groups and technological literacy. The information gathered about user interaction and feedback from subjects will be analysed with the purpose of gaining a better understanding on UI design for healthcare mobile applications with special emphasis placed on users’ diversity. The results obtained are expected to contribute to the research community when designing UIs for mobile devices.

A common understanding in HCI literature is that “there is no design that fits all” [58, 61]. Although this asseveration holds true due to user diversity, in this work it is argued that a retargetable UI may be possible by identifying key UI features and implementing a design offering multiple UI configuration options. This way, the system will be able to support the needs of users from different age groups.

5.2 Data collection

5.2.1 Subjects

For evaluation purposes, a total of 16 subjects were employed, 7 female and 9 male users, with a distribution of four subjects per age group, see Table 3.3. The 16 partici-
pants come from different backgrounds and exhibit a diverse technological literacy. All of them have previous exposure to computers and mobile phones although in varying degrees. Also, about 50% of the subjects are Spanish speakers, a language supported by the AirRespeck mobile application.

Additionally, the experiments were performed during short meetings held near the subjects’ homes or at their residences in order to procure a familiar environment.

5.2.2 Methodology

Data collection was performed during 25 minutes long sessions comprising of various phases using individual interviews, timed exercises, and questionnaires. The experiments were conducted using a Samsung Galaxy Tab 4 tablet with a 7” screen or a Moto G (2nd generation) with a 5” screen, both devices running Android Lollipop 5.1.1. Each session was organized as follows:

1. **Introduction** Small introduction to the project, its objectives, and the different steps of the experiment.

2. **First questionnaire** The subject is asked to complete questionnaire A.1. This questionnaire contains several questions aimed at identifying the subject’s capabilities with technology and what are their priorities for using mobile devices. This is done before interaction with the mobile application.

3. **Introduction to AirRespeck** Next, the subject is introduced to the AirRespeck application. The application different features and options are explained and the subject is showed how to use the application.

4. **Timed tasks** After familiarization, the subject is requested to complete a series of timed tasks A.3. This step is aimed at evaluating navigation through various tasks which require the subject to navigate and find different screens. The participant was also required to look for an specific reading value, chose in a randomly manner, in different screens. In this step, we are concerned about navigation, information presentation and user interaction with the application.

5. **Second questionnaire** Finally, the subject is asked to complete questionnaire A.2. This is in order to obtain feedback about the UI.

In addition, a series of informal interviews were carried out during the UI design.
5.3. Data analysis

5.3.1 Technical skills

Overall, most of the subjects showed an interest in technology with six participants (37.50%) stating to be Moderately interested and another three subjects (18.75%) claiming to be Very interested in technology. When questioned about the time it takes them to use new technologies, six subjects (37.50%) answered About average and four (25%) said Faster than most people.

However, when taking into account age, Figure 5.1 shows that the Middle-aged adults group shows the most diversity, this is to be expected as different experiences and backgrounds allow for more variety. What is interesting to notice here, is that the Adolescents group show only About average and Faster than most people when this age group is traditionally expected to be highly confident using technology [3]. This is a limitation of the present study as there are numerous factors that have not been considered.

Figure 5.1: Self-estimated time taken to use new technologies.
As discussed before, various factors are known to affect skills with technology. Age, as expected, plays an important role when defining the subject’s background. This is due to various factors that can be roughly grouped into two categories: Environmental factors such as previous experience with technology, social and cultural backgrounds; and Psychological factors like motivation, intimidation, apprehension, or even shyness when interacting with the application [41].

During experimentation, some participants from the *Middle-aged adults* and *Elderly adults* groups in particular were affected by some psychological factors such as intimidation by new technologies and lack of motivation to use the application. The lack of experience is definitely a factor here. It is possible that this issues could have been avoided by allowing for a longer period of time for familiarization with the mobile application. Also, a lack of a *fun* element was noticed as will be discussed later in this section. Including any sort of entertaining task during experimentation could have helped these subjects to perform better [54].

On another note, the data collected also showed that the Android OS is the preferred platform and the one most users are more accustomed to work with (see Figure 5.2). This is evidently the result of the high availability of mobile devices powered with the Android OS and supports the development decisions made for this project.

