A development of mobile monitoring system for urban climatology

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We developed a real-time mobile monitoring system on air quality and thermal environment at the city block scale. We performed several participatory experiments providing participants with portable sensors connected to their mobile devices through Bluetooth, who walked in the city blocks and collected information on the surrounding them environments. The information was uploaded to a server via WiFi in real-time. We also used this system during local sport activity events (Tokyo Marathon, Tsukuba Marathon, etc.) to obtain physiological responses in participants to potential environmental exposure. Indeed, using this fine scale monitoring we could identify areas in city blocks with low air quality, which could be dangerous for continuing human health activity events and should be re-constructed.

Key Words : *mobile technology, atmospheric environment, health impact, monitoring*

1. Introduction

We developed a real-time mobile monitoring system[1)] on air quality and thermal environment at the city block scale. This system helps designing the city blocks to locally improve outdoor comfort and provides access to a high resolution spatio-temporal environmental database, which includes information on the fine-scale outdoor thermal environment, air pollution, magnetic field intensity, etc. Based on a citizen participation approach, this system provides an opportunity for citizens to collect data in the area where they live, work or exercise. To test and validate the system we performed several participatory experiments providing participants with portable sensors connected to their mobile devices through Bluetooth, who walked in the city blocks of interest and collected information on the surrounding them environments. The information was displayed on their mobile devices and uploaded to a server via WiFi in real-time. We also used this system during local sport activity events (Tokyo Marathon, Tsukuba Marathon, etc.) to obtain physiological responses in participants to potential environmental exposure. Indeed, using this fine scale monitoring we could identify areas in city blocks with low air quality, which could be dangerous for continuing human health activity events and should be re-constructed.

2. Methods

(1) System specifications

"EcoMobileCitizen" integrates good practices and "states-of-art" of the existing tools and methods, limiting as much as possible the disadvantages that might arise within the process of using such system. We design our system in a way to minimize the barriers of participation: (1) no vendor tie-ins, all sensors can be supported by design; (2) special focus on usability: simple, easy-to-use user interfaces; (3) special focus on users: give full control to users of their own collected data; (4) no limitations on locations: the system can work in any country, centralized or distributed.

"EcoMobileCitizen" combines environmental and physiological sensors, a mobile phone application, and a mapping-enabled website into an easy to use system, allowing common citizens to measure their environments and, if they choose to, share their collected data. The contributed data can be made available on the map website for personal, scientific, and urban policy decision making purposes.

The system includes:

I. A user-friendly Android application (EcoCitizen Android) that can connect to portable sensors wirelessly, download recorded measurements, and upload data to a public map server.

II. A website, which aggregates incoming data from client applications such as EcoCitizen Android, and display on a user-friendly public map of environmental data.

The concept of using sensors connected to mobile phones along with functionality and robustness of the sensors is evolving very fast and needs urgent, useful, and flexible "human friendly" applications.

Fig.1 Application on the Android system.

Our target is to develop a generic and highly extensible Android application (**Fig.1**) that can collect environmental data from a variety of sensors, and publish data on a map data server. In particular, responses from portable sensors connected to the Android device are explored in real-time.

The mobile phone displays personal exposure to pollutants either by using its Bluetooth® interface to collect data directly from a portable sensor device or by collecting this data from the web portal. The phone based application processes local data, and integrates the results with remote data, to present a unified view of one's personal exposure and surrounding environment.

The short term goal is to view measurements from sensors sent by the Android application. The long term goal is let anybody contribute their measurements. For that, the technical details and protocol will be publicly documented.

The data sent to a central computer server are processed, analyzed, and visualized, enabling 'city pollution maps' of areas of interest to be constantly updated and internet-accessible. On the web page users are able to select start/end times, geographical extents and sensor identifiers, and view a combination of historical and real-time data. This interface allows users to compare how observations from the same sensor differ over space and how well different sensors correlate with each other over the same space (and time) extents.

