S3: Environmental Fingerprinting with a Credit Card-sized NFC Powered Sensor Board

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Abstract
People have become more aware about their environment and pay more attention to conditions, *e.g.*, air quality, and UV light exposure. Conventional technologies for reading environmental conditions are expensive, bulky, situated, and do not meet people's need for a mobile and portable tool for environmental fingerprinting on demand. We present a mobile-enabled client-server system for personalized environmental fingerprinting and crowdsourced environmental fingerprint datasets using a smartphone and a portable credit card-sized NFC powered sensor board.

Author Keywords
Environmental fingerprinting; Environment sensing with smartphones; Portable NFC-powered sensors.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (*e.g.*, HCI): Miscellaneous

Introduction
Awareness of environmental conditions such as temperature, humidity, ultraviolet (UV) index, and air quality is on the rise. People have become concerned about these environmental conditions, amid deteriorating global statistics on air quality, global

warming, and UV light exposure. Conventional technologies for reading environmental conditions are expensive, bulky and situated [9] and do not serve people's need. In other words, people are mobile and need portable tools to be aware of their immediate environmental conditions on demand. Smartphones are now widely used [12,13] and endowed with embedded sensors. However, most smartphones lack the sensors needed to collect environmental data such as UV, temperature, air quality and water quality. Smartphones can be supplemented with external sensors via wireless communication channels such as Bluetooth, and Near Field Communication (NFC), which makes it possible to use smartphones for Environmental Fingerprinting. We define Environmental Fingerprinting (EF) as the process by which an entity becomes aware of its environmental context via sensing data in its surroundings.

Related Work

Zhang *et al.* [16] developed a sensing system to fingerprint air quality of urban places and to provide a personalised air quality tool for users. They used an optical sensor device that measures temperature and concentration of dust in the surrounding air. The sensor then transmits the measured data via Bluetooth Low Energy (BLE) connectivity to a smartphone. The smartphone annotates the data with Global Positioning System (GPS) coordinates and time of day. The data was analysed with a machine learning algorithm to predict the air quality of the metro station, and to calculate and visualise health impact index on the smartphone. Fahrni *et al.* [5] developed Sundroid to fingerprint ultraviolet (UV) index for people to be more aware of their UV exposure. The Sundroid application sensed data from a body-worn sensor, over a Bluetooth connection. The UV index data is tagged with geolocation and timestamp and then visualised on the smartphone. Sundroid also notifies users in high UV index environment. Aram *et al.* [1] developed a Bluetooth based sensing system comprising of an electronic circuit board, powered with a 1000mAh lithium battery, and aBluSen, an Android based mobile phone application. To evaluate the accuracy of the sensing system, the sensor was placed in a climatic chamber in a laboratory, where the temperature in the chamber was varied during a three-hour experiment. The results demonstrated that the temperature recorded by the sensing system accurately matched the temperature variation imposed by the climatic chamber.

Smartphone Connectivity to External Sensors

Short-range wireless radio technologies such as Bluetooth and Near Field Communication (NFC) are used to connect smartphones with external sensors [14,15]. In comparison [2,4,10] with NFC, Bluetooth has a longer range of connectivity. However, NFC takes lesser time and often instant to connect devices while Bluetooth may take a much more time to discover and connect devices. The drawback of Bluetooth connectivity, in general, is high consumption of device battery life. NFC on the other hand, consumes less battery power. In NFC passive mode, only one device, for instance, the smartphone (the initiator) needs a power source (*e.g.* battery). This is not the case for Bluetooth connectivity where all connected devices must have a battery or power source.

System Design and Implementation

We designed the Simple Smart Sensor (S3) system as a two-tier client-server architecture system. The client

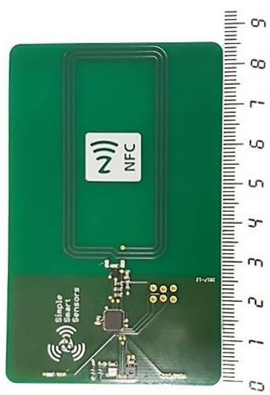

Figure 1. A picture of the NFC-powered SensorCard with a meter rule. The SensorCard is at the prototype stage. The sensors currently on-board the SensorCard are humidity, temperature, UV index and ambient light. More information about the SensorCard could be read at http://slentre.net/s3/

application is an Android application called S3 app, which runs on an NFC-enabled smartphone. The S3 app collects temperature, humidity, ambient light, and UV index data from a credit card-sized NFC powered sensor board named the SensorCard, as seen in Figure 1. The S3 app persists the sensor data to a local SQLite database. An AWARE framework [7] service running in the background periodically synchronises the sensor data to the Server. The server is an AWARE dashboard persisting to a MySQL database.