**Figure 5.2: Technological skills with different mobile OSs.**
5.3.2 Information presentation

As finding relevant information is one of the most important needs of users, it is important to assess this UI facet. The application offers different methods for information presentation, discussed in Subsection 4.3.5, each with different characteristics. Results, evidence that most subjects, about 62.50%, preferred visual representations of data. Figure 5.3 shows that eight (50%) and two (12.50%) participants preferred the Segmented bar and Semi-circular gauge respectively, while only two subjects (12.50%) preferred a Text list.

Figure 5.3: Preferred information presentation method.

In this context, it is important to mention that language is another important factor when trying to convey information to users from different backgrounds. Correct choice of terms and translation will affect how well the subjects can understand the information presented.

As indicated before, near 50% of the participants are native Spanish speakers with varying levels of English proficiency. As the application supports four different languages, including Spanish, no significant issues were found during the tests. Only minor problems with technical terms, specifically some air quality values.
5.3.3 User interaction

During experimentation, the participants performed various timed tasks in order to evaluate their interaction with the UI. The subjects were presented with both alternative UIs: Basic and Advanced. The task completion time was measured in seconds (s) with an error margin of about +/- 1–2 seconds. The average task completion time is used for plotting all charts in this section.

**Basic UI**

Based on the data collected, there were not significant variances in the task completion times for participant from the Adolescents and Young adults groups with times staying below 5 seconds. On the other hand, completion times for the Elderly adults group was higher with an average of 13.8 seconds as shown in Figure 5.4.

This group performed relatively well in navigation tasks being 10 seconds the average time taken. Interpreting the information given in the Graphs screen show to be the most challenging task. However, this screen is not supposed to be available to users from this specific age group but rather for advanced users or researchers. It was included here only for completion reasons.

![Diagram showing task completion times](image)

**Figure 5.4: Average task completion time on Basic UI.**
5.3. Data analysis

Advanced UI

In contrast, when inspecting the data collected for the interaction with the advanced UI no significant differences are found for the younger subjects, Adolescents and Young adults with task completion times staying within the error margin (+/- 1–2 seconds). On the other hand, participants from the Elderly adults group experienced more difficulties requiring more time to complete the tasks increasing from an average of 10 seconds in the Basic UI to 15 seconds in the Advanced UI.

There are no surprises here, the UI configuration for the Advanced alternative differs from the Basic one, specially the controls implemented. A particularly common issue observed was some motor skill problems when using the devices touchscreens.

![Figure 5.5: Average task completion time on Advanced UI.](image)

Now, we examine the data collected for the Elderly adults group. Subject S16, who belongs to this group, presented particularly limited motor skills capabilities due to advanced age. Figure 5.6 shows the task completion time for subject S16 and the average task completion time for subjects S13, S14, and S15 also part of this group. For navigation tasks (i.e. navigating through screens) subject S16 takes a longer, an average of 7.25 seconds, time than the other subjects (S13, S14, S15). This can be explained by this subject’s motor skill disabilities. In contrast, when looking at tasks that require the subject to find and identify specific values, the difference in the time taken drops considerably to an average of 2.58 seconds. Hence, we can say that information presentation was not an issue for this subject.
Figure 5.6: Task completion times for subject S16 and average of subjects S13, S14, S15 on the BasicUI.

**Settings screen**

The subjects were also prompted to perform changes in the UI through the *Settings screen*. The results show that overall the *Adolescents* group performed well with an average of 7 seconds. Participants from the *Young adults* and *Middle-aged adults* groups expended similar times taken to complete the tasks. Subjects from the *Elderly adults* group performed better in certain tasks, specifically changing the font size and the way readings are presented.

**5.3.4 Feedback**

Finally, data collected shows that overall the subjects feel comfortable using the mobile application. In Figure 5.8 we can see that around 47% of the participants felt that the application was easy to use though that the pollution information is useful. Another 33% said that it is easy to find different elements in the application. Nonetheless, there are two concerns, 47% of the subjects answered *Neutral* when asked whether they remembered how to used the application. Memory retention and lack of practice are the issues here. In addition, 73% of the participants stated *Neutral* when questioned if the application was fun to use. This is clearly a problem for engaging users who otherwise are likely to stop using the application after initial introduction.
Figure 5.7: Average task completion time on Settings screen.