The map can be used to identify air pollution spots associated with a specific area of space, allow us to capture the individual daily exposure pattern and analyze the correlations among different people exposure area's profile. Better understanding of air quality issues can help to prevent citizens from entering particular dangerous areas or can encourage them to be pro-active in reducing the danger.

(2) Sensors and mobile devices

Two types of portable low-power low weight wireless sensors were used in this study: EcoSenspod produced by Sensaris company (France) and BioHarness™ BT by Zephyr™.

The EcoSenspod were used to measure environmental indicators such as hydrocarbons, carbon monoxide (CO), oxidizing gases (NO_2), VOC, temperature, and humidity. These portable devices offer an advantage of wearable non-invasive environmental sensing, which do not require highenergy use.

The BioHarness™ BT device uses smart fabric non-invasive technologies and enables the capture and transmission of comprehensive physiological data such as heart rate, heart variability, breathing rate, skin temperature, posture and activity level; it enables genuine remote monitoring of human performance and condition in the real world.

The sensors were connected to Android device (HT-03A DoCoMo), which is an obvious choice for our study, because it has WiFi and Bluetooth®, it is programmable, provides accurate location and time estimation, comes with a growing set of cheap powerful embedded sensors, such as GPS, accelerometer, gyroscope, etc., it is always on, can be always connected to sensors, and the market share of Android devices is increasing most rapidly among similar devices in Japan and worldwide.

(3) Data handling

The experimental data are collected by voluntary participants (citizens of Tsukuba and Tokyo area) who were randomly selected to perform personal mobile environmental monitoring in a priori selected areas. The areas were selected either by the participants (where they usually go), or by an event (marathon), or by researchers (an area of interest). Participants were actively involved only in the collection of data and they could contribute to an effort they found meaningful.

Participants were asked to participants to carry portable sensors connected to the Android devices via Bluetooth®. The responses from the sensors are explored in real-time and the results are viewed on the screen of the mobile phone. Positional data are recorded via mobile phone's GPS. Data are stored on a mobile phone or/and sent to a web server using WiFi when the user is near the WiFi point. Participants can access their data any time by login into a system.

We performed repetitive experiments to calibrate the sensor outputs.

Variability in the sensor's estimates differed from sensor to sensor and needed to be calibrated. For each sensor the calibration procedure was undertaken, using identified sensor thresholds, accuracy over time (+k%) and precision (or repeatability). Thresholds were not identified for this type of sensor. Accuracy may vary over time and +10% was considered to be good. Precision (or repeatability) was found to be low.

Over time, the electronic circuitries and sensor components (optical in UV sensor, for example) can change. Changes can be exaggerated if there is continuous exposure to air pollutant or exposure to very high intensity sources.

With such in mind, one has to be extremely careful with data interpretation and should use approximation techniques to obtain more robust and reliable outputs.

We applied the eco-mobile citizen system in several case-studies in order to validate the system. In this project the opportunities for applications were numerous. We selected two case-studies, which we think can show the possibilities of the system. Even within the objectives of this project we met many challenges and all sort of limitations. The study is not completed, it needs an extra attention from the scientific point of view. The limitations should be discussed and decisions about the future of the project should be made.

3. Eco-monitoring at Tsukuba Marathon and runner's performance

The experiment was hold in November 2010 in Tsukuba-city with one marathon runner (**Fig.2**). We inquired the participant to measure NO_x and other indices along his individual physiological parameters during the run. The parameters were recorded by the sensors and downloaded later-on to the server (**Fig.3**). The runner could enter the system and see his results on the screen of his computer. The personalized requests were made by the participant, who wanted to see the variability of his heart rate parameters and cadence during the run and check if the data correlate with the air quality data.