Scenarios

Juha is a 30-year-old postdoctoral researcher at a university. He needs to collect UV index, ambient light, temperature, humidity, and air quality for his research. With this data combined with local weather data, he can research into how these conditions influences people's work output at the university. He has clear budget constraints and wants to use a crowdsourcing approach. He recruits 40 students and equip them with SensorCards (Figure 1) and smartphones with the S3 app installed. Twice weekly for a period of six months, he can export high quality sensor data annotated with GPS and timestamp, from the server. He can do quality data collection within his budgetary constraints and he is happy to use the S3 System as a tool in his research.

John is a 56 years old industrial worker and asthmatic patient. He is aware that the air quality, temperature, and humidity of his environment influences his asthmatic condition. He needs actionable recommendations and reminders to check the air quality, humidity, and temperature of his environment. With the S3 app and the SensorCard he can now avoid environments that impacts negatively on his condition. John has now seen improvement in his health condition and the number of times he needs to use an inhaler

UI design, Evaluation, and Implementation

We followed a hybrid waterfall and interaction design software development models in the UI design, evaluation and Implementation process. In this process, we first conceptualised the application based on the already developed scenarios. We then translated the scenarios into early paper prototype sketches which were in turn reviewed and transformed into mockup interfaces. Figure 2 shows the UI of the mockup prototype. Next, we recruited 30 participants; 20 males, 10 females, with their ages ranging between 20 to 32 years (mean=25.97, SD=2.85) through a university mailing list for a user study. During the user study, participants were asked to perform three tasks with the mockup prototype. Participants were asked to fill the System Usability Survey (SUS) in addition to an open-ended questionnaire; a) How was the information about temperature/UV/Humidity presented? b) Did you find any part of the application difficult to understand? c) Have you used a similar application before? d) Do you have any feature suggestions for the application?

The analyses of the SUS questionnaire resulted in a score of 84.50, in a scale of 0 to 100. The SUS score indicated participants' satisfaction with the S3 app in terms of learnability and usability. Third, we followed the Grounded Theory [3] approach and used the Atlas.ti[1] tool to analyse the open-ended questionnaire responses with the open coding method.

[1] http://atlasti.com/

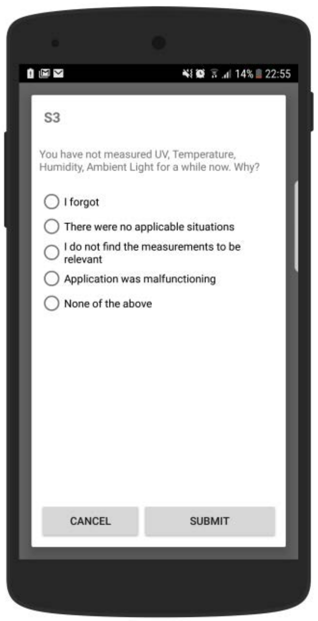

Figure 3. Automated feedback sampling interface.