In regards to specific elements from the UI, Figure 5.9 shows that 80% and 67% of the subjects strongly agreed on the controls being easy to use and the information presented being understandable respectively.
Figure 5.8: Subjects’ feedback on the mobile application.
Figure 5.9: Subjects’ feedback on the UI.
Chapter 6

Conclusions & Future work

This thesis explored the novel idea of implementing a retargetable UI for healthcare mobile applications, specifically health effects of air quality. With this purpose, various UI design approaches in HCI literate were reviewed. Numerous factors and common issues that affect usability and user interaction with the UI in mobile devices were identified and the AirRespeck application was developed in cooperation with the side project Assessing the impact of exercise on personal exposure to air pollution.

In order to better understand the usability, information presentation, and user interaction with the mobile application developed, various sessions were conducted with a group of 16 subjects from different age groups. The participants were asked to complete questionnaires and perform a series of tasks.

Results show that younger users generally do not have issues when interacting with UIs even when they are not familiar with a given system. However, information presentation was an issue specially with users from non-technical backgrounds or not interested in technology. Older users performed relatively well when interacting with the Basic UI contrasting with a reduced performance using the other alternative, the Advanced UI. However, the configuration options allow them to modify specific elements of the UI. The feedback given shows that participants are in general satisfied with the design.

An interesting finding was the impact that psychological factors such as have on interaction. This can be attributed to the lack of experience with technology. Although during evaluation this was observed only on some subjects from the Middle-age adults and Elderly adults groups. It is likely that younger users experience similar issues, for
instance illiterate or users from developing countries with restricted access to technology.

As for the UI implemented, we can say that it is retargetable up to an extent. Age is considered and the UI adapts accordingly presenting the relevant elements i.e. buttons or tabs, different font size, etc. Additionally, users are able to further customize the UI appearance in the *Settings screen*. However, the limited interaction time dedicated for experimentation somewhat hinders these findings.

Overall, we can conclude that the key UI features that play part in a retargetable UI can be grouped into two categories:

**Information presentation** The way information is presented to users is one of the most important aspects of any UI. Data must be clear and understandable taking into consideration naming, terms, language, proper translation, and cultural background. Data presentation such as temperature readings should be presented in context and include additional aids e.g. scale and colour coding.

**User interaction** How users interact with the UI is also an important issue. Controls should be presented according to specific user needs allowing for a variety of different inputs such as buttons with different sizing and spacing n between, menus with simple structures.

In future work, it will be interesting to expand the scope of this project in order to include more factors that influence usability and user interaction. Unfortunately, due to time constraints this project is limited in terms of the scope considering only age and technological literacy. Also, it could be useful to add an initial configuration tutorial where users are given a walk-through of the available configuration options and asked to choose the preferred one. This was discussed during the design process but due to time limitations was not implemented in the mobile application.

Regarding the UI design process, the adoption of user centred design practices could greatly improve the UI efficiency and development process by involving actual users into the design process. This, however, will require access to users from diverse backgrounds which may not be feasible.

Finally, during this project some stability issues were experienced with the Bluetooth connection with the sensors i.e. latency and lagging discovery and connection times. The cause of this are some well-known issues with BLE implementation for An-
droid due to poor standardization across Android devices. As a result, user experience may be affected due to users having to wait for long periods of time.
Glossary

**Active Android**  ActiveAndroid is an active record style ORM (object relational mapper) to save and retrieve SQLite database records without SQL commands [69]. 28

**Bin**  Particulate matter data collected by sensors is divided into virtual bins based upon size. 37

**GitHub**  GitHub is a web-based Git repository hosting service. It offers all of the distributed revision control and source code management (SCM) functionality of Git as well as adding its own features. Website: https://github.com. 28

**Google Play services**  Google Play services provides access to various Google-powered features such as Maps, Google+, and more, with automatic platform updates distributed as an APK through the Google Play store [33]. 28

