ArdSense: extending mobile phone sensing capabilities using open source hardware for new Citizens as Sensors based applications

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Abstract

Nowadays, mobile phones have become sophisticated communication and sensing devices that can be used for creating powerful mobile sensor networks. The users' participation in such sensor networks is based on the voluntary basis and results of their efforts are consumed by the wider community. But the primary role of mobile devices is for communication and embedded sensors are primarily used to support advanced look and feel functionality of mobile devices. Therefore it is not expected that the majority of mobile phones on the market will ever be equipped with sensors that could be used for some specific or professional applications. There are possible applications such as air pollution tracking, temperature, humidity, and air pressure measuring, person's pulse rate measuring and others for which existing sensors can be only partially used or can't be used at all. In order to address that issue, we propose in this paper a sensing system based on the Citizen as Sensors concept that uses additional hardware sensing module. Presented module is based on the open source hardware and extends the mobile phone sensing capabilities. The system mixes mobile phone's communication and location capabilities with the use of additional external sensor in order to provide possibilities for the broader set of Citizen as Sensors based applications.
Keywords: Sensors, open source hardware, VGI, mobile phone

1 Introduction

Nowadays, most people usually carry sophisticated sensing devices which can be utilized in order to extend existing and create new sensor networks [1]. These sensing devices are mobile phones which become the most used mobile devices for fulfilling everyday computing and communication needs. Mobile phones are lately equipped with a rich set of sensors such as an accelerometer, digital compass, gyroscope, GPS, microphone, and camera [12]. These sensors can be used anytime and anywhere because of the mobile nature of mobile phones which introduces more flexibility compared to static sensors. In addition to being sensor carriers, mobile phones are also communication nodes in a mobile phone network thus enabling the communication of the sensor readings.

Mobile phones' sensors are today used more than ever. There is a constant growth of applications that exploit sensors whether for personal sensing or for group/community sensing [10]. This trend in creating new sensing applications is driven by the fact that each new generation of mobile phones have new types and improved existing types of sensors, the programmability of new mobile phone platforms is higher than before, application stores improve both availability for users and motivation for researchers and developers to produce new sensing applications, higher mobile network data bandwidth enables more data to be shared etc.

This paradigm of users that are collecting sensor readings using their mobile phones is called *Citizens as sensors*. This approach doesn't only take into account collection of raw sensor readings but also the contributions of users' subjective sensations, opinions and observations [9]. In addition to *Citizens as Sensors* paradigm, it is notable that such sensor readings are frequently related to the location where they were acquired. Therefore mobile sensing applications often require pinpointing and attaching geo-location to such sensor readings and thus they also can be considered as VGI (Volunteered geographic information) applications.

But the primary role of mobile devices is their use for voice, short messages, and mobile Internet communication. The integrated sensors are mainly used to support additional phone functionalities such as screen rotation, GPS location and navigation, (in most cases) low quality image capturing etc. Therefore the initial role of existing integrated sensors is not to be used for professional sensing applications but to support device's look and feel.

There are possible applications such as air pollution tracking, temperature, humidity, and air pressure measuring, person's pulse rate measuring and others for which existing sensors can be only partially used or can't be used at all. In addition, by using existing sensors, readings can be inaccurate or can greatly depend on the skills of the person that is collecting such measurements. Also, it is hard to expect that, for instance, gas sensors will ever be embedded into the future mobile phones because they will add to the battery consumption and to the overall price without substantially benefiting the main functionalities of the mobile phone. Therefore, we think that sensors that are embedded in the majority of mobile devices are not enough for ever growing mobile sensing market. Thus there exists the need for the cheap and simple platform that could extend the existing mobile phone sensing capabilities for different sensing purposes.

