Sensor Applications

Urban Wellbeing: A Portable Sensing Approach to unravel the link between Environment and Mental Wellbeing

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Abstract—In this letter, we present the development and evaluation of the *Urban Wellbeing* mobile application that employs real-world, momentary assessment of the environment and it's link to wellbeing using multi-model sensor data and self-report wellbeing. Several industry standard environmental sensors comprised of Particulate Matter, Ozone and Nitrogen dioxide, Nitric oxide and Nitrogen oxides as nitrogen dioxide are analysed each hour with the average of them combined and calculated as the Air Quality Index. By using mobile technology and on-board sensors we simultaneously collected for the first time live feed of data such as: the environment type, exact location, image of the environment, level of noise and obtain perceived mental wellbeing, fused at the point of data collection. Through an extensive assessment approach on real-world data, we are able to demonstrate the link between busy, polluted and green spaces and its impact on wellbeing. The results also indicate that in environments whereby air quality is poor and noise is very loud typically participants experience a negative wellbeing.

Index Terms—Mobile sensing, sensors, environment, wellbeing, air quality, mobile applications

I. INTRODUCTION

Exposures to environmental factors (such as Particulate Matter 2.5, noise, and gases) have been shown to significantly impact momentary mental wellbeing [1], [2], [3]. As the population grows across the world it is expected that around 66% of the global population will live in urban areas by 2050 [4]. Currently 91% of people are living in areas whereby air quality guidelines are not met [5].

Literature in the area of smartphone momentary wellbeing assessment using environmental factors is lacking with limited contribution of using objective sensor data. Urban Mind uses a smartphone application to assess the environment through a series of questions [6]. The results highlight the use of a smartphone-based assessment tool to gain a perspective into the natural features within the environment and the impact to mental wellbeing. Prior to this, a 'pen and paper' approach to assessing the Ecological Momentary Assessment of Well-Being were more common in research studies [7].

Sensor-based technologies have the greatest opportunity of understanding the impact of exposure within a range of urban environments [8] as well as understand the impact to individuals through assessment-based questionnaires [9]. These devices are becoming increasingly popular due to their generally low-cost price, availability to capture multiple data modalities in real-time and overall small size to develop into miniaturized electronics [10], [11], [12]. Previous studies using mobile applications have demonstrated highly effective results in classifying mental well-being [2], [3], [13]. To date, most other research studies have focused on fusing after data collection.

To overcome this we have developed *Urban Wellbeing*; a mobile application that fuses the data on collection to help in unravelling the relationship of mental wellbeing in urban environments. For the first time, we present a cross-platform mobile system able to unobtrusively fuse wellbeing states and objective sensor data in the form of environmental factors such as air quality, noise and gain a perspective on the environment through image and location. The aim and contributions of this work are the following:

- Propose a novel approach in the form of a cross-platform mobile system to collect real-world environmental pollution data using industry standard air quality sensors, level of noise, location data and momentary mental wellbeing.
- Demonstrate the effectiveness through a 'in the wild' real-world study with 40 individual assessments made through the application.
- Correlation analysis and map overlay highlight collected variables indicate air quality and the type of environment to directly impact mental wellbeing.

The rest of this work is organised as follows. Section II describes the developed mobile application and sensing variables from each assessment. Section III details results of the experiment and demonstrates the opportunities the app has to quantify the relationship of the environment and mental wellbeing. Section IV concludes the findings of this work.

II. SYSTEM DESCRIPTION

A. Sensing System

Urban Wellbeing is a cross-platform mobile application that aims to bring us closer to understanding the impact of urban environments to mental wellbeing as an interactive assessment tool. The application uses real-world environmental sensor data obtained by using the phone's exact location, collected from the nearest Automatic Urban and Rural Network (AURN) positioned the UK, as depicted at Figure 1.