**Gson**  Gson is a Java library that can be used to convert Java Objects into their JSON representation [34]. 28

**Kanji**  Kanji or kan’ji, are the adopted logographic Chinese characters (hànzi) that are used in the modern Japanese writing system along with hiragana and katakana. 19

**Kotlin**  Statically typed programming language for the JVM, Android and the browser [45]. 25, 28

**MPAndroidChart**  A powerful Android chart view / graph view library, supporting line- bar- pie- radar- bubble- and candlestick charts as well as scaling, dragging and animations [44]. 28
Okhttp An HTTP & HTTP/2 client for Android and Java applications [80]. 25, 28

Presbycusis  Presbycusis (also spelled presbyacusis, from Greek presbyς ”old” + akousis ”hearing”), or age-related hearing loss, is the cumulative effect of aging on hearing. 18

Respiratory rate  The rate at which breaths occur, usually measured in breaths per minute, is called the ventilation rate or the respiratory rate. 33, 36

Retrofit  Type-safe HTTP client for Android and Java [82]. 25, 28

Tape  A lightning fast, transactional, file-based FIFO for Android and Java, [81]. 25, 28

Version control  Version control, also known as revision control or source control, is the management of changes to documents, computer programs, large web sites, and other collections of information. 28
Acronyms

**ADT** Android Development Tools is a Google-provided plugin for the Eclipse IDE that is designed to provide an integrated environment in which to build Android applications. 28

**ARMD** Age-related macular degeneration is a medical condition which may result in blurred or no vision in the center of the visual field. 18, 34

**BLE** Bluetooth Low Energy is a wireless personal area network technology designed and marketed by the Bluetooth Special Interest Group aimed at novel applications in the healthcare, fitness, beacons, security, and home entertainment industries. 23, 25, 52

**CO** Carbon monoxide (CO) is a colourless, odourless, tasteless, poisonous gas produced by incomplete burning of carbon-based fuels, including gas, oil, wood and coal. 5

**HCI** Human–computer interaction researches the design and use of computer technology, focusing on the interfaces between people (users) and computers. Researchers in the field of HCI both observe the ways in which humans interact with computers and design technologies that let humans interact with computers in novel ways [92]. 11–15, 27, 30, 32, 39, 51

**IDE** An Integrated Development Environment is a software application that provides comprehensive facilities to computer programmers for software development. 28

**NO2** Nitrogen dioxide is one of several nitrogen oxides. It has a variety of environmental and health impacts. It is a respiratory irritant which may exacerbate
asthma and possibly increase susceptibility to infections. In the presence of sunlight, it reacts with hydrocarbons to produce photochemical pollutants such as ozone. NO2 can be further oxidised in air to acidic gases, which contribute towards the generation of acid rain. [26]. vi, viii, 76

**NOx** Combustion processes emit a mixture of nitrogen oxides (NOx), primarily nitric oxide (NO) which is quickly oxidised in the atmosphere to nitrogen dioxide (NO2). 5

**O3** Ozone is not emitted directly into the atmosphere, but is a secondary pollutant generated following the reaction between nitrogen dioxide (NO2), hydrocarbons and sunlight. Whereas nitrogen dioxide acts as a source of ozone, nitric oxide (NO) destroys ozone and acts as a local sink (NOX-titration). For this reason, O3 concentrations are not as high in urban areas (where high levels of NO are emitted from vehicles) as in rural areas. Ambient concentrations are usually highest in rural areas, particularly in hot, still and sunny weather conditions which give rise to summer “smogs”. [26]. vi, viii, 5, 6, 76

**PM** Atmospheric particulate matter are microscopic solid or liquid matter suspended in the Earth’s atmosphere. Airborne PM includes a wide range of particle sizes and different chemical constituents. It consists of both primary components, which are emitted directly into the atmosphere, and secondary components, which are formed within the atmosphere as a result of chemical reactions. Of greatest concern to public health are the particles small enough to be inhaled into the deepest parts of the lung. [26]. 2, 5, 6, 25, 37