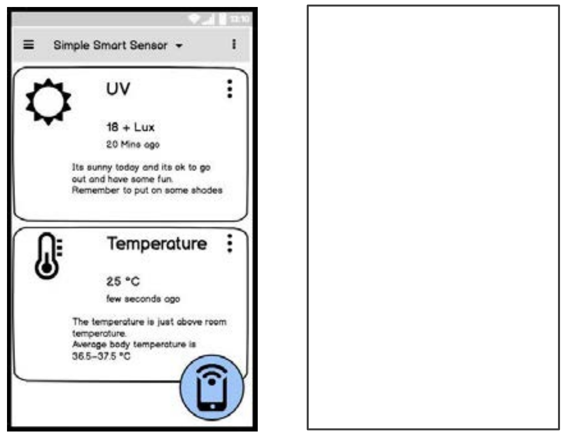

Figure 2. Mockup user interfaces of the S3 app

We read participants responses and indexed the themes into codes. We then semantically connected the codes to result into a conceptual model that presents the themes or concepts in the user study data. The analysis reviewed 3 major concepts; Perception of Use, Ease of Use, and Information Presentation. Figure 4 shows the conceptual model reviewed in the user study data. The results of the qualitative analyses structured the complex user feedback into a much clearer story of user expectations. In summary, participants were familiar with the interfaces of the S3 prototype owing to their experiences with other mobile phone applications. However, participants preferred a simplified and more visualised presentation of sensor values and perceived the textual description of the sensor values, in Figure 2, as too much information and less important. Finally, we developed the functional prototype, taking into consideration the feedback from the user study. Figure 3 and Figure 6 shows the user interfaces of the final developed interfaces of the S3 app.

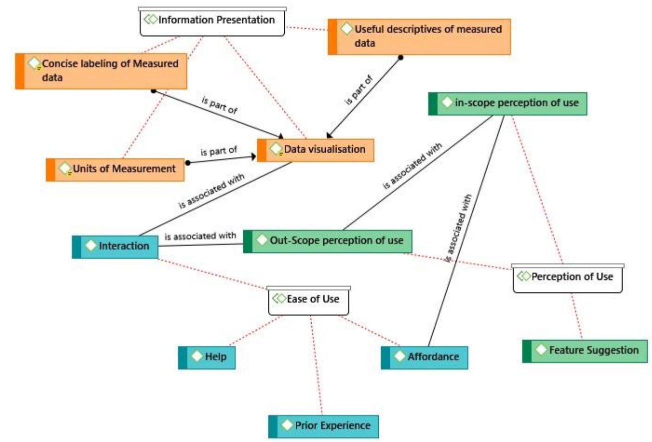

Figure 4. Conceptual model resulting from analysis of user study data

The main interfaces show each sensor data in list of cards. The users just tap the smartphone with the SensorCard to read new data. Other interfaces of the S3 app are user preference settings, help pages and About app.

The Server

The data collected on all devices are synchronised into a MySQL database hosted on the AWARE framework server. The AWARE framework server then essentially becomes a data repository which provides access through MySQL login credentials, which are available on the dashboard. The AWARE dashboard can be configured and hosted on other cloud storages other than the AWARE framework server, for instance, on Google cloud, and Microsoft Azure. Furthermore, system configurations such as how frequent the S3 app synchronises data to the server can be configured from the AWARE dashboard. The new configurations are downloaded unto the device running S3 app the next time they connect to the AWARE server. These server features are available for expert users for example researchers. For everyday users, the S3 app alone serves their needs.

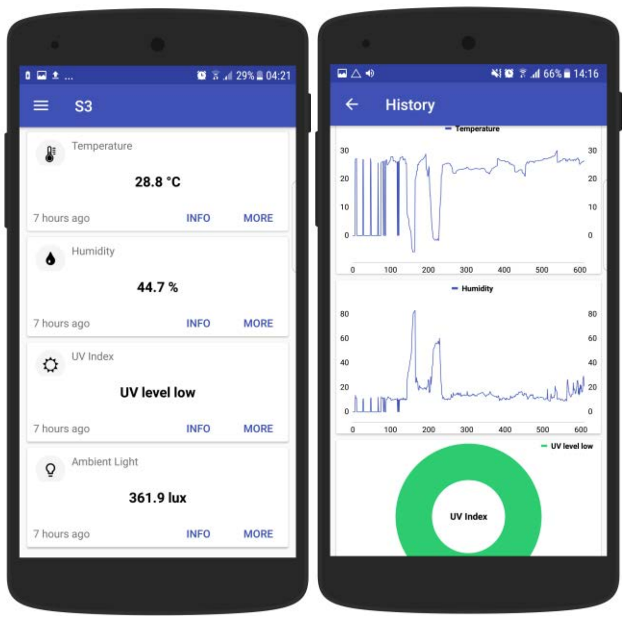

Figure 6. Final user interfaces of S3 app. Main interface on the right and sensor data visualisation on the right

Test Run

To demonstration of the S3 system as a mobile enabled client-server tool for crowdsourced EF datasets, we collected 1,576 samples of UV, temperature, humidity, and ambient light data, both indoors and outdoors of our campus.