Duration of the experiment: 9:00 - 13:00

We used only NO_x and CO_x in this project, which did not show any significant correlation with the

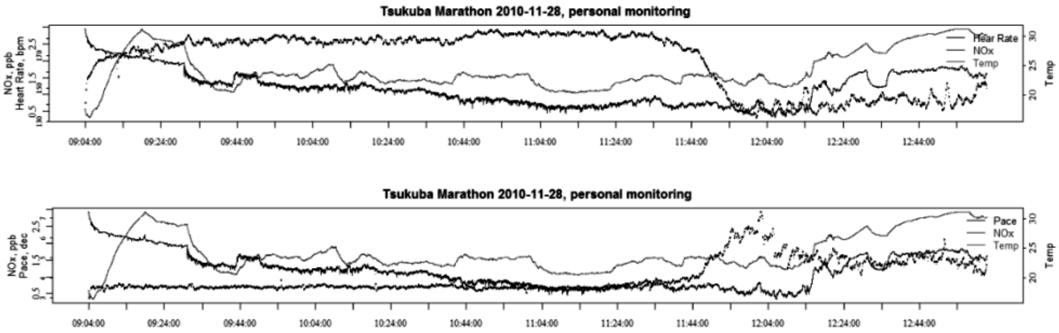

Fig.2 Monitoring results at the Tsukuba Marathon.

physiological responses. However, this result is not conclusive. The experiment has to be repeated using other available sensors including O_3 or PM2.5. The correlation of the pollutant with temperature has to be further investigated. These kinds of experiments are time and money consuming.

However, one of the goals of our study was to make people aware of the surrounding them environments, which in this case we achieved. The participants become interested in using the system and to perform continuous monitoring of his performance in the future marathon runs, observing the patterns of relationship between his performance and air pollution.

The data he collects can be used in the analysis of this relationship to improve our understanding of the causes that might affect his performance in the marathon.

Fig.3 Monitoring results at the Tokyo Marathon (noise).

4. Tsukuba Center air quality monitoring

(1) Background

We conducted an experiment to validate our system in April 2012 in Tsukuba city with the help of paid participants. This case is different from the Tsukuba Marathon study, because we used more than one participant and they were paid.

Details of the experiment are as follows;

Duration of the experiment: from 21 to 25 of April 2012

Duration of the participation in the experiment: at least 3 consecutive days

Area: Tsukuba Center, between Gakuen-Nishi Odori and Kita Odori

Time: morning (8:00-11:00), afternoon (15:00-18:00)

Number of sessions per day: 6

Sessions: morning (starts at 8:00, 9:00, and 10:00), afternoon (starts at 15:00, 16:00, and 17:00)

Duration of one session: ~30 minutes

Number of participants: 20

Age of participants: from 20 to 65 y. o.

Is it possible to participate in more than one session?: Yes, if one is in the morning and another one is in the afternoon.

Instructions for the experiment: Were provided on the day before the experiment

Guidance and assistance: Were provided during the experiment

Participants were asked to register here: http://bit.ly/HjJEoG

Website: http://blog.ecomobilecitizen.com/project/

(2) Method

The participants were collecting environmental data during 5 days of experiment by walking inside a predefined area in the center of Tsukuba city. The participants were provided with very light wearable devices (mobile phone, air pollution sensor and a body worn heart monitor) and were asked to walk along different routes (S1 to S9) in the area of interest in one session and then repeat the same route patterns on the next 4 consecutive days. Participants were encouraged to provide their feedback any time during the experiment.

We used the commercial devices from Sensaris and Zephyr companies (**Fig.4**; **Table 1**); however, our system is not tide-up to a particular company. Any sensors that have a Bluetooth capability can be used in this project. If necessary a specific driver can be written for the new device.

Tools used in the experiment:

•EcoMobileCitizen Map:
http://www.ecomobilecitizen.com

•EcoMobileCitizen Android App:
http://blog.ecomobilecitizen.com/android/

(3) Walking scenarios in the area of experiment

We chose the area, because of its simple rectangle shape (easy to give directions to participants) and it is located in the middle of the city, where the pollution is expected to be high (**Fig.5**; **Fig.6**; **Fig.7**). The crossing of two main roads (B) creates a contrast with the crossing in the opposite corner of the rectangle (D). In the middle of the rectangle there is a bicycle road, where is daily flow of walkers and bicyclists. There is a little park with a lake on the right of the bicycle road close to a less crowded traffic area (DC), and on the left of the bicycle road there is a residential area, which is close to the busy traffic area (AB).