**PM10** Airborne particles of less than 10 micrometres in diameter [26]. vi, vii, 6, 33, 36, 75

**PM2.5** Airborne particles of less than 2.5 micrometres in diameter [26]. vi, vii, 6, 33, 36, 75

**SOx** Sulfur oxides (SOx) are compounds of sulphur and oxygen molecules. Sulphur dioxide (SO2) is the pre-dominant form found in the lower atmosphere. 5

**UI** The user interface, in the industrial design field of human–computer interaction, is the space where interactions between humans and machines occur. iii, v–vii, ix, 1–3, 11–13, 15, 16, 19–23, 26–40, 43–47, 49, 51, 52
Bibliography


[18] Denning, T., Andrew, A., Chaudhri, R., Hartung, C., Lester, J., Borriello, G., and Duncan, G. Balance: towards a usable pervasive well-


[28] FOR ENVIRONMENT FOOD, D., AND AFFAIRS, R. What is the daily air quality index?, 2016. [Online; accessed 13-August-2016].


[34] Google. Java library to convert java objects into their json representation, 2016. [Online; accessed 10-August-2016].


[43] INGRAHAM, N. Apple’s app store has passed 100 billion app downloads, 2015. [Online; accessed 01-April-2016].


[51] KIVIRINTA, J. The right ui for elderly people; a review of recent and current research, 2013.


[61] **Markopoulos, P., and Bekker, M.** Interaction design and children. *Interacting with computers* 15, 2 (2003), 141–149.


[69] Paro, M. Activeandroid is an active record style orm (object relational mapper), 2016. [Online; accessed 10-August-2016].


[74] Rodgers, A., Corbett, T., Bramley, D., Riddell, T., Wills, M., Lin, R.-B., and Jones, M. Do u smoke after txt? results of a randomised trial of


[77] **Sager, I.** Before iphone and android came simon, the first smartphone, 2012. [Online; accessed 01-August-2016].


[80] **Square.** An http & http/2 client for android and java applications, 2016. [Online; accessed 10-August-2016].

[81] **Square.** A lightning fast, transactional, file-based fifo for android and java, 2016. [Online; accessed 10-August-2016].

[82] **Square.** Type-safe http client for android and java, 2016. [Online; accessed 10-August-2016].


Appendix A

Evaluation questionnaires

A.1 Previous experience with technology

Taken before interaction with the application.

1. What is your age?
   O 12 to 18
   O 19 to 39
   O 40 to 59
   O 60 or older

2. What is your gender?
   O Female
   O Male

3. What is your occupation?

4. How interested are you in technology?
   O Not interested at all
   O Not very interested
   O Somewhat interested
   O Moderately interested
   O Very interested
5. How skilful would you say you are with technology or electronics?
O Not skilful at all
O Not very skilful
O Somewhat skilful
O Moderately skilful
O Very skilful

6. How long does it take you to use new technologies, software, or apps?
O I am hopeless
O Longer than most people
O About average
O Faster than most people
O Immediately

7. How capable are you with the following technologies?

<table>
<thead>
<tr>
<th></th>
<th>Not very capable</th>
<th>Somewhat capable</th>
<th>Moderately capable</th>
<th>Advanced capability</th>
<th>Very capable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computers</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Tablets</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Smartphones</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Mobile phones</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Video game consoles</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>

8. How capable are you with the following Operating Systems for smartphones?

<table>
<thead>
<tr>
<th></th>
<th>Not very capable</th>
<th>Somewhat capable</th>
<th>Moderately capable</th>
<th>Advanced capability</th>
<th>Very capable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Android</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>iOS</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Windows Mobile</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>

9. How capable are you performing the following tasks on a smartphone?

<table>
<thead>
<tr>
<th></th>
<th>Not very capable</th>
<th>Somewhat capable</th>
<th>Moderately capable</th>
<th>Advanced capability</th>
<th>Very capable</th>
</tr>
</thead>
</table>
### A.2. Experience with the application

Taken after interaction with the application.

<table>
<thead>
<tr>
<th>Activity</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Making calls</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sending text messages</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Browsing Internet</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Using social networks</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Playing mobile games</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Listening to music</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Watching videos</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taking pictures</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Installing/deleting apps</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customizing the settings</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 10. Rank in ascending order (1 being the most important and 9 the least important) the reasons why you use a smartphone?