Our research focuses on the development of the open source hardware [2] based sensing platform that can supplement mobile phones' existing sensors in order to create new high end sensing applications. The research emphasis is on the use of additional sensors connected to the additional hardware component in conjunction with mobile phone's GPS and communication capabilities for implementing VGI based application for collecting sensor readings. This paper describes the architecture of the proposed mobile sensing system based on Arduino Uno open-source electronics prototyping platform [4], Android based mobile device with appropriate application, server component and WebGIS application for dissemination of sensor readings acquired from users.

The rest of the paper is organized in the following way. The second chapter describes the current state of the art in the field of mobile based VGI and *Citizen as Sensors* applications. The third chapter presents the proposed architecture of the ArdSense system, explains functionalities of the system modules and provides some implementation details. The fourth chapter gives conclusion and directions for the future work.

2 State of the art

The applications based on the *Citizens as Sensors* concept (synonyms: *People as Sensors* and *Humans as Sensors*) can be divided into two basic groups. Applications that belong to the first group are used in the form of opportunistic sensing. This imposes that users are not actively contributing sensor readings, but the process runs in the background and in most cases uploads sensed data to the server. Such applications should be completely transparent to the user in the terms of common phone usage. The main advantage of this approach is that user doesn't need to be involved in the data collection process like in cases of noise pollution monitoring described in [14] and [13]. But the opportunistic sensing approach also raises privacy issues, adds to the increased battery and data transfer consumption which can't be easily controlled by the user.

The second group of applications consists of participatory sensing applications which require active user's involvement in the process of sensing and/or uploading data. Users need to either trigger the process of sensor reading or need to manually enter theirs subjective observations on a matter. In most cases it is a combination of the two. The typical example of such application is Waze [8]. Waze enables drivers to send their traffic reports along with the GPS sensor readings (position and speed) which can help other drivers to avoid congested routes or to be aware of major accidents along the route. The advantage of such applications is that there is no need to deploy a massive physical sensor network into the road network, nor the cars need to be equipped with expensive sensor and communication equipment when each driver can use his/hers mobile phone. The main drawback is the interpretation of the meaning due to the subjective nature of the peoples' observations. Will such reports be interpreted by everybody in the same (or at least similar) way?

Lately a large number of similar applications emerge that use peoples' opinions as the main source of data. Examples of such applications are UbiFit [12] for monitoring person's physical activity, Fix My Street for reporting local community problems [5], Ushahidi application for interactive mapping, used during various emergency events like Haitian earthquake and Thailand Flood Crisis [1].

In addition to the mentioned *Citizens as Sensors* concept, there are two more terms that are often considered as synonyms: *Collective Sensing* and *Citizen Science*. Bernd Resch in [1] clearly disambiguates between them. The *Collective Sensing* is based on the analysis of the anonymised user generated content that is created through the use of the popular Web and mobile applications such as Twitter, Facebook, Foursquare etc. *Collective sensing* can also be based on the data collected by the other mediums. For instance, in [3] Sagl et al. present the collective human behaviour patterns analysis based on the anonymised data obtained from the mobile network operator. The *Citizen Science* is a subset of Citizen as Sensors concept that requires active involvement in the data collection process and some domain knowledge of the user.

As stated earlier, most of the sensed data has a spatial component and therefore can be considered as a subset of VGI. Therefore, the most common way for visualising the sensors reading is by using GIS applications [14]. GIS enables users with different spatial queries and therefore the harvested data can be used for different analysis. For instance, by using data created by noise pollution monitoring applications, user can decide which neighbourhood is better for hers relocation. Most of the applications already provide tools for such analysis or make suggestions to users that are deduced by received data.

Because applications based on the *Citizens as Sensors* concept are not only meant for sensor data collection and visualisation, but also to provide users with new value extracted from the sensed data, Lane et al. in [12] suggest architecture of such systems to be based on the following three main parts: S*ense*, *Learn* and *Share*. The *Sense* part is done on the mobile phone part of the system, either by collecting data from the sensor or data entered by the user. The *Learn* part can be implemented on the phone side, on the server side or on both sides. The *Share* part of the system is used for dissemination of either received raw data or the extracted information.