The objective was to observe the differences in air quality inside the rectangle, taking various routes, and to check if the impact of the air pollution is higher in the area were people reside.

The goal for the participants was to carry the devices inside the area of interest and build their awareness about surrounding them environments, by using the system for gathering physiological and ecological data, and also to observe their own performance in the experiment.

Fig.4 Example of devices.
(upper: Eco-sensors, lower: BioHarness sensor).

Table 1 The measured parameters.

Devices	Collected Environmental Parameters	N of devices	Company
CO_2 sensors	CO_2, temperature, humidity	6	Sensaris
Eco-sensors	CO_x, NO_x, noise, temperature, humidity	6	Sensaris
UV and ozone sensors	UV, ozone, temperature, humidity	5	Sensaris
RemPod Geigers	Radioactivity	2	Sensaris
BioHarness sensors	ECG, heart rate (were positioned just below the chest muscles)	9	Zephyr
Android phones	Used as data collectors and transmitters	5	HTC

Participants were having three sessions in the morning (starts at 8:00, 9:00, and 10:00), and three sessions in the afternoon (starts at 15:00, 16:00, and 17:00). They can access the system and check their performance any time they have access to the Internet.

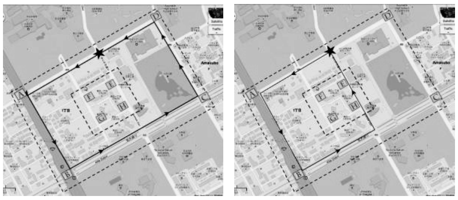

Fig.5 Example of route maps for monitoring around the Matsumi Park (in cases of S1, S2).

Fig.6 Participants attaching sensors.

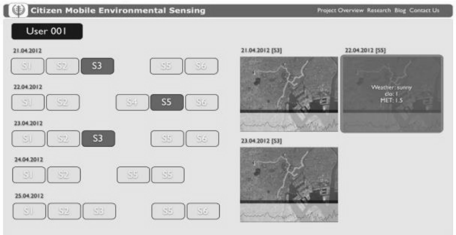

Fig.7 Monitoring results accumulated in the server.

We used background measurement to update calibration parameters from sensors. We used AM-101 (Kyoto Elec. Co, Ltd.) station located in the center of the Tsukuba-city near Medical center (a star on the route map). The measured parameters were the fish-eye view, skin temperature, ambient temperature and humidity.

Analysis of the obtained results and careful interpretation require a considerable amount of time. The data quality is a main issue in the project, the robustness of devices is an essential part of the project, and human effort is most important factor that drives the project.

One should keep in mind that this is a pilot project with a very limited resources, thus the expectations should be reasonable when reading this report. This is just a summary, which describes the vision and methods, which can be, with the right imagination, applied in environmental studies with more carefully designed experiments, with more robust equipment and solid support.

5. Conclusions

In urban cities the air quality is not constant across the area, it varies spatially and in time. Depending on traffic and weather conditions the air pollution level and therefore its effect on human health can be different. Participatory sensing of environmental and physiological parameters enables collection of data by ordinary citizens in the areas where they walk or usually active. With portable and widely available sensors connected to a mobile phone, citizens can measure environmental indicators (CO_x, NO_x, Noise, UV, or radiation) and physiological indicators (heart rate, respiration rate, blood pressure, etc.), which can be used to evaluate the individual exposures to air pollutants and possibly to provide a new understanding of the mechanisms underlying the effect of air pollution on health.

“EcoMobileCitizen” project integrates good practices and “states-of-art” of the existing tools and methods, limiting as much as possible the disadvantages that might arise within the process of using such system. We design our system in a way to minimize the barriers of participation: (1) no vendor tie-ins, all sensors can be supported by design; (2) special focus on usability: simple, easy-to-use user interfaces; (3) special focus on users: give full control to users of their own collected data; (4) no limitations on locations: the system can work in any country, centralized or distributed.

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