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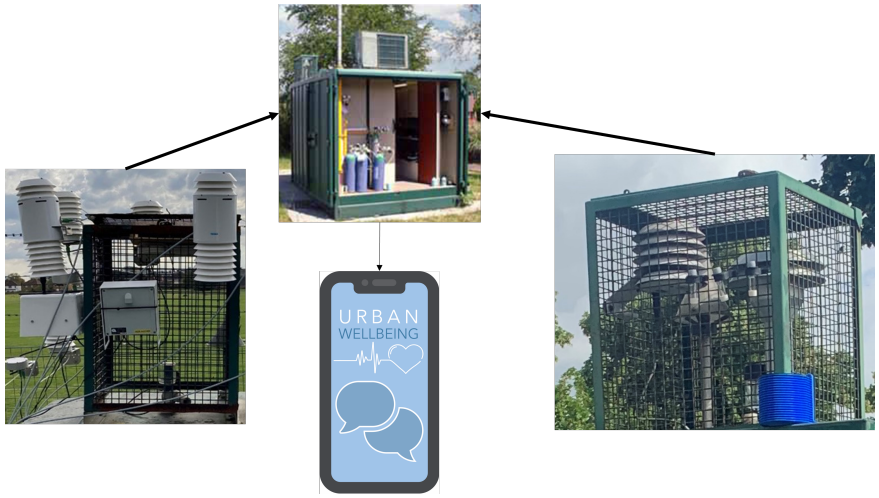

Fig. 1. The process of several environmental sensors within the Automatic Urban and Rural Network (AURN) and feed directly into the Urban Wellbeing mobile application.

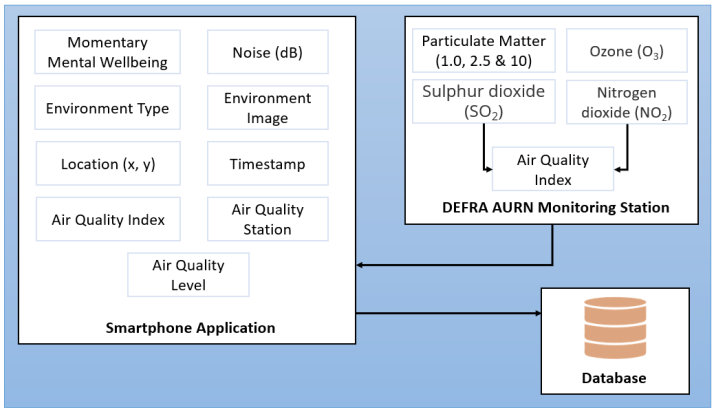

Fig. 2. Combined data collection and processing workflow of Urban Wellbeing involving Smartphone application, AURN Air Quality Index and Database.

These sensors are industry standard and are placed in every City across the United Kingdom with there being around 274 sites [14], which are able to measure a range environmental factors such as Particulate Matter, Non-volatile Particulate Matter, Nitrogen dioxide, Sulphur dioxide, Ozone, Nitric oxide, and then calculates altogether the pollutants as an Air Quality Index [15].

B. Sensing Variables

To obtain real-time environmental data, *Urban Wellbeing* is made up of several on-board and fixed sensors as seen in Figure 2. At each assessment point, there are several sub-processes which include the collection of environmental sensor data from a AURN station (nearest to the participant at the time of the assessment), noise level of surrounding environment, momentary mental wellbeing assessment and gaining information on the type of environment. At the end of each assessment, the collected data is submitted to a database. The following variables and descriptions of each are given below:

1) Momentary Mental Wellbeing: In order to record their perceived wellbeing, we have adopted the 'Personal Wellbeing Index for adults' which asks the user how they are feeling with their life as a whole [16]. This has been adapted in the form of a five-point Likert SAM scale [17] to provide a proven method for self-reporting subjective wellbeing. In our preinstalled mobile app, the user is met with five well-known emojis, displayed on buttons from *1=negative/low* to *5=positive/high* .
2) Environment Type: To understand where the user is located, a question is asked to the user whether they are currently within an inside or outside environment as seen in Figure 1 (b).
3) Location: The GPS coordinates are captured from the phone's actual location in both longitudinal and latitude.
4) Noise (dB): As seen at Figure 1 (e), noise levels are recorded as part of the assessment. This is calculated by recording a series of noise clips in decibels which are collected over a period of 5 seconds.
5) Environment image: Within the assessment the application requests a photograph to be taken by the user which should show the environment that they are standing within, as seen at Figure 2 (d).
6) Timestamp: At the end of the assessment the timestamp is collected from the phone which is an essential variable required when fusing the collected sensor data together.
7) Real-Time Air Quality Index (AQI): The index captures a range of environmental pollutants which is measured either across a full hour, 8 hour or full day intervals. In the case of this work this is comprised of seven industry standard environmental sensors comprised of Particulate Matter, Ozone and Nitrogen dioxide, Nitric oxide and Nitrogen oxides as nitrogen dioxide: There are two ways in which the quality index is calculated which involves either taking the highest recorded value and averaging out the values across a period of time [18]. For Urban Wellbeing, the application obtains the averaged air quality as the index.
8) Air Quality Level: The level is assessed by using the score produced on the calculation of the air quality index. The level is made up of 4 layers consisting of low to very high, with greater the score the more cause for concern that exposure to the environment is likely to cause health concerns.
9) Air Quality Station: The application collects the monitoring

station ID in order to understand where the air quality index and level have come from in the location to where the individual was standing.

C. Experimental Setup

Following ethical approval from Nottingham Trent University's Ethics Committee, between July and November 2022, participants were encouraged to download either the iOS or Android mobile application to their smartphones. Before completing the assessment, participants were presented with an on-screen informed consent which they had to agree to in order to take part in the study. The general idea was for participants to walk around where they live, in any direction they wanted whilst taking the assessment. After a period of time, the app would remind participants to complete an assessment of their wellbeing. In total, there were 40 assessments completed during this trial period.

III. RESULTS AND DISCUSSION

The developed Urban Wellbeing mobile application has been tested "in the wild" across a range of different urban environments to evaluate the performance of quantifying the impact of the environment on momentary mental wellbeing.

We have used a Pearson's R Coefficient Matrix to examine the correlation patterns between environmental sensor variables and mental wellbeing, which is depicted in 3 from which it can be seen that the Environmental sensor data (labelled Air Index) positively correlates (0.2) with noise. In addition, the label correlates negatively (-0.4) with noise indicating that when noise is increased wellbeing is reduced. This is a similar occurrence in other studies [3], [2].

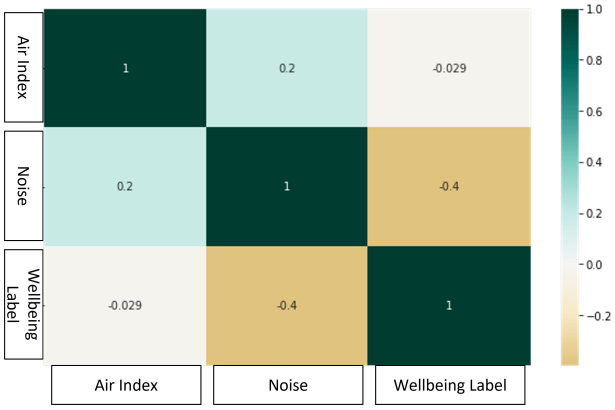

Fig. 3. Correlation Matrix: Comparison of Environmental Factors Vs Physiological

The collected sensing data from the application can be visualised as seen in Figure 4 demonstrating three assessments completed by three independent users across Nottingham, from which it can be seen that at each point, Environmental Air Quality Index level; self-labelled wellbeing; noise level and an image of the environment was collected from the sensors. An Air Quality Index is deemed acceptable when the score is between 0-50 with values of 50-100 becoming more serious for those with sensitive needs to air pollution [19].