Although sensing applications are in most cases based on the use of physical sensors that are embedded into the mobile phone and that each new generation has new and improved sensors, it is hard to expect that majority of the future mobile phones will have all possible sensors that could meet the needs of the future crowdsensing applications. In order to fill the gap between the physical sensing capabilities of the most used mobile phone models and the needs for contemporary and future mobile sensing applications new projects emerge which aim is to add sensors that are missing. The example of such project is Sensordrone [6] that has been recently successfully funded on the Kickstarter.com. The Sensordrone is a module that contains environmental sensors (like carbon monoxide detectors and hydrogen sulphide detectors) supported with more than 10 already available Android applications. Also, similar approach is used in Valarm [7] which is based on Android application for visualizing and analysing various sensors readings that is primarily meant for commercial use.

Nevertheless, at the present time such sensor extensions are not cheap (Sensordrone costs 179$ at presales) and such modules are not always available. This fact can leverage the threshold for users to participate in the volunteer sensing efforts that require such sensing capabilities. Therefore, we think that mobile phone sensor extensions based on the open source hardware can be used for such purposes. The open source hardware is the type of hardware that fulfils following requirements: the interface to the hardware and its design must be explicitly made public and the tools that are used to create the design should be free [2]. By using open source hardware, each volunteer can buy hardware components and personally assemble sensing module based on the provided designs and code. Such effort doesn't require of the user to be an electronics and programming expert.

There are a number of powerful open-source physical computing platforms like Arduino, Beagle Board, Bug Labs, Raspberry Pi etc. They are based on simple I/O boards and low-power processors from different manufacturers like Atmel or Texas Instruments. Such boards are easily programmable, small in size, provide connections for both digital and analogue sensors and can be extended with shields or modules for WiFi, ZigBee or Bluetooth communication. The fact that these development platforms are widely available and relatively cheap (around 30$ for basic models) and can be used width different sensors available on the market makes them a good choice for developing mobile phone sensor extensions.

The example of using Arduino in conjunction with Android smartphone is for example described in [15]. Here for the sensing side of the solution is used Arduino development board and pressure sensor. Sensor readings are communicated via Bluetooth to the smartphone where Android application is used for the visualisation part. The examples of such applications are numerous, but they are in most cases meant for personal use, and sensor readings aren't disseminated for wider public.

3 The ArdSense system architecture

Existing applications based on the concept *Citizens as Sensors* has shown to be very successful in everyday use and the number of users of such applications is constantly growing. Although the use of mobile phones is considered as a big advantage of such systems compared to the traditional sensor networks because of mobility, ease of communication, users' involvement, embedded sensors, etc. it can also be considered as a limitation due to the limited number, types and quality of the sensors embedded into the mobile phones. This needs to be overcome in order to exploit the advantages of such concept for the areas that require the use of more sophisticated sensors.

In this section we present the system that is based on the *Citizens as Sensors* concept, more specifically *Citizens Science* concept that is using the extension of the physical sensing capabilities of mobile phones implemented as additional sensing device based on open source hardware. We propose the architecture of our system that is based on the *Sense, Learn, Share* model. The proposed system architecture consists of three main parts (Figure 1):

- ArdSense module with ArdSense Android application.
- ArdSense Server.
- ArdSenseWebGIS ArdSense mobile Client application.

3.1 ArdSense module and ArdSense Android application

The ArdSense module is a piece of hardware that is built using three main hardware components (Figure 2):

- Arduino Uno development board
- DHT11 temperature and humidity sensor
- JY-MCU Arduino Bluetooth wireless serial port module
- Additional resistors and wirings.

Arduino Uno is a prototyping development board with Atmel microchip that is the point of integration of other hardware parts. This is a powerful board that can be easily utilized for development of various interactive devices or environments and is intended for artists, designers, hobbyists, hence people that are not professional hardware developers. The microcontroller that is installed on the board can be easily programmed using the Arduino programming language similar to C programming language and the intuitive and easy to use Arduino development environment [4].The company and the community that follows this project publish circuit designs and related program sketches on regularly bases which lead to the gradual learning curve even for inexperienced users.