Figure 7 shows a user tapping the back of the smartphone with the SensorCard to read data from the card. The sensor data was then exported from the S3 server to a CSV file and plotted in Figure 5. In Figure 5 , the temperature data is in on top of the stack (blue filled), the humidity data is in the middle (red filled) and the ambient light data is at the bottom of the stack (orange filled).

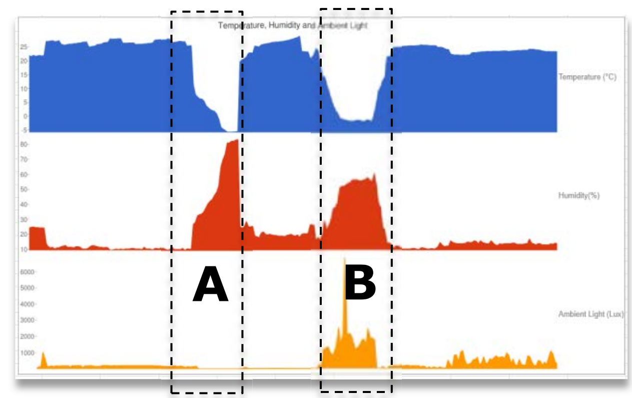

Figure 5. Time series plot of temperature, humidity, and ambient light sensor data. The section labelled A of shows the outdoor data sample collected at dawn, and the section labelled B shows outdoor data collected in the morning

Figure 7. Demonstration of how data is collected using the S3 application and the SensorCard.

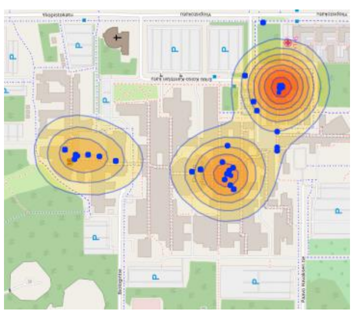

Figure 8. Heatmap of temperature sensor data

Figure 8 also shows the temperature data plotted on a heatmap with the University of Oulu campus as a basemap. The heatmap was drawn with the heatmapper[2] online tool.

Discussion

Current methods of EF require sophisticated, expensive, and stationary infrastructure [1]. Using smartphones for EF breaks these limitations and provides the advantage of a personalised, mobile, and widely used [2, 3] tool EF. Current research efforts in EF generally limits to a specific sensor and uses Bluetooth as means of connectivity, for instance in, [6, 7]. However, one fundamental challenge in using Bluetooth as connectivity for external sensors is the drain on smartphone battery life. Smartphone users are concerned about their battery life [6] , places three times more value on the lower levels to dying battery levels than fully charged levels [8] and tends to turn off Bluetooth at low battery levels [11]. We provide a solution that senses data from a multi-sensor zero power SensorCard via NFC, which significantly reduces the drain on smartphone battery. Similar to [14], we visualise the sensor data and additionally synchronise the data to an online repository. We also implement novel feature for automated feedback sampling feature (Figure 3) to enrich data collection. The feedback questionnaire can be dynamically defined from the server. We identified that since the data sensing process is not opportunistic, users may simply forget to actively use the SensorCard and the S3 application. The incorporated automated feedback questionnaire is used to periodically remind users and enquire about the non-usage of the tool.

[2] http://www.heatmapper.ca/

Conclusion

We have demonstrated a scenario driven process that developed a mobile enabled client-server tool for crowdsourced EF dataset. To the end user the S3 application and the SensorCard is a portable tool for personalised EF. Similarly, the tool will impact on research by providing a viable alternative to conventional tools in EF and data collection for research. The tool also provides a proof of concept for further improvement and deployment into the commercial software market.

Now for future work, the S3 application currently visualises the sensor data but provides limited insights from the data to users. Similar to the solution in [16] a machine learning model could be implemented analyse the sensor data, to provide further insight to users . The SensorCard and the S3 app would expanded to sense air quality and water quality.

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