- Work related activities
- To contact family & friends
- To access Internet
- To access social networks
- To access music & video
- To access maps
- To play mobile games
- To take pictures
- To call emergency services


1. Answer the following questions about the mobile application

<table>
<thead>
<tr>
<th></th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Useful pollution levels</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Useful respiratory rate</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>It is easy to use</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>It is user friendly</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>It is easy to learn to use it</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>I remember how to use it</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>I can find things quickly</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>I am satisfied with it</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>It works as expected</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>It is fun to use</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>I am confident using it</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>I will use it frequently</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>I would recommend it</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>

2. Answer the following questions about the user interface

<table>
<thead>
<tr>
<th></th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Display layout is clear</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>I understand the data</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>It is easy to navigate</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Controls are easy to use</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Controls are accessible</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Menu is easy to find</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Text is readable</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Colours are clear</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>It is easy to customize</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Settings are easy to use</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Settings are clear</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Settings are enough</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>

---

\[1\] Based on System Usability Scale (SUS) [84].
A.3 Navigation and interaction timed tasks

Set of timed tasks that the subjects were asked to perform.

<table>
<thead>
<tr>
<th>No</th>
<th>Task</th>
<th>Time taken (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Navigation</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Go to Main screen</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Go to Air Quality screen</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Go to Graphs screen</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Go to Settings screen</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Find value in Main screen</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Find value in Air Quality screen</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Find value in Graphs screen</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Settings</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Change the font size</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Change readings display mode - Main screen</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Change readings display mode - Air Quality screen</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Change menu mode</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Enable/disable icons in Tabs</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Change spacing between buttons</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Enable/disable Graphs screen</td>
<td></td>
</tr>
</tbody>
</table>
Appendix B

Air pollutant scales

B.1 PM2.5

Based on the daily mean concentration for historical data, latest 24 hour running mean for the current day.

<table>
<thead>
<tr>
<th>Index Band</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>µg/m³</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Very High</td>
</tr>
<tr>
<td></td>
<td>0-11</td>
<td>12-23</td>
<td>24-35</td>
<td>&gt;36-41</td>
<td>&gt;42-47</td>
<td>&gt;48-53</td>
<td>54-58</td>
<td>59-64</td>
<td>65-70</td>
<td>71 or more</td>
</tr>
</tbody>
</table>

Figure B.1: Scales used for PM2.5 [28].

B.2 PM10

Based on the daily mean concentration for historical data, latest 24 hour running mean for the current day.

<table>
<thead>
<tr>
<th>Index Band</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>µg/m³</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Very High</td>
</tr>
<tr>
<td></td>
<td>0-16</td>
<td>17-33</td>
<td>34-50</td>
<td>51-58</td>
<td>59-66</td>
<td>67-75</td>
<td>76-83</td>
<td>84-91</td>
<td>92-100</td>
<td>101 or more</td>
</tr>
</tbody>
</table>

Figure B.2: Scales used for PM10 [28].
Appendix B. Air pollutant scales

B.3 O3

Based on the running 8-hourly mean.

<table>
<thead>
<tr>
<th>Index Band</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>µg/m³</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Very High</td>
</tr>
<tr>
<td>0-33</td>
<td>34-66</td>
<td>67-100</td>
<td>101-120</td>
<td>121-140</td>
<td>141-160</td>
<td>161-187</td>
<td>188-213</td>
<td>214-240</td>
<td>241 or more</td>
<td></td>
</tr>
</tbody>
</table>

Figure B.3: Scales used for O3 [28].

B.4 NO2

Based on the hourly mean concentration.

<table>
<thead>
<tr>
<th>Index Band</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>µg/m³</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Very High</td>
</tr>
<tr>
<td>0-67</td>
<td>68-134</td>
<td>135-200</td>
<td>201-267</td>
<td>268-334</td>
<td>335-400</td>
<td>401-467</td>
<td>468-534</td>
<td>535-600</td>
<td>601 or more</td>
<td></td>
</tr>
</tbody>
</table>

Figure B.4: Scales used for NO2 [28].