Arduino Uno can receive digital or analog inputs from different types of sensors and can control lights, motors, and other actuators. In addition it can provide power supply for the components that are connected. The Arduino can be powered using batteries with voltage levels between 5-12V. The main

Figure 1: ArdSense system architecture

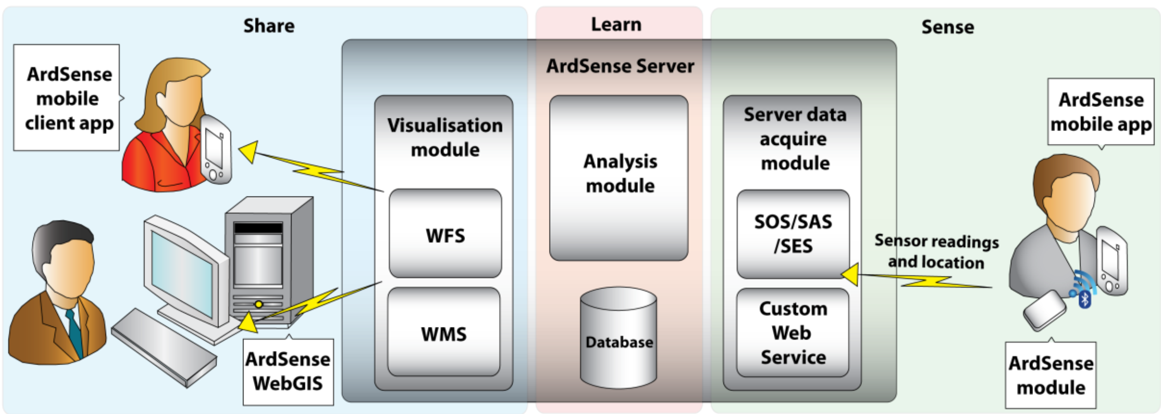
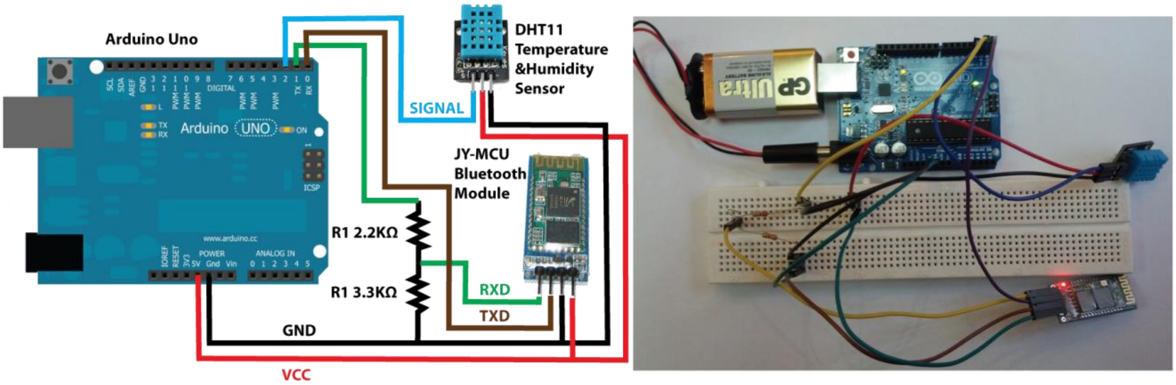


Figure 2: ArdSense module, left: schematic, right: real circuit.



use of the Arduino prototyping board in the ArdSense module is for receiving and interpreting the signal from the sensor. The prototype of the module uses DHT11 temperature and humidity sensor. It is a cheap (around 5$) digital sensor that can measure temperature in the range from 0-50 °C with the accuracy of ±2°C and humidity in the range from 20-90%RH with the accuracy of ±5%RH. The sensor is used just for the proof of concept and can be easily replaced with any other type of the suitable sensor.