The visualisation highlights that when in green spaces wellbeing was labelled positively or very positively and noise was relatively

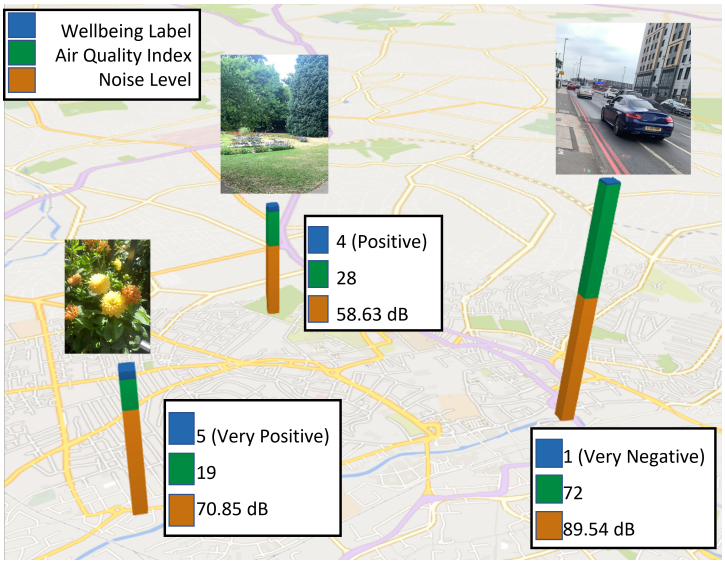

Fig. 4. Graph overlay from three participant's data. Each column represents on location trace tagged with the level of noise, Air Quality Index, self-reported wellbeing label and an image of the current environment.

low and Air Quality was very good (AQI 19 28). In comparison to a very negative wellbeing indicated when Air Quality was poor (AQI 70) and noise high. In other studies, noise has correlated with wellbeing showing that the level can impact how someone is feeling [2], [3]. In addition, previous research on the impact of noise has shown that anything above 80 dB can be dangerous in prolonged scenarios [20]. At each point analysed, it demonstrates that by using environmental sensor data, mental wellbeing is impacted by factors within the environment such as Air Quality, Noise and the surrounding image of an environment.

Figure 5 depicts several images taken from each time a participant completed an assessment where they self-labelled their wellbeing as either very negative or negative.

Fig. 5. Several obtained photographs from the Urban Wellbeing app where wellbeing was self-labelled as 1 (very negative) or 2 (negative) as indicated at each image.

The purpose of obtaining an image in the process was to increase knowledge into the relationship impact between the environment; namely air pollution factors, mental wellbeing and noise. Analysis of the photographs obtained from the mobile app in the scenario of a negative wellbeing show that walking near or close to busy traffic and a congested high street could impact mental wellbeing. In addition, it is worth noting that in these 6 scenes the collected sensing data shows that noise levels were averaged at 85 dB in these locations. On the other hand, further analysis into the photographs taken where wellbeing was either positive or very positive shows individual's in green spaces, free from traffic and noise levels typically lower than 65 dB, depicted at Figure 6.

Fig. 6. Several obtained photographs from the Urban Wellbeing app whereby wellbeing was labelled as 5 (very positive) or 4 (positive) as indicated at each image.

IV. CONCLUSION

In this paper, we demonstrate for the first time a portable sensing and momentary wellbeing assessment tool for the quantification of the relationship between the environment and mental wellbeing through the use of real-world environmental sensor data. The data obtained from 40 assessments shows that when people are in green spaces, wellbeing is labelled either positive or very positively. On the other hand, in busy, polluted and crowded environments wellbeing was labelled as negative or very negatively. These findings and opportunities for greater research in this area have potential implications from the perspectives of mental wellbeing and urban planning and design of green spaces. Using this mobile application in the real-world, we envisage that the real-time sensor data, wellbeing and photograph data could be used in further research studies to understand the impact of environmental factors on mental wellbeing. In the future, an increase of AURN station locations across the UK will further help in understanding the link between environment on mental wellbeing.

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