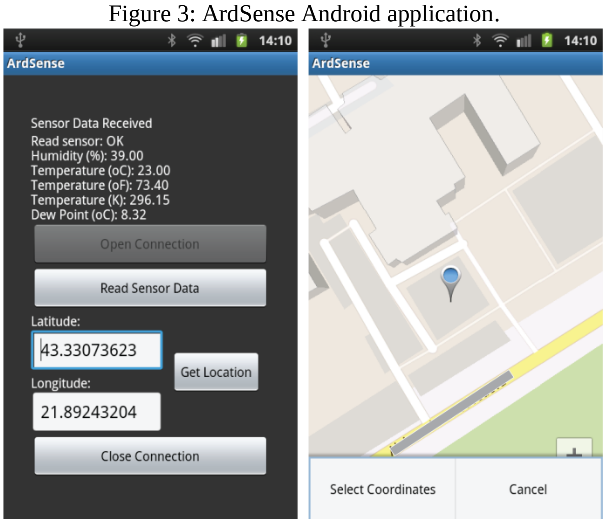
The JY-MCU module is a cheap (around 10$) Bluetooth wireless serial port modem that is easy to use and to programme. It can be also powered from the Arduino Uno board and is connected to its Tx and Rx pins for transferring and receiving data. The baud rate of the module can be easily adjusted using AT commands for any type of use. In our prototype, we are using the module for communication between mobile phone and the Arduino board.

The Arduino board is preloaded with the code that loops infinitely. In each loop it is checked whether the component received request command over Bluetooth connection. After the request has been received, the sensor is read using the DHT11 library and the appropriate temperature in Celsius degrees and the humidity in per cents is obtained. Afterwards, the received temperature and humidity are sent over the Bluetooth serial connection to the ArdSense Android device application using simple string-based application level communication protocol.

The sensing part of the platform is simple enough to make us think that, provided with appropriate instructions, schematics and source code, possible users would be able to easily assemble such hardware. Such volunteer groups, which we think would use this platform, could also share their experiences gathered during assembling in order to help new users.

ArdSense Android (Figure 3) is a participatory sensing application that requires user's involvement in acquiring sensor readings and is used for two main tasks. The first one is to provide Bluetooth communication with ArdSense module and support the mentioned simple application protocol by parsing the received data. The other is the use of the GIS module and the GPS location capabilities of the mobile phone. The process of acquiring sensor readings goes as follows: the user initially triggers the ArdSense module and receives the sensor values. Afterwards, the user obtains the location using GPS and its position is shown on the map. If for any reason user cannot acquire the location, she can choose it by pointing on the map. After the location has been locked, the user can send the data to the server. In addition to the functionality of uploading sensor readings, the application provides the possibility to be used for personal purposes. The temperature is presented in Fahrenheit and Kelvin degrees and dew point is calculated based on the temperature and humidity.

Figure 3: ArdSense Android application.



3.2 ArdSense Server

The ArdSense Server is used for obtaining, storing, analysing and disseminating sensor readings to the users. It has three main components:

- Data acquisition module
- Analysis module
- Visualisation module

Data acquisition module provides the interface for receiving sensor data from users' mobile phones. At this level of the prototype development, it is implemented as a simple Java applet that stores data to the database on the server. Our aim is to use our sensor network platform (platform name is omitted due to the double blinded review) [11]. We think that the Sensor Web platform and OGC standards in the form of

Sensor Observation Service (SOS), Sensor Alert Service (SAS) and Sensor Event Service (SES) are also suitable for this kind of use regardless of the mobile and user controlled nature of the ArdSense module.

Although received data can be consumed by other users as they are received, in the form of discreet spatio-temporal sensor readings, such data provides possibilities for different analysis that can produce additional information for users. The Analysis module is used for performing different analysis on the received dataset. For instance, with this particular sensor, users can obtain mean temperature values for some location for the requested period of time at the particular time of day provided that volunteers have regularly uploaded their sensor readings. Such analyses are today available only for the locations where official institutions or private weather companies track temperature values. Also, Analysis module can provide spatial data analysis using algorithms like IDW, Splines and Kriging which can, depending on the size of the required area and disregarding the factors that influence the weather on the micro scale (vegetation, hydrology etc.), give a pretty good estimation for the temperature in the locations without measurements. The Visualisation module is used for the dissemination of the sensor data and results of the analysis. The module consists of WMS and WFS OGC services that provide map segments, sensor readings and analysis results in the form of raster and vector layers. At the moment, both applications use Google maps instead of proprietary maps and dedicated WMS.

3.3 ArdSense WebGIS client ArdSense mobile Client app.

Users are able to consume the available data using two types of applications: WebGIS and ArdSense mobile Client. Therefore, data that are contributed by volunteers can be used by others that are not providing sensed data and thus can be useful for the broader set of users and positively influence on the others to get involved in the data collection. The ArdSense client application is a light version of the full application without sensor communication part.

3.4 The adoption of *Sense, Learn, Share* model

As shown on the Figure 1, the proposed architecture follows the mentioned *Sense, Learn, Share* model. The *Sense* part of the system consists of the ArdSense module, ArdSense mobile phone application and the Data Acquire module.

The *Learn* part consists of Analysis module. Since the system is based on the sensor readings of physical environment characteristics there is little or no semantics provided by the user in the data. Nevertheless, the system can be extended with some advanced analysis that could take into account user's profile. For instance, the system could suggest the user to avoid streets with higher temperatures in the summer and take ones with shadows where the measured temperature is lower or if the user has some respiratory problems, the system could warn him about the locations with very high humidity rates.

Visualisation module of the ArdSense Server and ArdSense WebGIS client and ArdSense Android client application are the *Share* part of the proposed architecture. The availability of the WebGIS application on the Internet and the distribution model of the Android applications guarantee the easy access and the possibility for higher adoption of such concept among the users. Also, by using OGC services, other GIS applications can consume data from the proposed system.

3.5 Possible usa-cases of the presented ArdSense platform

The aim of presented platform is to be used by a group of dedicated volunteers that, for example, want to organize themselves in order to monitor temperature changes in the city area. Since the platform can support the use of different sensors by applying some changes, the platform could be used for monitoring different environmental parameters like air pollution, nuclear radiation (using simple Geiger counters), noise pollution etc. Although there exist public institutions which main task is monitoring such parameters, sometimes NGOs and other non-profit organizations want to monitor their work and check the official results. Also such volunteer effort could provide data on a much lower scale compared to the official sensor measurements, especially in countries where national institutions can't invest in development of large fixed sensor network infrastructure.

But in order to make such measurements good enough for everyday usage, there needs to exist a large user base of dedicated volunteers that will periodically (daily, hourly) provide measurements in accurate and reliable manner. In addition, volunteers should take care of the locations from which they collect measurements in order to provide better spatial distribution of available data.

4 Conclusions and future remarks

In this paper we propose sensing system based on the Citizen as Sensors concept that uses additional hardware module based on the open source hardware that extends the mobile phone sensing capabilities. Unlike similar projects that require specific sensing products that must be purchased in order to participate in the community and be able to sense additional environment characteristics, proposed module can be assembled by using components, schematics and code that are available online without the need for user to be an expert in the domain. This fact can boost motivation for inclusion of new volunteers worldwide in the similar sensing projects.

The future research on the matter will need to address the development of the generic module that will provide the possibilities for the plug and play like use of different sensors (air quality, heart rate, radiation etc.). The platform should be tested in real conditions in order to check how many volunteers and how big effort do they need to invest in order to cover some space with accurate and timely measurements. Also, possibilities for exploiting Sensor Web concepts and integration with open source spatial analysis tools should be investigated in the future.

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